NTIA Special Publication 24-573

ISART™

International Symposium on Advanced Radio Technologies™

ISART 2022:

Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making

NTIA Special Publication 24-573

Proceedings of the 19th
International Symposium on Advanced Radio Technologies™

Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making

June 13–16, 2022 • Fully virtual

U.S. DEPARTMENT OF COMMERCE

Alan Davidson
Assistant Secretary of Commerce for Communications and Information
National Telecommunications and Information Administration

August 2024

Organizing Committee

Technical Chair

Michael G. Cotton, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS)

General Chair

Rebecca Dorch, J.D., National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS)

Technical Advisory Committee

Josephine M. Cantalupo, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA)

Dr. John Chapin, Special Advisor for Spectrum, National Science Foundation (NSF)

Howard H. McDonald, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA), Retired

Eric Nelson, Director (Acting), National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS)

Gregory C. Wagner, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA)

Proceedings Editors

Lilli Segre, Publications Officer, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS)

Elizabeth W. Manus, Technical Writer/Editor, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS)

Preface

ISART™ 2022 was the 19th in a series of symposia hosted since 1998 by the Institute for Telecommunication Sciences, ITS: the Nation's Spectrum and Communications Lab. The International Symposium on Advanced Radio Technologies™ (ISART) provides a neutral forum where business experts, technologists, scientists, and government regulators can share their points of view, debate issues, and engage in a holistic and expansive exploration of the future use of existing and emerging radio technologies. The technical focus that characterized the first decade of ISART has broadened to encompass science-informed conversations on the policy and economic impacts of advanced radio technologies. ITS believes that this expanded dialogue and debate has greatly benefited the spectrum stakeholder community. Ideas first floated at ISART have found their way into breakthrough technologies and innovative regulation.

The ISART 2022 Prequel, held in conjunction with the 2021 NTIA Spectrum Policy Symposium, introduced the question of whether the regulatory process could be more responsive to the rapid pace of technical evolution. ITS issued an ISART 2022 Call-for-Input focused on potential models for regulatory improvements to evolve spectrum sharing. The input received contributed substantively to shaping the final agenda for ISART 2022, *Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making*.

This theme reflects the reality that to make more spectrum available for everyone who needs it—to make spectrum sharing work without degradation of service—engineers and policymakers must work together. The pace of innovation for hardware is significantly faster, and for software exponentially faster, than the pace of the current regulatory process. ISART 2022 asked how regulatory processes might be reimagined to shorten the current span of years or decades from intent to enactment that can stifle innovation, optimization, and economic opportunity.

With the COVID-19 pandemic still ongoing, ISART 2022 was a fully virtual event. ITS worked hard to ensure the virtual agenda included plenty of opportunity for the discussion and networking that has always been a hallmark of ISART. ISART 2022 drew a record 230 registrants, the most the symposium has ever had, and 50 panelists and speakers. Speakers and registrants included U.S. government, international, academic, and industry representatives, providing a broad range of perspectives and ideas.

The text of these proceedings is taken from a transcription of the video record, which is available as a YouTube playlist on the NTIAGov channel. A best effort has been made to correct spellings of names and terms of art, but it is in no way an "edited" transcript. Presentation files have been posted in the Past Programs area of the ISART website.

Certain products, technologies, and corporations are mentioned in this report to describe aspects of the different current or potential future approaches to the topics covered in the symposium. The mention of such entities should not be construed as any endorsement, approval, recommendation, or prediction of success by the Department of Commerce or any of its agencies, nor as any inference that they are in any way superior to or more noteworthy than similar entities that were not mentioned.

Contents

Executive Summary

The theme for ISART 2022 was *Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making*. Continuing the practice begun at ISART 2015, ISART 2022 offered participants in-depth tutorials on background topics in advance of the symposium. The tutorials focused on the existing regulatory process for spectrum sharing and on lessons learned from the evolution of prior efforts.

Altogether, ISART 2022 encompassed 10 tutorials; an opening Fireside Chat; 3 keynote addresses; 2 technical presentations; and 6 panels designed to present viewpoints of multiple stakeholders, including industry experts, technologists, scientists, and government representatives. The eighth and final wrap-up panel identified key conference findings and potential next steps for ways to consider actualizing a national strategy for spectrum sharing.

National Telecommunications and Information Administration (NTIA) Assistant Secretary Alan Davidson and Wiley Rein LLP partner and former NTIA Deputy Assistant Secretary Anna Gomez set the policy context for the technical panels that followed their Fireside Chat. Davidson and Gomez made clear that, with $48B for infrastructure and workforce development to distribute in various programs, NTIA's focus is on making sure that everybody in America has access to high-speed, affordable, reliable Internet service. And, since wireless technologies are an important part of enabling that, expanding access to spectrum is key to enabling wireless technology. Davidson focused on the need for continuing collaboration across federal agencies and between federal and non-federal users. Between 2010 and 2020, NTIA and the Federal Communications Committee (FCC) collectively reallocated or repurposed over 7500 MHz of federal and non-federal spectrum to make it available for commercial wireless services and 5G. Over 1000 MHz of that was mid-band spectrum. More is needed, and to get to more, both open collaboration and scientific innovation will be needed.

In the opening panel, the ISART Chairs and members of the Technical Planning Committee explained the motivation behind the theme of ISART 2022 and the impetus for the goal of the symposium: To chart a roadmap and gain consensus for data-, science-, and technology-driven means to evolve and expedite spectrum sharing analyses and regulatory decision-making and to identify opportunities for continuous improvement in development beyond the current linear spectrum-sharing process. Organizers posed a central question: To enable true, dynamic, real-time automated spectrum sharing, might it be possible to extend the regulatory horizon from initiation of spectrum sharing feasibility studies and the first set of regulatory rules through early implementation and deployment stages of a new technology—which could trigger reassessment of aspects of the rules—and then through the process of scaling up and expanding deployments?

Participants were asked to imagine ways to implement a future regulatory process designed to be iterative, more responsive to the rapid pace of technical evolution, and more reliant on applied engineering analysis. After implementing full system deployment within the context of full market maturity, could the ecosystem then be studied, the models and interference protection criteria validated, and the lessons learned applied to other sharing scenarios?

The first keynote address, by NTIA Associate Administrator and Director of the Office of Spectrum Management Charles Cooper, reviewed major policy and governmental activities currently underway. In particular, Cooper highlighted the increasing collaboration between NTIA and the FCC; the NTIA's efforts toward releasing a National Spectrum Strategy; and the developing institutional practices and processes that rely on data-, science-, and evidence-based decision-making to maximize spectrum efficiency in support of a forward-looking strategic policy based on national priorities.

The second panel of the first day, moderated by Bryan Tramont, Managing Partner at Wilkinson Barker Knauer LLP, presented industry perspectives on lessons learned from the experience of several decades of implementing spectrum sharing. Recapping past deployments as well as looking to the future, panelists pointed out themes that would continue to recur throughout the symposium. Panelists identified the need to speed up creative and innovative—but also technically feasible—rulemaking based on objective, high quality, band-specific data and research produced by an objective party that can actually do the technical analysis. Industry requires regulatory clarity and certainty to justify R&D investment, which drives technological innovation, yet regulators lack sufficient resources to engage in the spectrum sharing–related research, development, and testing projects and studies that can provide timely and trusted data early enough in the process. Thus, post-deployment enforcement becomes an issue—but might it be possible to build enforcement into new rulemakings and new sharing schemes up front, with the goal of making preemptive, adaptive changes to the actual uses in the sharing schemes so enforcement need not be brought to bear on the problem.

On Day 2, the second keynote address was delivered by Dr. Evan Kwerel, Senior Economics Advisor in the Office of Economics and Analytics at the FCC and the 2021 recipient of the Partnership for Public Service Paul A. Volcker Career Service Award, for pioneering the use of competitive spectrum auctions. Kwerel's brief history of how spectrum auctions came into being highlighted the importance of multistakeholder collaboration for successful innovation that turns ideas into implementable policy.

The first panel of Day 2, moderated by Giulia McHenry, Chief of the Office of Economics and Analytics at the FCC, addressed the Economics of Spectrum Sharing. Panelists discussed both the potential obstacles and the opportunities presented by an iterative regulatory approach that implements agile economic and policy reform to move with the speed of technology advances. The discussion introduced a variety of speculative proposals to maximize the value and use of the spectrum by adapting other market models to spectrum licensing. Just a few of the concepts thrown out for discussion were: use-it-or-share-it, secondary markets and spectrum leasing, incentives to motivate spectrum efficiency, act locally but think globally, and the potential demand for short-term usages that could constitute a market. At the same time, panelists acknowledged that existing statutory and regulatory requirements would need to be cohesively adapted to enable such changes—and regulatory change is neither fast nor agile. Two recurrent underlying themes were also the need for rules to prevent interference between users coupled with enforcement to make sure the rules are followed, and expanding the concept of risk-informed sharing to encompass both safety and investment risks.

Day 2 closed with a panel on Data Sharing and Transparency moderated by Edward Oughton, Assistant Professor of Data Analytics at George Mason University. Panelists explored administrative, technical, and system solutions to allow more spectral data sharing and improve transparency in order to improve spectrum management for the future. A recurring theme was protection of sensitive data, whether the concern be national security or intellectual property. Administratively, it takes time and resources to craft memoranda of understanding or non-disclosure agreements that pass muster with the technical and the legal teams on both sides, so both sides need to feel the exchange of data has sufficient value to invest in the effort. Some examples were cited of successful data sharing between industry and the DoD that—over time—led to relaxation of overly conservative constraints to allow greater commercial use of the spectrum.

On the technical side, a key enabler is standardized metadata, but the metadata standards need to be extensible and must continue to evolve to capture germane characteristics of evolving technology. Beyond that are issues of data formatting, where data formatted for the convenience of one research group may not meet the needs of a different group. Does the exchange of data provide sufficient value to invest resources in transforming the data for use by others? Are there technical solutions to enable sharing usable information from a sensitive dataset without exposing the raw data? For example, is it possible to generate synthetic datasets based upon real data, that are broadly correct and can be validated, in order to make an end-run around data privacy and security issues? Panelists reviewed current trends, future directions, and technical solutions—present, in development, and hypothetical.

Day 3 opened with a keynote address by Frederick D. Moorefield, Jr., Deputy Chief Information Officer for Command, Control, and Communications (C3), Office of the Secretary of Defense, Chief Information Officer. The DoD is the largest federal user of spectrum, and arguably the user with the greatest variety of spectrum dependent systems. Mr. Moorefield emphasized the DoD's understanding that cooperation, collaboration, trust, and transparency are the keys to enabling improved spectrum sharing to be able to realize the advantages of all the new wireless technologies. Regulation, he asserted, must evolve apace with technical capabilities.

JP de Vries, Director Emeritus and Distinguished Advisor, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, served as moderator of the next panel, on risk-informed interference analysis. He opened the discussion by asking panelists how risk management can be introduced into an organization that has never considered it before, and, then, how risk management can be introduced into the discussion of spectrum sharing. If risk analysis in spectrum sharing is defined as the identification and characterization of the parameters that will produce unacceptable performance degradation of the wireless system, then it follows that one must accurately identify the parameters, quantify degradation, and somehow weigh the probability of degradation against the severity of impact of degradation—and all of this goes into some kind of model that performs those calculations based on the data that is fed into it.

While the goal of the regulators is spectrum efficiency, the users who need to coexist in the sharing scenario have very specific objectives that their systems are designed to achieve and have different perceptions of the severity of impact in each case. Here, the issues of data sensitivity, trust, and transparency arise again, because in order for the models to provide generally accepted answers, engineers need realistic data to work on and the models themselves need to be trusted. Somewhere between sharing decisions based only on the worst case scenario and trust in a black box, the adage "all models are wrong, some are useful" leads to managing risk through collaboration among stakeholders. Such collaboration results in agreement on the model to be used, as well as some understanding of each party's risk tolerance, and, finally, to stakeholder acceptance of a regulatory framework for coexistence that contains risk within bounds acceptable to all parties.

The Technical Presentation that followed, by William Kozma, Jr., Computer Engineer in ITS's Telecommunications Theory Division, in fact focused on propagation models. Propagation models originally published in the 1960s and '70s are still in use today as the foundation for interference analysis, and thus risk calculations. These general purpose models were based on electromagnetic theory and first principles, with statistical analysis based on measurement data layered on top. Median predictions, however, are not sufficient for the types of scenarios being considered today. So Mr. Kozma described various ways that ITS is working to improve those models and also extend the frequency range. To ensure that these efforts do not re-create a "black box," findings, datasets, and code-signed software implementations are being published—with open access—as quickly as possible.

The panel that followed, moderated by Mr. Kozma, picked up on the topic of Model Standardization, specifically with regard to propagation models. Standardization, it was pointed out, involves not only the models, but also the software implementations. Software implementations, especially as increased computing power allows the building of much more complex models, allow integration of many more parameters and greater granularity. With regard to the models, the availability of both more geodata and a large body of relatively recent measurements for model validation is contributing to improving modeling accuracy. When more and larger measured datasets are available, it's possible to apply artificial intelligence and machine learning (ML) for empirical contributions to model development, and eventually ML might allow moving from site-general to site-specific models as more localized data becomes available. This raises the need to agree on standardized measurement methods, share comparable datasets, and trust in the accuracy of the measurements. Model development can, in fact, be inherently iterative, with feedback loops of continuously collected data sharpening the models so that spectrum sharing becomes dynamic.

The final day of the Symposium opened with a Technical Presentation by John Chapin, Special Advisor for Spectrum at the National Science Foundation (NSF) on Fast Interference Management. Dr. Chapin cited the Defense Spectrum Organization (DSO) definition of interference management: "the activities and processes executed to enhance electromagnetic compatibility and prevent, prepare for, respond to and recover from electromagnetic interference." Reviewing various legacy sharing schemes, he pointed to rapidly evolving technologies that delegate more decisions to edge devices that can respond in milliseconds to changing RF environments, accelerating both the speed of interference prevention and the speed of interference response in every band.

This set the stage for the seventh panel on Technical Enablers for Evolving Regulatory Processes, moderated by Professor Doug Sicker of the Computer Science Department at the University of Colorado-Denver. This panel dove deep into the minutiae of the technology—circuit boards, dynamic radar, cognitive software-driven capabilities, sensing at machine speeds, active electromagnetic interference cancellation, virtualization, softwarization, algorithmic innovation, artificial intelligence, the use of sub-terahertz bands, Open RAN, green (i.e., energy-efficient) communications, and more. Each panelist also cited specific real-world applications, and emphasized the need to break down silos, understanding that a communication or interference problem is also a computational problem with physics and limitations of physical devices.

The symposium closed with a "Wrap-up and Roadmap" conversation among the panel moderators to reprise key themes. One identified by diverse panelists on several panels: the importance of establishing trusted data-sharing mechanisms early in the process, and then translating the data into information that is both meaningful and relevant to government and industry decision-making. A corollary to that was wide-ranging agreement that there is lots of room for improvement to existing models, beginning with validation against real-world data.

For an agile approach to spectrum management to be possible, implementation planning and execution is more important than the strategy itself: Plans should be updated annually instead of every decade or two. Establishing the ground rules and framework for a national-level spectrum strategy requires intense and continuing coordination. Virtualization offers the opportunity to collect and share enormous quantities of data. The challenges are first, to establish frameworks to collaboratively conduct reasonable sharing and compatibility studies that extract meaning from data to provide the evidentiary basis for regulatory decisions; and, second, to acknowledge that multiple stakeholders with different assumptions, perspectives, and concerns will interpret the meaning of the results of any evidence-based, science-based method differently, so that moving forward comes back to standardization and transparency, to open technical discussion among stakeholders.

In this context, risk-based analytic approaches like calculating probability, assessing likelihood, thinking about impact, statistical data analysis, uncertainty analysis, and so forth, are becoming normalized within the spectrum community. Even so, different stakeholders worry about different impacts, worry about them differently, and assess risks differently. A potential source of learning how best to apply risk-based approaches to spectrum sharing is to look to other industries that have been doing risk assessment for 40 years. As pre-deployment risk assessment has become more widespread, there is still a need to develop risk management protocols. Risk assessment is what is done beforehand; after deployment, risk still needs to be continuously managed, because inevitably things will happen, will change—some for the better, some for the worse—and risk management practices are one way to introduce the flexibility to accommodate change.

While several exciting technology-based approaches for spectrum coexistence were presented, for any of these to be integrated into the policy space, a meaningful trust framework has to exist—a lot of experimentation, a lot of testbeds, and a strategy to integrate the results so that the technology can be believed and accepted. Funding, it was agreed, is lacking and lagging, for the critical research to be performed proactively rather than reactively, and for mechanisms that can support the type of open conversations where everybody can come together and resolve differences, and come to consensus on standards.

Openness and data sharing—early, often, and across disciplines—is important to generating the new ideas and approaches that are going to solve spectrum sharing problems rapidly and creatively. To move forward toward a more iterative and a more dynamic spectrum management policy, stakeholders need to understand which technical problems they should be solving and in which bands. That requires a nationwide framework, national investment strategy, and strong coordination across silos.

The conference closed with the results of an audience poll on whether an iterative—or, as some might say, Agile—regulatory process would be beneficial: 55 percent said it would be beneficial, but at the same time, 56 percent said it would be a little risky.

ISART 2022: Proceedings of the 19th International Symposium on Advanced Radio Technologies—Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-Making

The topic of the 2022 International Symposium on Advanced Radio Technologies™ (ISART 2022), which took place fully virtually June 13, 14, 15, and 16, 2022, was "Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making." The stated goal was to chart a roadmap and gain consensus for technical and regulatory means that can foster spectrum sharing innovation, optimization, and economic opportunity. Pre-recorded tutorials provide six overviews of the current U.S. regulatory process to establish spectrum sharing and overviews of four lessons learned from use cases and past regulatory efforts. The symposium featured NTIA Assistant Secretary Alan Davidson; three keynote addresses; two technical presentations; and six technically substantiative panels designed to present viewpoints of multiple stakeholders, including industry experts, technologists, scientists, and government representatives. A wrap-up panel identified key conference takeaways and potential next steps for ways to consider actualizing a national strategy for spectrum sharing. The text of these proceedings is taken from transcriptions of video recordings. A best effort has been made to correct spellings of names and terms of art, but it is not an "edited" transcript.

Keywords: Advanced Wireless Services-1 (AWS-1); Advanced Wireless Services-3 (AWS-3); Citizens Broadband Radio Service (CBRS); Federal Communications Commission (FCC); Department of Defense (DoD); Interdepartment Radio Advisory Committee (IRAC); interference; propagation modeling; spectrum auction; spectrum management; TV White Spaces; U-NII, usufructuary rights

1. Tutorial Series #1: Current U.S. Regulatory Process to Establish Spectrum Sharing

Pre-recorded tutorial presentations succinctly describe each step of the current spectrum regulatory process. The tutorials are designed to provide background on how the spectrum-sharing regulatory process currently works so that the panels can focus on evolving those processes.

1.1 Introduction to the Spectrum Sharing Regulatory Process and Spectrum Management in the U.S.

Rebecca Dorch, Senior Spectrum Policy Analyst, NTIA Institute for Telecommunication Sciences

Rebecca Dorch: I am Rebecca Dorch, the senior spectrum policy analyst at the Institute for Telecommunication Sciences (ITS), which is the research lab of the National Telecommunications and Information Administration (NTIA). This video is the introduction to the first series of short tutorial videos for the 2022 International Symposium on Advanced Radio Technologies, ISART, whose topic is on evolving spectrum sharing regulation through data-, science-, and technology-driven analysis and decision-making.

ISART is a U.S. government–sponsored conference hosted by the Institute for Telecommunication Sciences in Boulder, Colorado, since 1998. The first series of tutorials focuses on the current U.S. regulatory process to establish spectrum sharing. This introduction to that series provides a brief summary of the dual regulatory authority over the radio spectrum by NTIA and the Federal Communications Commission (FCC).

[Slide]

Radio transmissions have been regulated by the federal government since the Radio Act of 1912. The first effective regulation of radio transmissions, however, occurred with the formation of the Interdepartment Radio Advisory Committee (IRAC) in 1922. IRAC coordinated government-users' use of the spectrum. IRAC still exists today, is chaired by NTIA, includes 19 federal agencies with spectrum assignments, and facilitates spectrum coordination among the federal agencies and liaises with the FCC on issues impacting both federal and non-federal spectrum. The basic role of the representatives appointed to serve on the IRAC is to function, when meeting, in the interest of the United States as a whole. More information on the IRAC is in the tutorial by Peter Tenhula.

The Federal Communications Commission was established in 1934 by the Communications Act of 1934. The Act, as it's often referred to in shorthand, created the FCC as an independent federal regulatory agency directly responsible to Congress, charged the FCC with regulating interstate and international communications by radio, television, wire, satellite and cable, gave the FCC jurisdiction over radio regulation for the 50 states and territories, the District of Columbia, and U.S. possessions, and then carved out and codified the president's authority to manage the federal government's use of radio spectrum in Section 305 of the Act.

Responsibility for management of the federal government's use of spectrum is delegated by the president to the NTIA administrator, who serves as the president's principal advisor on telecommunications and information policy. In this role, NTIA frequently works with other executive branch agencies to develop and present the administration's positions, both domestically and internationally.

NTIA is also responsible for performing telecommunications, research and engineering, including resolving technical communications issues for the federal government and administering infrastructure and public telecommunications facilities grants. ITS was brought into NTIA in 1978 in order to assure that NTIA would have in-house research capabilities to support data-, science-, and technology-driven regulation. The responsibilities for managing spectrum have basically always been bifurcated, with the NTIA, as part of the executive branch, managing federal government use of spectrum, and the FCC, as an independent agency, responsible to the legislative branch managing all other uses of the spectrum.

[Slide]

NTIA and the FCC also have complementary but different rulebooks and advisory committees focused on spectrum matters that are organized under the Federal Advisor Committee Act, or FACA. FACAs are comprised of experts from outside the federal government, appointed as special government employees that offer expertise and perspectives to the federal agency. I mention this because during ISART, speakers will often refer to the NTIA Red Book, more formally referred to as NTIA's Manual of Regulations and Procedures for Federal Radio Frequency Management, but also known as the Red Book because of its color. And speakers will also refer to the Commerce Spectrum Management Advisory Committee (CSMAC), pronounced, alternatively, SEE-smack or CIS-smack, which offers NTIA expertise and perspectives on a broad range of spectrum policy issues, technologies, and potential reforms. Speakers will also refer to the FCC's rules at part 47 of the Code of Federal Regulations, CFRs, or as just "the rules". The 47 refers to the title of the United States Code. The printed volumes of the CFR are updated every year and, every year they are a different color. Speakers will also refer to the FCC's FACA on spectrum as the Technological Advisory Council, or TAC, that helps the FCC identify important areas of innovation and development of informed technology policies.

As we begin the discussion during ISART 2022 on evolving spectrum sharing regulation through data-, science-, and technology-driven analysis and decision-making, one other historical fact to note, which has facilitated spectrum allocations, reallocations, and repurposing, is that the Communications Act of 1934 did not mandate specific allocations of bands for exclusive federal or non-federal use. Rather, the frequency allocation stemmed from agreements between NTIA and the FCC and international agreements that are reflected in the table of frequency allocations that are contained in both the NTIA Red Book and in Part Two of the FCC's rules.

[Slide]

Up next in this tutorial series, distinguished communications experts will provide background on how specific aspects of the spectrum sharing regulatory process currently work.

1.2 Spectrum Repurposing and Sharing: Drivers and Authorities

Peter Tenhula, Senior Fellow, Spectrum Policy Initiative, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, Boulder, Colorado

Peter Tenhula: Welcome to this ISART 2022 tutorial on the drivers and authorities for spectrum repurposing and sharing. I am Peter Tenhula, Senior Fellow with the Spectrum Policy Initiative at the Silicon Flatirons Center for Law, Technology, and Entrepreneurship at the University of Colorado, Boulder.

Before retiring from federal service in 2021, I served as Deputy Associate Administrator in the Office of Spectrum Management at the National Telecommunications and Information Administration. I also worked at the Federal Communications Commission for a little more than 15 years and had a job in the private sector for about six years between the FCC and NTIA.

This tutorial will provide a brief overview on some of the legal, regulatory, and policy drivers of spectrum reallocation initiatives in the United States. I do not address every band that has recently been reallocated for new or shared uses, nor do I cover the various economic and technical drivers that help support these policy decisions.

By the way, I worked on many of these initiatives at NTIA or in the FCC, so please note that the tutorial represents my own personal views and perspectives. Anything presented here does not necessarily represent the views of NTIA, FCC, Silicon Flatirons, or any of my other former employers.

[Slide]

In this tutorial, I will first give some background on the original statutory and historical framework governing spectrum allocation and reallocation policies in the U.S. Then I'll give some modern examples and trends involving congressionally driven reallocations and spectrum auctions, along with other domestic and international drivers.

[Slide]

According to the first head of NTIA and former FCC general counsel Henry Geller, he said, quote, "Section 303c of the 1934 Communications Act authorizes the FCC to assign bands of frequencies to various classes of stations and to assign frequencies for each individual station. The first of these functions is considered to be the commission's allocation authority. While the latter serves as a mandate to make specific frequency assignments and authorizations," end quote.

In his 1978 congressional testimony, Geller pointed out that there is no explicit frequency allocation authority in the statute. Nor is any one governmental entity provided the authority to allocate spectrum to the various classes of stations. The division of the spectrum between federal and non-federal users and the sharing of certain frequency bands between both groups is accomplished by coordination between NTIA and the FCC. This slide shows excerpts from the original law the 1927 Radio Act that set up this dual scheme. On the left is Section 4 of the 1927 Act, which is the same language that can be found in Section 303 of the current law.

On the right is Section 6 of the 1927 Act, which is the president's authority to assign frequencies to each class of radio station, which is now contained in Section 305 of the Communications Act. This provision, Section 6, also set forth the president's original powers in the event of war or national emergency, which is now found in Section 706 of the Communications Act.

The president's authority under Section 305 has been delegated to NTIA, but the Section 706 authority has not. While this is a very simplified version of the legal origin story for the Dual Spectrum Management Authority granted to the FCC, the president, and NTIA, a 2014 congressional staff white paper described the situation as this: "Distinctions between Federal or non-Federal bands of spectrum are administrative creations made through agreements between the FCC and NTIA."

[Slide]

The first official table of frequency allocations was established a few months after enactment of the Radio Act in February 1927. The first table was not adopted by the new Federal Radio Commission but was part of the International Radiotelegraph Convention held in Washington, D.C. in the fall of that same year. They called it the table of "distribution and use of frequencies," from 10 KHz (kilohertz) to 23 MHz (megahertz).

The services, or classes of stations, listed in this first table included fixed, mobile, maritime mobile, broadcasting, radio beacons, air mobile services, direction finding, and amateurs. Only a few of the first allocated bands were shared among multiple services. Frequencies between 23 megahertz and 60 MHz were designated for amateurs and experiments or labeled as non-reserved—not reserved. Over the next several decades, this international table of allocations was modified and expanded at regular international radio conferences to add services and bands. Now let's fast forward to the 1990s.

[Slide]

To date, there have been seven pieces of legislation in the U.S. directing the repurposing of spectrum. In every case, these congressionally mandated reallocations were tied to larger budget or spending bills. Why is this? Well, in one word: auctions.

It all started in 1993, when Congress first authorized the FCC to conduct spectrum auctions and the Omnibus Budget Reconciliation Act of 1993, a mammoth bill that dealt with a number of spectrum and non-spectrum budget policy issues. In order to raise money for other unrelated spending initiatives in the bill, Congress mandated transfers of spectrum from federal government use to non-government or mixed or shared use.

In the 1997 Budget Act, Congress required the acceleration of certain government spectrum repurposing and mandated the reallocation of some of the UHF television broadcast band for commercial use to be auctioned and some for public safety use not to be auctioned. Congress also added Subsection Y to Section 303 of the Communications Act, specifically authorizing the FCC to, quote, "allocate electromagnet spectrum so as to provide flexibility of use," end quote, if certain conditions were met.

Auctions for flexible use licenses in the 1710 to 1755 MHz band for Advanced Wireless Services, or AWS-1, and the 700 MHz band were some of the results of the 1993 and 1997 statutes.

In the 2002 Auction Reform Act, Congress eliminated several statutory auction deadlines imposed by the 1997 Budget Act. Then, after a 15 year hiatus, Congress got back into the spectrum reallocation game in 2012 as part of the Middle Class Tax Relief and Job Creation Act of 2012, which ultimately led to the auctions of more television spectrum in the 600 MHz band and two bands reallocated from federal government use—the 1695 to 1710 MHz band and the 1755 to 1780 MHz band, or AWS-3.

The 2015 Spectrum Pipeline Act required NTIA and the FCC to identify 130 MHz of federal and non-federal spectrum for repurposing. Several bands are subject to feasibility studies under this law.

The Mobile Now Act of 2018 required the identification of additional spectrum for repurposing and called for various studies and reports related to spectrum repurposing of certain spectrum bands.

More recently, the Beat CHINA for 5G Act in 2020 [Beat China by Harnessing Important, National Airwaves for 5G Act of 2020; bill was not enacted into law] set a deadline for the FCC auction of the 3450 to 3550 MHz band, which was reallocated from federal government use and auctioned in record time.

The latest legislation that has been enacted was part of the 2021 Infrastructure Bill, which provides for further assessment of the 3100 to 3450 MHz band and an FCC auction by November of 2024.

[Slide]

When the FCC repurposed the 2 GHz (gigahertz) microwave bands for mobile personal communication services, PCS, in the early 1990s, it required the PCS auction winners to directly reimburse displaced microwave licensees for their relocation costs.

In the Balanced Budget Act of 1997, there was a new provision that authorized federal entities to accept cash or in-kind payment as compensation for costs associated with vacating spectrum transferred from federal to non-federal use. However, auction winners were not obligated to provide compensation or negotiate with displaced federal spectrum users.

In 1998, the Strom Thurmond National Defense Authorization Act modified the 1997 Balanced Budget Act provisions to require auction winners to compensate any federal entity affected by a relocation in advance of incurring any relocation costs. However, before they could be applied to any particular spectrum band, these initial negotiation-based cost reimbursement mechanisms were replaced with a completely different federal cost reimbursement approach.

The 2004 Commercial Spectrum Enhancement Act, or CSEA, adopted the Spectrum Relocation Fund approach, which was expanded in the Middle Class Tax Relief Act and Job Creation Act of 2012 to cover spectrum sharing costs incurred by federal agencies. The SRF is funded by a portion of auction revenues for reallocated government spectrum bands and affected agencies are reimbursed directly from the fund.

This Spectrum Pipeline Act of 2015 established a method for federal agencies to tap into the Spectrum Relocation Fund to conduct sharing feasibility studies and research that increases the likelihood of making additional federal spectrum available for reallocation and auction, including for shared use. Early legislation listed on the previous slide excluded certain types of allocations from FCC auctions, including broadcasting and public safety services.

Unlicensed spectrum is, by its nature, also exempt from auctions. In 1997, Congress lifted the auction limit for broadcasting licenses. But in 2000, as part of the ORBIT Act [Open-Market Reorganization for the Betterment of International Telecommunications Act], Congress restricted the use of auctions for spectrum allocated for the provision of international or global satellite communications services. The NDAA [National Defense Authorization Act] for [fiscal year] 2000 included a couple of interesting provisions. The first one required the president to reclaim or take back two federal spectrum bands previously identified for repurposing for exclusive federal government use on a primary basis by the Department of Defense. The other provision established certain procedures and safeguards whenever the Department of Defense is required to surrender use of spectrum to ensure that replacement bands are available that have comparable technical characteristics and capabilities.

[Slide]

Along the lines of one of the most puzzling mysteries of life involving chickens and eggs, sometimes it’s not obvious which comes first, congressional action compelling a spectrum reallocation or something else.

More often than not, the repurposing wheels are set in motion by a White House or FCC initiative that is then followed by a congressional action, especially when, as the recent trends on the prior slide show. Congress needs to use auction revenues to pay for something else in the spending or budget bill. This slide identifies just a few examples where Congress did not get involved in driving a repurposing effort from the start or at all.

The first examples present a couple of rare cases where non-federal spectrum was repurposed for government use at the request of the White House or NTIA. In both cases, a compelling need on behalf of national defense led the FCC, without notice and comment, to quickly reallocate spectrum for new federal applications. The D.C. Circuit Court of Appeals in the 1959 *Bendix* [*Aviation*] case upheld the FCC action and affirmed the president’s broad powers as commander in chief, which, as I discussed at the beginning of the tutorial, is preserved in Sections 305 and 706 of the Communications Act of 1934.

Presidential memoranda represent a recent trend that helps mobilize the entire executive branch to collaborate with NTIA and the FCC to find federal and non-federal spectrum to reallocate for new wireless mobile services for 3G and 5G for 3G and 4G mobile services. Presidents Clinton and Obama issued memos to get the ball rolling. Then Congress stepped in with the Auction Reform Act of 2002 and the Middle Class Tax Relief Act of 2012.

The President's Council of Advisors on Science and Technology Policy, or PCAST, got into the spectrum allocation game in 2012 with his report entitled "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," which led to another presidential memo in 2013 and spurred the FCC Citizen Broadband Radio Service, or CBRS.

More recently, the Trump White House's AMBIT Initiative led to the Beat CHINA for 5G Act in 2020, which required the FCC reallocation and auction of the 3450 to 3550 MHz band by the end of 2021. However, it was actually the Mobile Now Act in 2020 that required the sharing feasibility assessment of that band. Chicken or egg? Confused yet?

Other examples of FCC-driven reallocation initiatives include efforts in the early 1990s and the emerging technologies proceeding that first proposed repurposing fixed microwave spectrum for new mobile services, leading to the PCS auctions.

To implement the 1997 Budget Act, the FCC outlined its reallocation plans in a 1999 policy statement. The FCC's broadband plan, which Congress mandated in the American Recovery and Reinvestment Act of 2009, included a chapter on spectrum repurposing and sharing that identified 500 MHz of spectrum that could be made available for wireless broadband services by 2020. Former FCC Chairman [Ajit] Pai in 2018 announced a comprehensive strategy to, quote, "facilitate America's superiority in 5G technology," also known as the 5G Fast Plan. The strategy included several high, mid, and low band spectrum bands, along with additional unlicensed bands that the FCC planned to release into the marketplace for flexible use.

Last but not least is the longest running approach to reallocating spectrum since 1927. Regular international conferences have expanded the allocation of usable spectrum from 23 MHz to above 275 GHz. I don't know a lot about the international drivers for repurposing and sharing.

Plus, I'm out of time, so I'm going to have to end this tutorial on that disappointing note.

[Slide]

Nevertheless, I hope that the information provided in this tutorial was helpful to you. If you have any questions, please feel free to contact me at the email on this slide. Additional information on the status of various bands that are the subject of repurposing or sharing initiatives is available at the hyperlink shown on this slide.

Thank you for your attention. I hope you enjoy ISART 2022.

1.3 Overview of the NTIA Approach to Spectrum Sharing Feasibility Studies and Analysis

Edward Drocella, Chief, and Nickolas ("Nick") LaSorte, Electrical Engineer, Spectrum Engineering and Analysis Division, NTIA Office of Spectrum Management

Edward Drocella: Thanks for listening in. I'm Ed Drocella, and with me I have Nick LaSorte. We're with the NTIA Office of Spectrum Management, Spectrum [System] Engineering and Analysis Division.

[Slide]

Most of us are listening into ISART because we're interested in spectrum, whether it is accessing the spectrum

[Slide]

or, in the case of NTIA, we support the agencies in accessing spectrum so they can perform their missions.

[Slide]

Engineering studies, electromagnetic compatibility, feasibility or interference analysis is at the core of spectrum management.

[Slide]

Typically, a feasibility study is the first step to getting spectrum access.

[Slide]

So join us for the rest of the video as we show you some of the ways that we approach feasibility studies.

[Slide]

From a federal perspective, the goal of an analysis is to protect our spectrum users from harmful interference. While it is hard to eliminate all non-harmful interference, harmful interference is not acceptable, as it can influence the primary missions of the federal spectrum users. We understand the definition of harmful interference can lead us down a rabbit hole.

Harmful inference can be defined by the federal user for each system. If we can, for the purposes of this video, let's set aside trying to provide a generalized definition of harmful interference. There are essentially three areas where we do spectrum studies.

[Slide]

First, we can do a feasibility analysis to reduce harmful interference. If a federal user is experiencing harmful interference, they can't perform their mission. When we deconflict interference they can perform their mission. Reducing interference also increases spectrum efficiency and effectiveness.

[Slide]

Number two, we do a spectrum study if an agency requests a new frequency assignment or if they want to introduce a new system into the band. Increasing the number of federal users increases the overall spectrum efficiency and effectiveness in the band.

[Slide]

And, number three, we do a spectrum state look at potential spectrum sharing opportunities with non-federal users. We can share the spectrum of frequency, geography, and time.

[Slide]

Spectrum studies are a balancing act. We try to encourage use of the federal spectrum, minimizing harmful interference while not underutilizing the band. The rest of the video will discuss important topics to take into consideration when performing feasibility studies.

[Slide]

First, we will cover how we try to quantify and reduce uncertainty in a feasibility study.

[Slide]

Second, we will discuss some of the processes that we use to try to build trust among stakeholders that are participating in a feasibility study.

[Slide]

Third, we will discuss some of the models and tools that we use in a feasibility study.

[Slide]

Our first topic: uncertainty. One of the questions we might have when approaching a feasibility study is How do we quantify and reduce uncertainty in our spectrum studies?

[Slide]

Spectrum access, whether it's putting a new system in the band or sharing spectrum, involves trying new things. Trying new things has risk and rewards and with that comes uncertainty. I think we can agree that spectrum users want to have some level of certainty about the environment that they will be operating in—specifically, that they will not receive interference. And if they do experience harmful interference, that it will be resolved quickly.

[Slide]

Models are at the heart of a feasibility study. These models can include a radio frequency or RF link budget. We can model how the federal users operate in terms of frequency, geography, and time. Or we can model the commercial base station deployment. A model is useful only if we understand that it does not represent the world as it really is. With the limitations of the model in mind, we use them to explore the possibilities of spectrum sharing.

[Slide]

We can do this by sensitivity analysis. First, we try to identify where a small change to the input causes a large change to the output. We could say this input is sensitive. It's also good to know if a large change to an input doesn't have an effect on the output. This allows us to prioritize the inputs by the sensitivity. Then we can focus on the most sensitive inputs and reduce their uncertainty. There are several ways we can try to reduce uncertainty.

[Slide]

One way to reduce uncertainty is through measurements. A good measurement might take us from an 80-percent certainty to a 98-percent certainty. We might have known something about the input before and the new information can update that prior knowledge. We can call this Bayesian inversion.

[Slide]

Another way to reduce some of the uncertainty is by model decomposition. We do this by breaking the model into more manageable pieces and reducing the uncertainty of each piece.

[Slide]

In most cases, an input parameter may not be a single value, but instead can be represented by statistical distribution. When we model inputs as distributions, we can use a Monte Carlo analysis.

Does every spectrum study need to have all the inputs modeled as a distribution? Not necessarily.

[Slide]

Spectrum studies can start out very simply. Through an iterative process, we reduce the uncertainties in a spectrum study. Then we reassess the sensitivity of the model. Over time, the model can be improved. We should approach all models with reservation. In Part 2, we'll talk about how we can approach evaluating spectrum studies, while also encouraging an environment to build trust.

[Slide]

In Part 1, we talked about how we try to handle the uncertainties of a feasibility study. Since spectrum access involves other users, we try to build trust and consensus among the stakeholders. In Part 2, we will discuss how we try to do this during a feasibility study.

[Slide]

Maybe the first step to building trust and consensus in spectrum studies is through the peer review process. The hope is we can reach a point where the spectrum study is transparent and we can all agree on the math. We should keep in mind that the peer review process is not about throwing stones. Again, models are not reality. The goal is to improve the model. When we ask questions, we are not seeking conflict, we are striving to understand.

Is the peer review process hard? Absolutely, yes. But it improves the feasibility study, building trust of the stakeholders.

[Slide]

Another foundation of science is repeatability and reproducibility. We hope that the data used in a feasibility study can be shared. For example, providing the individual components of the link budget in a spreadsheet. And then, can someone else independently get similar results using the shared data?

[Slide]

We understand there are some limitations for federal and non-federal stakeholders to publicly share data. For example, the federal users may not be able to share technical parameters for their system. In the CBRS [Citizens Band Radio Service] band, federal users were able to share an overall interference threshold to get around this limitation. Also, it can be hard for non-federal users to publicly share commercial base station deployment.

[Slide]

We hope all the feasibility study data can be shared with the spectrum regulators. We understand that funding for agencies may not be available to reproduce someone else's work. To support the mission of the agency, NTIA welcomes this task. The hope is that we can all agree on the math.

[Slide]

An example of building trust occurred in an ITU-R spectrum study performed by NTIA in conjunction with DoD, NASA, NOAA, FCC, and the unlicensed device industry. The study examined expanding the Unlicensed National Information Infrastructure (U-NII) rules with the devices employing Dynamic Frequency Selection (DFS) in the 5 GHz band. Industry proposed sharing options and they were evaluated by the group. Transparency allowed the analysis of results to be shared among the stakeholders. In the end, all the stakeholders agreed that sharing was not possible. In summary, peer review allows us a process to build trust and consensus among the stakeholders.

[Slide]

This takes us to our final topic, Part 3. We will talk about some of the current tools and models that we use in feasibility studies.

[Slide]

People can use any software tools they like for their feasibility study. We advocate that the software has the capability to share the analysis data to enable peer review. A feasibility study is typically centered around an RF link budget. For the rest of Part 3, we'll discuss some of the models used in a link budget.

[Slide]

The first model we'll discuss is frequency dependent rejection, which is referred to as FDR. As the frequency separation between the transfer and receiver increases, the FDR increases. This allows systems to share the spectrum in the frequency domain.

[Slide]

Another model used in the link budget is path loss. Based on the sharing scenario, there can be many models to choose from. The peer review process can help us reach agreement on which model to choose and how to use it in the feasibility study.

[Slide]

One part of the path loss model is clutter loss. Everyone agrees that clutter loss exists. But the question is how and when to apply clutter loss. Improving and validating clutter loss models is an area where more work is needed.

[Slide]

Thanks for joining us in this tutorial on feasibility studies in the spectrum management regulatory process.

First we covered how we try to quantify and reduce uncertainty. Then we highlighted some of the processes that we use to build trust among stakeholders. Finally, we showed some of the fundamental models that we use in a feasibility study.

[Slide]

This ends our presentation and, again, thank you for your time.

1.4 Overview of the FCC's Rulemaking Process

Suzanne Tetrault, Partner, Wilkinson, Barker, Knauer, LLP

Suzanne Tetreault: I'm Suzanne Tetreault. I've been a communications attorney for many years; most of those years spent at the Federal Communications Commission. I'm here today to talk about what the FCC's rulemaking process looks like.

[Slide]

I'm going to cover a few different topics, beginning with what causes the FCC to start rulemaking in the first place. Then I'll talk about some key legal requirements that shape the process, what it actually looks like in practice, and what happens when the FCC is ready to actually issue an order adopting rules.

[Slide]

There are a number of different things that can cause the FCC to start a rulemaking. The first of those isn't really within the FCC's discretion. When Congress enacts communications related legislation, it often instructs the FCC to adopt implementing rules.

Another possibility is that the FCC may receive a petition for rulemaking, which any member of the public can file.

The third and most frequent reason that the FCC starts a rulemaking is because it has identified as a problem that needs to be addressed or a particular policy that it wants to implement. So, for instance, if the FCC is interested in implementing spectrum sharing in a particular spectrum band, that may be a reason for it to start a rulemaking process.

[Slide]

There are a number of different legal requirements that apply when the FCC—or any other federal agency, for that matter—wants to adopt rules. I'm going to focus just on the two, perhaps most important, of them.

The first is that the FCC must have statutory authority for the rules that it wants to adopt, which is to say that the FCC can only do the things that Congress has told it it can do. The agency has very broad authority when it comes to radio spectrum issues, but it must be able to point to something specific in the Communications Act to justify the rules that it wants to adopt.

The other overarching requirement is the Administrative Procedure Act, which establishes the basic framework for rulemaking within the federal government, across all of the agencies. The basic process is summarized with the phrase "notice and comment." The agency has to give notice to the public of what it's proposing to do and accept comment from the public on that proposal. There are very limited exceptions to the notice and comment requirement and you'll see that process implemented in nearly all FCC rulemakings.

[Slide]

So what does that notice and comment process look like in practice? To begin with, the FCC may have discussions with industry or other interested stakeholders before it takes official action as part of the process of deciding whether it wants to begin a rulemaking in the first place. The first official step, though, is to publish a document called a notice of proposed rulemaking (NPRM) in the Federal Register. That's the "notice" part of the notice and comment process. That notice of proposed rulemaking will explain why the agency thinks a rule may be appropriate, and it'll make a proposal—sometimes very specifically, with the text of a new rule written out; other times, more generally. It'll ask some questions about the pros and cons of that proposal and may ask about alternatives as well.

As an alternative to starting with a notice of proposed rulemaking, particularly when the agency has a lot of general questions about what it wants to propose, it can start with a document called A Notice of Inquiry, which is very similar to the notice of proposed rulemaking, but it's not affirmatively proposing to adopt rules yet at that point. So it has to be followed up by a notice of proposed rulemaking if the FCC decides to go forward.

Once that notice of proposed rulemaking has been issued, the comment part starts. Written comments are accepted by the agency. They establish a deadline for those comments, which is generally at least 30 days, sometimes longer than that. The FCC also routinely allows parties to file reply comments, which is to say that they can comment on what other people said in the initial comment round.

It's also important to recognize that those written comments are not the only public input that happens at the FCC. The FCC allows ex parte contacts, which means that you're allowed to have meetings with the FCC to talk about the proposals. You simply have to put something in the record afterward to identify for the public what it was you discussed with the FCC. That notice of proposed rulemaking is typically the only step required to get to the adoption of rules, but sometimes the FCC will issue a further notice of proposed rulemaking if the comment process identifies additional questions that it would like to have more comment on.

[Slide]

Once the FCC has received and review those comments, it has to decide whether it wants to go forward with its original proposal, or possibly change the proposal a bit in response to the comments, or potentially even decide not to adopt any rules at all for the time being.

If it does decide to adopt rules, it issues a report and order that lays out the specific text of those rules, along with an explanation of why the agency has now decided to adopt them. As part of that explanation, the FCC is legally required to consider and address all of the significant comments that it received during that notice and comment process. So for instance, if someone has filed comments that are opposing what the FCC wants to do, if the agency decides to go forward with it anyway, it has to acknowledge those comments and explain why it has decided that the better course is to move ahead. The report and order is also going to establish an effective date so that everyone knows when they have to comply with those rules. The report and order is not necessarily the last step in this rulemaking process. There are a few possibilities that can inject another stage.

One is that interested parties can always file a petition for reconsideration of an FCC order if they believe, for instance, that the FCC didn't fully address the record or that it made a mistake. If the FCC gets a petition for reconsideration, it has to consider that and then issue another order in which it either stays with the original decision or modifies it in some way.

Some FCC orders are also subject to the Congressional Review Act, which gives Congress the possibility of disapproving those regulations. That happens rarely, but it does occasionally happen. And finally, FCC orders are subject to court review. They can always be appealed, and oftentimes they are given the stakes when some of these rules are adopted. Any of those things can postpone the date on which the FCC rules are able to take effect, and oftentimes you will see at least a reconsideration or a court review, if not both.

Once the FCC has adopted rules, if it later decides that it wants to change them, it has to go through the same steps that I've just described for any revisions as it went through for adopting the rules initially.

Thank you.

1.5 Overview of the NTIA Interdepartment Radio Advisory Committee

Peter Tenhula, Senior Fellow, Spectrum Policy Initiative, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, Boulder, Colorado

Peter Tenhula: Welcome to the ISART 2022 tutorial on the Interdepartment Radio Advisory Committee, fondly known as the IRAC. This tutorial will provide a brief overview of the IRAC and its role and impact on technical and policy issues regarding spectrum sharing.

I am Peter Tenhula, Senior Fellow with the Spectrum Policy Initiative at the Silicon Flatirons Center for Law, Technology, and Entrepreneurship at the University of Colorado, Boulder.

Before retiring from Federal service in 2021, I served as the chair of the IRAC and was the Deputy Associate Administrator in the Office of Spectrum Management (OSM) at the National Telecommunications and Information Administration, or NTIA. I also worked at the Federal Communications Commission, or FCC, for a little more than 15 years. And I also worked in the private sector for about six years.

This tutorial represents my own personal views and perspectives. Anything presented here does not necessarily represent the views of NTIA, the FCC, Silicon Flatirons, any of my other former employers, my wife, my kids, or anyone else that I might know.

[Slide]

In this tutorial, I will first explain how the IRAC fits within the overall U.S. spectrum policy and management framework.

[Slide augmentation]

Then I will describe the current membership and structure of the IRAC and highlight some of the long-running committee's historical background.

[Slide augmentation]

Finally, I'll discuss the interagency coordination process and its role and impact on technical and policy issues regarding spectrum sharing.

[Slide]

The introductory talk by Rebecca Dorch in this tutorial series provided an overview of the dual spectrum management structure in the U.S. To quickly recap, under the Communications Act of 1934 and the NTIA Organization Act, Spectrum Management responsibilities and policy functions are split between the Federal Communications Commission, an independent agency, and NTIA, a bureau within the U.S. Department of Commerce.

In sum, the FCC is responsible for regulating the spectrum resources used by non-federal users, and NTIA oversees the use of spectrum by federal government agencies. NTIA's spectrum management rules are published in the Manual of Regulations and Procedures for Federal Radio Frequency Management, also known as the Red Book. Coordination of national spectrum policy and management issues between the FCC and NTIA occurs at several levels and is generally governed by a memorandum of understanding (MOU) between the two agencies that was executed in 2003. While the current MOU does not specifically mention the IRAC or other interagency advisory groups, I will address the interagency coordination process later.

Another interagency advisory body is the Policy and Plans Steering Group (PPSG), which was established by NTIA in 2005. The PPSG includes higher-level representatives at the Assistant Secretary or equivalent level, from agencies that are major stakeholders in the spectrum issues under consideration and includes FCC and White House representatives. The PPSG provides advice to the NTIA Assistant Secretary on spectrum-dependent telecommunication policies, strategic plans, and helps resolve major contentious spectrum policy issues.

Within this dual structure, the IRAC provides advice to NTIA on a wide range of matters, from assigning frequencies to U.S. government radio stations, to developing policies, programs, procedures, and technical criteria pertaining to the federal agencies use of spectrum, most of which are documented in the IRAC's recommended changes to the NTIA manual.

[Slide]

This slide shows the 19 federal agencies that make up the IRAC membership. The IRAC bylaws contained in Chapter 1 of the NTIA manual provide that the basic role of agency representatives appointed to serve on the IRAC is to function when in committee in the interest of the United States as a whole. Most agencies have a primary representative and one or more alternates. The names and contact information for the current IRAC members are available on the NTIA website (www.ntia.gov/category/IRAC). There are three observer agencies, and the FCC has a liaison, representative, and alternates.

NTIA appoints the chairperson and vice-chairperson of the IRAC. An agency vice-chairperson is elected by the IRAC members for a three-year term. The duties of the agency vice-chairperson include the review of meeting agendas from the agency's perspective, coordination of issues with the chairperson, and developing and presenting agency member concerns to the IRAC or NTIA.

The IRAC meets once a month.

[Slide]

This slide shows the structure of the IRAC, including the six standing subcommittees and four currently active ad hoc groups. Most of the work of the IRAC takes place or originates in the subcommittees. Each subcommittee's assigned functions are set forth in the IRAC bylaws. The duties and objectives of the ad hoc groups are set forth in the terms of reference that are approved by the IRAC.

Each subcommittee is chaired by staff from NTIA's Office of Spectrum Management. Each ad hoc group has a convener, typically OSM staff, except that other agency representatives have served as conveners. For example, the agency vice-chair of the IRAC typically serves as a convener for Ad Hoc Group 213 on IRAC operations and procedures. Ad Hoc 206 usually gets reactivated immediately following a world radio conference. Secretariat functions are handled by NTIA's Office of Spectrum Management for the full committee and each subcommittee.

The IRAC was established 100 years ago by Secretary of Commerce Herbert Hoover, and his first meeting was held on June 1st, 1922. It is the longest continuously serving interagency advisory committee within the Federal Government. Its original purpose was to find means for making the most effective use of radio technology, then being used for government broadcasting services. Originally named the Inter-departmental Advisory Committee on Governmental Radio Broadcasting, it soon recognized the need to consider other telecommunication matters of interest to the departments and agencies and in 1923 changed its name to the Interdepartment Radio Advisory Committee.

The IRAC has a rich history and has had a significant role in most every spectrum-supported development, from maritime services to FM and TV broadcasts to aviation to advanced mobile and radar capabilities to satellite communications to spread-spectrum techniques, and many more innovations over the decades.

With the enactment of the 1927 Radio Act, the dual authorities of the Federal Radio Commission and the president, under the new law, require the IRAC to continue its role as advisor to the president related to the constitutional responsibilities of Chief Executive and as Commander in Chief to manage access to spectrum by federal government radio stations.

Under President Franklin Roosevelt in the 1930s and early 1940s, oversight of the IRAC shifted to the newly formed FCC in 1934 and [also] the FCC Board of War Communications during World War II. In 1940, the first coordination memorandum was approved by the FCC and the IRAC, stating that each organization will give notice to all proposed actions which would tend to cause interference to nongovernment or government station operations.

During the Truman administration and following a comprehensive evaluation of U.S. telecommunications regulatory structure by the Communications Policy Board, chaired by Irvin Stewart, the IRAC was reconstituted under a new White House telecommunications advisor to the president. That is when the FCC became a liaison member of the IRAC.

A few more highlights from the past several decades: The first Manual of Regulations and Procedures for Frequency Management was approved by the White House Director of Telecommunications Management in 1965. When NTIA was established in 1978 by President Carter in an executive order, he stated that the Secretary of Commerce, to the extent he deems it necessary, may continue the Interdepartment Radio Advisory Committee, and that committee shall serve in an advisory capacity to the Secretary. That executive order was codified in 1992 in the NTIA Organization Act, which references the IRAC's advisory role in Section 105b.

As I mentioned earlier, the current FCC and Coordination Framework for Spectrum Matters is implemented under a 2003 MOU, according to a March 2022 FCC and NTIA joint press release. This MOU is the subject of review and recommended revisions by a bilateral task force of NTIA and FCC staff. Some of the current MOU's provisions are very similar to those contained in the 1940 memorandum. The next IRAC meeting will be its 2,060th. Under the current coordination framework and NTIA's implementation of the 2003 MOU, I would guess that the bulk of the agenda for the next meeting constitutes a number of pending FCC rulemaking and adjudicatory matters that are being coordinated with the NTIA and through the IRAC with the other federal agencies.

[Slide]

To conclude this tutorial, I would like to provide a quick overview of how the FCC-NTIA MOU was implemented when I was chair of the IRAC and describe how most policy and routine licensing matters were coordinated.

First, some legal authorities and regulations to be aware of in connection with federal agency inputs into FCC proceedings.

The NTIA Organization Act gives NTIA the, quote, "responsibility to ensure that the views of the executive branch on telecommunications matters are effectively presented to the [FCC]," end quote. This means that other executive branch agencies usually need to go through NTIA before making filings with the FCC on spectrum or other telecommunications policy matters.

The FCC's rules provide NTIA and other federal agencies with which the FCC shares jurisdiction flexibility regarding interagency deliberations and making public filings in FCC proceedings. If the FCC's proposed action must rely on the agency's disclosure, the rules provide for advance coordination to ensure that the agency involved retains control over the timing and extent of any disclosure that may have an impact on that agency's jurisdictional responsibilities. If the agency involved does not wish such information to be disclosed, the commission will not disclose it and may disregard it in its decision-making process.

Under the FCC-NTIA MOU that I mentioned before, the two agencies have agreed to provide each other at least 15 business days' notice of proposed actions that could potentially cause interference to government or nongovernment operations. The way this usually worked for FCC actions when I was the IRAC chair, and I assume is still the process, is that the IRAC chair or vice-chair would share draft items that NTIA staff gets from the FCC staff for coordination with the IRAC member agencies. Agencies would typically get 10 business days to provide feedback to NTIA staff. And, based on these inputs and its own review, NTIA would informally give its thoughts and feedback on the proposed action items, which are also discussed at IRAC meetings.

While these internal government documents and deliberations are not available to the public, NTIA often submits comments or filings into the public record of key proceedings. Under the MOU, final action by the FCC does not require approval by NTIA. But the current MOU also says that the FCC and NTIA will resolve technical, procedural, and policy differences by consensus whenever possible.

Routine federal assignments, FCC license applications and requests for special, temporary, or experimental authority are coordinated through IRAC's Frequency Assignment Subcommittee and usually take less than 15 days to complete coordination.

Under the 1940 and 2003 MOUs, the FCC and NTIA agreed to maintain current lists of assignments and to exchange information necessary to coordinate spectrum use. NTIA's website includes additional information, such as a list of non-federal license applications that the FCC is coordinating with NTIA and the IRAC. This list is available at www.ntia.gov/webcoord. But this list does not currently include pending requests for FCC special temporary authorizations, or STAs, and it does not include non-routine applications that require waivers or written FCC decisions.

Chapter 11 of the NTIA manual provides information on public access to the IRAC and NTIA's federal spectrum management process. Since most of the spectrum is allocated for shared, federal, and non-federal use, or these uses are in adjacent bands, the IRAC plays an important role and often has a significant impact on many high-profile technical and policy issues regarding spectrum sharing and repurposing. The federal agencies on the IRAC, as well as the PPSG, provide valuable advice and recommendations to NTIA under a collegial process that has worked well for a century.

[Slide]

I hope that the information provided in this tutorial was helpful to you. If you have any questions, please feel free to contact me at the email on this slide. Additional information on the IRAC and the NTIA Manual is available at these hyperlinks.

Thank you for your attention. I hope that you enjoy ISART 2022.

1.6 Putting the Spectrum Sharing Regulatory Process All Together—CBRS as a Case Study

Rebecca Dorch, Senior Spectrum Policy Analyst, NTIA Institute for Telecommunication Sciences

Rebecca Dorch: Hello again. I am Rebecca Dorch, the Senior Spectrum Policy Analyst at the Institute for Telecommunication Sciences (ITS), which is the research lab of the National Telecommunications and Information Administration (NTIA).

This video is the conclusion to the first series of short tutorial videos for the 2022 International Symposium on Advanced Radio Technologies, ISART, whose topic is on Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-Making. ISART is a U.S. government–sponsored conference hosted by the Institute for Telecommunication Sciences in Boulder, Colorado since 1998.

The first series of tutorials focused on the current U.S. regulatory process to establish spectrum sharing. This concluding tutorial in that series uses the Citizens Broadband Radio Service, CBRS, as a case study showing how the different aspects of the spectrum sharing regulatory process actually work in a specific spectrum sharing scenario; and how NTIA, the FCC, the Department of Defense (DoD), and industry all worked collaboratively together to create a successful framework for spectrum sharing between incumbent DoD radars already operating in the band and performing mission critical operations, and commercial incumbents also operating in the band and providing satellite services and terrestrial wireless services, while enabling new licensed and unlicensed entrants into the band to provide innovative new services and 5G.

[Slide]

This CBRS case study starts by looking at the vision for CBRS, the process as explained by Peter Tenhula in the tutorial on Spectrum Repurposing and Sharing: Drivers and Authorities [Tutorial Series #1, 1.2 Spectrum Repurposing and Sharing: Drivers and Authorities]. Next, the case study looks at technical research and feasibility analysis conducted to inform development of the rules for this new service, the process explained in Ed Drocella's tutorial on NTIA's feasibility analysis [Tutorial Series #1, 1.3 Overview of the NTIA Approach to Spectrum Sharing Feasibility Studies and Analysis]. With CBRS, research on technical aspects of sharing the band continued throughout the rulemaking process with critical technical input submitted into the rulemaking process at the FCC by NTIA, along with thousands of pages of comments from hundreds of interested parties, a process explained by Suzanne Tetreault in a tutorial on the FCC's rulemaking process.

Then we'll look at implementation of the new rules, from development of standards to testing, and auctions, and licensing. The Tuesday keynote by Evan Kwerel [Day 2, June 14 – Keynote: History of Spectrum Auctions] looks at auctions, and a panel on Wednesday will discuss standards development using propagation as a case study [Day 3, June 15 - 5.5 Panel: Model Standardization - Propagation Case Study.]

Finally, this case study touches on monitoring and reporting on the CBRS sharing framework post-deployment. And, in the next series of tutorials and lessons learned from spectrum sharing, Andy Clegg shares Lessons Learned from CBRS [Tutorial Series #2, 2.3 Citizens Broadband Radio Service—Lessons Learned].

[Slide]

The origins of CBRS can be traced back to at least 2010 and then President Obama's presidential memorandum requiring that the federal government make available 500 MHz of federal and non-federal spectrum for both mobile and fixed-wireless broadband use by commercial users within 10 years, i.e., by 2020. NTIA's October 2010 Fast Track Report identified the 3.5 GHz band as a candidate for spectrum sharing in response to the president's initiative but found that the need to preserve essential services meant that the spectrum from 3550 to 3650 MHz could only be offered with very large exclusion zones extending inland nearly 200 miles from both the East and the West Coast of the United States, and thereby excluding a majority of the U.S. population.

In 2010, 2011, and 2012, ITS hosted ISART symposiums, where the spectrum stakeholder community gathered in Boulder to discuss technologies and science-based ways to achieve the spectrum sharing goals set out by the Obama administration. The focus of the ISART Program in 2011, to demystify radar technologies and understand radar's use of the spectrum, actually helped provide the technical foundations for developing the regulatory paradigm for radar and commercial sharing in the 3.5 GHz band, leading eventually to CBRS.

The 2012 report from the President's Council of Advisors on Science and Technology, often referred to as the PCAST report, made numerous recommendations, including to expand access to the 3550 to 3650 MHz radar band for commercial operations and make it an innovation band. The FCC subsequently proposed in December of 2012 to make 100 MHz of shared spectrum available in the 3.5 GHz band using small cell and database technologies.

[Slide]

This mid-band spectrum used by military radars off the coast and at inland radar test and development sites and at ports, was a candidate for sharing with commercial terrestrial LTE-type technology. NTIA, through ITS and the Office of Spectrum Management, OSM, conducted numerous technical studies on radar and sharing between radars and terrestrial mobile technologies, publishing the results to help everyone understand the technical issues that would need to be addressed to share the 3.5 GHz band and have effective coexistence between these very different types of technologies.

In 2014, the FCC then issued a further notice of proposed rulemaking proposing rules to make up to 150 MHz of spectrum available for a new innovation band, as originally described in the PCAST report. For the Citizens Broadband Radio Service, the FCC proposed innovative new rules to promote intensive shared use of the spectrum. Specifically, the FCC proposed a three-tier sharing framework. Incumbents, both federal and commercial, would be protected from interference from all lower-tiered new entrants. Second-tier priority access new entrants would be protected from interference from the third-tier general-access unlicensed new entrants.

In light of the 2010 Fast Track report from NTIA, the FCC proposed exclusion zones to protect the federal incumbents, noting plans for NTIA and the FCC to work together to assess exclusion zones in light of the new technologies and new data from technical studies and evaluations of coexistence between radars and wireless broadband services. NTIA, ITS, and OSM continue to conduct and publish the results from numerous technical studies on radar and on sharing between radars and terrestrial mobile technology. The NTIA, FCC, DoD, and industry stakeholders all worked on technical plans and solutions to reduce the impact of the exclusion zones while protecting critical federal systems.

During this time, industry and associations and academics and interested parties all filed thousands of pages of comments and reply comments and ex parte letters in the FCC's docket for CBRS. The FCC website shows that ultimately over 878 filings were received in this docket alone.

[Slide]

NTIA's further engineering analysis, shared with the FCC, found that the exclusion zones described in the Fast Track report could be reduced by 77 percent with microcell deployments and consideration of clutter. NTIA also recommended employing some of the solutions recommended by commenters in the docket, such as employing sensing technologies to essentially convert exclusion zones to protection zones and deploying a phased-implementation and approval process for the spectrum access systems and sensing capabilities.

The significant amount of early technical research conducted and analysis performed to assess the feasibility and viability of sharing spectrum in the 3.5 GHz band by both NTIA and industry, aided formulation of technical rules for sharing contained in the Report and Order the FCC adopted in 2015 to make 150 MHz of spectrum at 3550 to 3700 MHz available for wireless broadband and other innovative uses. Incorporating the views and information collected through three rounds of Notice and Comments and workshops, the first Report and Order adopted the three-tiered framework to coordinate shared federal and non-federal use of the band, enabled by a spectrum access system, or SAS, and environmental sensing capability sensors, ESCs, and adopted a hybrid framework for licensed and unlicensed opportunistic access to the spectrum by new entrants to enable local supply and demand to determine the best approach.

As noted in the tutorial on the rulemaking process, the FCC did receive petitions for reconsideration, which they addressed in the 2016 Second Report and Order and Order on Reconsideration to then finalize the CBRS rules in 47 CFR Part 96.

[Slide]

With the rules now final, it was time for the implementation stage, starting with the development by industry of standards and equipment; continuing research by NTIA and industry to refine the rules to maximize effective utilization of the shared spectrum; and revisions of the rules by the FCC. One interesting thing the FCC did in this rulemaking was to encourage an industry-led, multi-stakeholder group to focus on the complex technical issues and develop innovative solutions, technical specifications and standards, and accreditation programs.

The Wireless Innovation Forum, WInnForum, Spectrum Sharing Committee, an industry-led multi-stakeholder standards group, did just that: standing up committees to begin developing communications protocols and technical specifications for Citizens Broadband radio Service Devices (CBSDs) and spectrum access system operations, requirements for cybersecurity and operational security, and recommendations for test and certification processes and plans.

NTIA, through ITS and OSM, continued to perform research, 1) releasing official Extended Hata (eHata) Urban Propagation Model code in GitHub for use by SAS's, 2) publishing technical reports related to developing parameters for and testing of environmental sensing capability sensors, and 3) developing, in close collaboration with DoD, the FCC and input from the multi-stakeholder group, dynamic protection areas, DPAs, for use with ESCs to enable protection of the DoD radar systems, while providing greater flexibility and deployment areas for commercial operations, which were adopted by the FCC in May of 2018. WInnForum technical specifications for CBRS operations by SAS's and CSBDs, were relatively well settled by October of 2018. And SAS testing specs and code were relatively settled by December 2018. Also in October of 2018, the FCC updated the licensing and technical rules for priority access licensees, PALs, changing from census tracts to counties with licenses to be assigned by competitive bidding.

[Slide]

The SASs, ESCs sensors, and CBSD equipment all went through rigorous testing prior to the FCC certifying any of the components for operation. Bench and lab conformance and certification testing of the new spectrum access systems and environmental sensing capability sensors were conducted by ITS under Cooperative Research and Development Agreements (CRADAs) with the FCC conditionally certified SAS administrators and ESC operators.

Field Testing, analysis, and reporting on the SAS systems occurred through the FCC's initial commercial deployment testing. Analysis of the ESCs coverage of dynamic protection areas was performed by NTIA's Office of Spectrum Management. And also in 2019, the FCC was gearing up for auctioning the priority access licenses, which occurred in the third quarter of calendar year 2020, raising $4.58 billion.

[Slide]

Even with all of this going on, NTIA, the FCC, Department of Defense, and CBRS stakeholders continue to research ways to improve commercial access to the band, particularly around ports and inland sites with ground-based radars. Today, CBRS is deployed and growing. The regulators are monitoring the sharing framework, and, so far, it appears that all of the scientific research, carefully crafted technical rules, detailed standards and rigorous testing paid off.

And the framework does indeed appear to be working well.

2. Tutorial Series #2: Lessons Learned from Spectrum Sharing Regulatory Efforts and Use Cases

Recognizing lessons learned from the development and implementation of spectrum-sharing regulatory rules over the past decade can lead to process improvements. Each of these recorded tutorial presentations focuses on one individual prior spectrum-sharing proceeding and any lessons learned from that particular proceeding. These tutorials are designed to provide background for registrants less familiar with past proceedings and enable panelists to reference specific proceedings without needing to explain the context.

2.1 TV White Spaces—Lessons Learned

Rebecca Dorch, Senior Spectrum Policy Analyst, NTIA Institute for Telecommunication Sciences and Mark Gibson, Director, Business Development and Regulatory Policy, CommScope

Rebecca Dorch: Hello, I'm Rebecca Dorch, Senior Spectrum Policy Analyst at the Institute for Telecommunications Sciences (ITS), which is the research lab of the National Telecommunications and Information Administration (NTIA). With me today is Mark Gibson. Mark is Senior Director of Business Development and Spectrum Policy at CommScope. Mark has a wealth of knowledge and experience with many different spectrum sharing scenarios over his career. Mark has also served on the Commerce Spectrum Management Advisory Committee, which advises NTIA leadership on spectrum matters. Today, Mark has kindly agreed to share his expertise with us and discuss lessons learned from one of the spectrum sharing scenarios that is often used as an example of a spectrum sharing failure: TV White Spaces. Hello, Mark.

Mark Gibson: Hi, Rebecca. It's fun to hear you talk about failure.

Rebecca Dorch: Yes. Nice way to start.

Mark Gibson: Yep.

Rebecca Dorch: So let me start with a little bit of background here. So the Federal Communications Commission (FCC) actually has a couple of paragraphs on its website about TV White Spaces. If anybody's interested in it, they can look it up by just plugging in FCC and TV White Spaces, even TVWS works. There, the FCC explains what White Space is. And it's basically spectrum within the television band that is unused in low-population or low-density areas of the country, because not all of the available over-the-air television stations are actually in use in those areas where there's low population.

So the initial idea behind the TV White Spaces, was that this very valuable spectrum that was unused could be exploited for other purposes: for innovation, for experimental use, for expanded broadband capacity and access. So this effort then began in 2004; the initial set of rules being adopted in 2008. Now, preparing for this interview, I actually looked up the status of the proceeding and discovered that the FCC is continuing to work on the White Spaces proceeding, even here in 2022. And in fact in a January order, they indicated that they would be taking steps to sustain and spur growth of the White Spaces ecosystem and provide certainty.

Now, when I read that, I was struck by the word "certainty" because it was one of the descriptors you [Mark] used when we were talking about the TV White Spaces earlier. So before we get into the lessons learned, could you take a few minutes here and walk us through a little bit of the history of the TV White Spaces and some of the other spectrum sharing efforts that actually impacted the success of TV White Spaces.

Mark Gibson: Sure. Sure. And that's a great startup. So, you know, it's interesting, TV White Spaces. The first, I guess, say, idea behind sort of centralized dynamic spectrum sharing occurred in PCS, like, 1995. It was, it was called the frequency agile sharing technology and it was proposed by a company called American Personal Communications, or APC, in the D.C. market, and the idea was exactly like what we have in TV White Spaces and in others—I'm sure folks have heard about Spectrum Access System (SAS) and even the Automated Frequency Coordination (AFC)—where you have centralized database that can provide information to base stations to help them avoid interfering. In this case, it was with microwave. So that was in '95.

So over the years, the FCC thought, and this is because others had suggested, that the TV bands, much of the TV spectrum lay fallow because of old TV rules based on analogue television with really weird frequency separations. And so with the advent of digital television, it removed a lot of those antiquated protection requirements and left spectrum available. So they got the idea—and I don't think they got it on their own, I think there was some request for rulemaking—that started it along the path of having the band not even reallocated—because there's a lot of unlicensed use under Part 15 [FCC 47 CFR Part 15 covers regulations for radio frequency devices] that occurs across the TV spectrum, primarily for things like wireless microphones, wireless TV pickup, and things like that—but they thought having a more focused rulemaking on a sharing methodology, which then was the TV White Space database—oh, actually they didn't start with a TV White Space database, they started with sensing—that the devices would sense their environment, similar to the way it happens in Wi-Fi, you know, contention-based protocol, sensing, and collision avoidance, and things like that. But the universe was larger than they expected in terms of the area of operation. And they did a lot of tests in, actually, the D.C. area and realized that sensing by itself wouldn't work.

So they came along and added the database concept, sort of as the belt and suspenders, and actually over time the database concept took over and the sensing hasn't even happened yet.

So I think you mentioned that the rulemaking that this was started in 2004 and it established the whole concept of White Space, which, as you said, was the ability to allow unlicensed operation in the areas where TVs are not operating in a manner that would not interfere with TV receivers, which is, you know, everybody's TV sets, and all of that operation is managed by a database and theoretically everything works fine. But we'll get to some of the things that you say, may call it a failure.

Rebecca Dorch: Well, let me ask you, and this may be jumping ahead to one of the failures, but you had also talked about the, the frequency that was, is used for the TV White Spaces and how that the digital (DTV) transition impacted that. Was that part of the setup or is that part of the lessons learned here?

Mark Gibson: Actually, it's a bit in the middle. The DTV transition was envisioned across all of the TV bands, so that was Channel 14 to channel uh, the upper one, I forget what the upper channel is, I've got it here. Yeah, the upper channel. I can't remember what it was, but the upper TV channel, which was . . . Channel 51, which is 698 MHz at the upper end. So the entire DTV transition was to take advantage of, you know, digital television. And that was a big deal. That was managed by NTIA, by the way, the set-top box thing, which is the whole program.

Rebecca Dorch: The [unintelligible] program. Yeah.

Mark Gibson: But the idea was that the protection requirements that existed for the old analogue were no longer needed. And so that made a whole bunch of spectrum available that otherwise would have lain fallow, lay fallow. And so the idea was to make it available for this TV White Space. And it's interesting because, initially—right now it's got a niche play—but initially, the whole idea was called super Wi-Fi. And so the idea was to supercharge Wi-Fi on 6 MHz channels. It was going to be awesome. And then what happened, you'll get into this as one of maybe one of the roads to failure, was then they reallocated the upper portions of the band for the 600 MHz, and we'll talk about that in a moment. But it was really to take advantage of the DTV transition.

Rebecca Dorch: Okay, great. So when we chatted earlier, you did actually identify three key areas that you thought would provide lessons learned from the TV White Spaces effort. One of them was regulations and having to do with certainty or uncertainty and changes in the regulations; um, specifically, also with respect to the database testing and certification. Another one was the actual market for the TV White Spaces devices with it being maybe an undefined market for purposes of the types of equipment and the services that would be offered within the TV White Spaces spectrum. And then the databases, which you've already touched on just a little bit as one of the first externally managed databases, I believe. And there was a lack of clarity on some of the responsibilities of the administrators beyond what was in the regulations from the FCC. So you want to walk us through each one of these?

Mark Gibson: Sure. So I think, you know, we'll have a panel this week or maybe next week to talk about other lessons learned [Day 1, June 13 - Panel: Industry Lessons Learned from Spectrum Sharing]. And I've got a ton of lessons learned. But I call this regulatory uncertainty. And in fact, I say the band was sort of plagued with regulatory uncertainty. And, you know, I don't know that this is the fault of anybody. You know, the FCC was, for all intents and purposes, making some of this up as they went along, based on input from the community.

For example, the initial effort to use, uh, sensing only and then go to database was informed by the community. And actually the FCC conducted a lot of those tests. In fact, I remember seeing Julie Knapp [FCC Office of Engineering & Technology chief Julius Knapp] in his own garage doing testing, so that was kind of cool. But what happened was, the rules came out and then there was changes to the rules, and subsequent changes to the rules, and each of those rules changes caused the ecosystem, which included the database administrators, the device manufacturers, and the potential users, to have to react.

And so, and the other thing I'll say, and, you know, this is kind of where we get to the failure part of it, probably the biggest issue that we faced, ultimately, was the reallocation of the spectrum above channel 37, starting at 614 MHz, the 657 MHz or 658 MHz, to the 600 MHz band, and then set up the incentive auction. And that did a couple of things. One is it removed about 210 MHz of spectrum that could have been used for TV White Space. But also, most people will remember that the incentive auction, part of the incentives were for TV stations that were in that UHF spectrum to either go off the air for some compensation or to be relocated for a cost recovery relocation. And they all relocated down into the spectrum below Channel 37, which was 52 MHz all the way up to 608 MHz with chunks out of the middle. And so that effectively removed, like I said, 210 MHz of spectrum for White Space use. And then all the TV stations that were up there, which, there are more TV stations in UHF than there are VHF just because UHF is a lot cleaner, the VHF spectrum has just got a lot of noise in it.

So basically when that happened, the database administrators, ourselves included, just said, You know what, there's not a thing here and we're going to go off and do other things. So that was probably the main issue we had with respect to regulatory uncertainty.

And then because of this uncertainty, both in regulations and in spectrum availability, the device ecosystem was very slow to develop. There were several that put a lot of effort into it, some actually that were startups because of TV White Space, but they never really got their niche, if you will, or their groove. And today, a lot of that has been overtaken by some work that Microsoft is doing in their air band initiative. Some of them still exist. Companies like Adaptrum and Carlson. Carlson Wireless had a lot of use across other, unlicensed spectrum as well as in the 3650 to 3700 MHz band. But for there to be a robust operator ecosystem or user ecosystem system, there's got to be a device ecosystem. And that never really came together. And then finally, the—

Rebecca Dorch: —I'm sorry, Mark. Can I ask something? Is the reason why the device market didn't come together was because the market for the devices was not large enough to scale properly?

Mark Gibson: Yeah. Well, not only was it not large enough to scale, it was not large enough, period. There were never more than a thousand or so registrations in any TV White Space database. And today there's only 300, and there's a single database administrator.

You know, one of things I didn't mention was when the FCC, and actually they've done this pretty consistently with the subsequent efforts, but when the FCC issued the public notice for database administrators to submit proposals, um, they got nine initially and then they got another one. So a total of 10. So 10 people signed up to be database administrators. So there was no dearth of database administrators. But now you've got all these database administrators ideally, you know, competing for a very small market. And in the end, you know, you couldn't support nine. And in fact, the one that's doing it now is not even one of the originals. It's Red Technologies actually out of France, who actually are doing the same thing in France and in Canada.

So, yeah, the device ecosystem really never developed because the user ecosystem never developed. And so it's really right now very much a niche play. And that's the rural aspect that the commission talks about. Now when you read about it, it's mostly rural and unserved markets.

Rebecca Dorch: Okay, so if I can summarize, one of the problems potentially was that the upfront research was incomplete; and then the available spectrum changed on them mid-process—which is never a good idea to change where you're going to be operating—and then both the markets for the devices and the market for the users actually never really developed appropriately.

Mark Gibson: That's right. And the other thing you asked about was collaboration among database administrators. And this is another thing that sort of happened as we went along. What the FCC wanted to ensure was that, which is interesting, when the commission went from the traditional analogue TV to digital, the databases that the commission has for TV stations no longer contain the TV contours.

And for those who don't know, TV contours are the areas within which TV stations are protected, with reception of, of normal TV stations in those contours. Those are called protected contours, where the calculation of those contours change with digital television for lots of reasons, most of which is that DTV has a much better threshold.

So they were actually theoretically larger, but the commission didn't calculate them anymore. They made the database administrators calculate them and they made us all calculate them the same way. So we all had to work together to calculate the TV contours the same way, which one might argue we should have to, so we all have the same baseline data.

But then they made us work together to calculate spectrum availability the same way. So in the end, there was really no way for database administrators to differentiate themselves in terms of ability to provide spectrum availability. And maybe the commission didn't want that.

I think that's one of the lessons learned that went into went into Citizens Broadband Radio Service (CBRS) and then 6 GHz. But the amount of effort it took for the database administrators to coordinate that work was long and arduous and we were part of meetings that occurred monthly for about a year. So that was a lot of work and we weren't generating any revenue during those times, which we understand is a cost of doing business. But we didn't know about that going in.

Rebecca Dorch: That was, that's great. And I do think that that it was a lesson learned that was taken well by the commission and learned from for purposes of CBRS because the SAS administrators are actually able to differentiate themselves, even though they all have to use a lot of the same types of algorithms and ways of measuring and analyzing, but they can differentiate themselves in other ways.

So, all right. So let's kind of go towards that, which is, What other lessons learned has the industry, regulators, government, or service providers taken from the TV White Spaces lessons learned and applied them into more recent proceedings?

Mark Gibson: Well, there's a lot. Thankfully, you know, we all learned. But I'd say, you know, one thing I didn't mention was when the commission wanted these databases tested and certified for TV White Space, the FCC did the testing themselves. And then, of course, they would do the certification anyhow. And that was another problem that happened just because, you know, there was one guy doing it and they needed to do it, I think initially. So they understood what was involved with database testing.

So one lesson learned, and you and I have talked extensively about this: When they got to CBRS, they didn't do it themselves. They actually used a third party, which was ITS, and utilized that whole process, which we all have scars from that. But we got through it. But I'd say that compared to what they did for TV White Space, that process, at least theoretically, was well designed. And it was designed to ensure that the databases adhered to the requirements and the rules. And, you know, that's a whole other thing. But we had a set of requirements that was developed by the Wireless Innovation Forum, and those were based on the rules.

So we tried to ensure through that whole process that all of the SASs corresponded to a very specific set of requirements. And while it was arduous coming up with that, I think in the end, and I'll speak for ourselves, I think we're better for it. And I also think that a lesson learned going into the next instantiation of this, which is AFC for 6 GHz, is something that we're now going back and saying, Okay, we have the way the commission did it, we have the way we did it for SAS, now maybe there's another way to do it. So we'll see what happens. We're still waiting for them to decide how they're going to test the AFC. But that whole process is built on this framework that we established with CBRS and with TV White Space.

Rebecca Dorch: And in fact I think one of the lessons learned, obviously from the TV White Spaces database, which is why they actually asked another federal agency to do the initial database testing for the processes, is because the FCC hadn't really done that software-based testing in the past. And ITS is normally not in the business of doing the sorts of work that the private sector can do. But because this hadn't been done before and it was the first time that the FCC had had to look at a complex database that had software on it, that they then used us as a basic proof of concept in that sense.

And so now that we've established that we can do it, and we can do it and it's successful, I would expect that the next round of any certification of databases and software would in fact be handled in the normal sort of process that other types of certified devices are handled by the FCC.

Mark Gibson: I hope that—and you and I have talked about this, that you worked on sort of an after-action lessons learned yourself from that whole process—and so I hope that if you haven't presented that to the commission, that you can before we get into AFC, you know, because there's a lot of things that are unique to this whole thing that were fleshed out in that testing that I think would be helpful for the commission to have and make available. Because it's looking like they're going to go with third-party testing, you know, third-party test labs.

So the question right now is whether they use existing third-party labs, which are people that do device testing, or people that just want to do testing of the databases themselves. And I think from what you guys did, you know, probably one of the best things that comes out of that, in addition to having SASs certified, is those after-action guidances that the commission can use.

So if you have something like that, make it available. I think I'd love to see it.

Rebecca Dorch: Well, before we move on to lessons learned from CBRS, is there anything else on the TV White Spaces that you think that you wanted to mention, where we have learned and the commission has learned and the whole industry has learned and we've improved our processes and efforts based upon, based upon how difficult TV White Spaces was for a lot of folks?

Mark Gibson: Well, you know, TV White Space is the first thing, you know. So it's like, um it was a first generation. So all first-G stuff is always kind of a little bit kludgy, sort of . . . . What you end up with is not what you thought it would look like as you go into it. I think for CBRS, notwithstanding the length of time it took, which is really a combination of things, I think coming out of that, it's pretty much what we expected it would look like going into it. But there's two things, I think—at least one thing, maybe two— that I think we need to keep in mind, and that is we can't change the rules of the game in the middle, when we're expecting commercial entities to be database providers, for example, like I said, the whole reallocation of spectrum, thereby removing the market. And this is happening now to CBRS. And again, this is a lesson learned. We'll talk about, you know, next week or this week or whenever this runs.

But on either side of the CBRS band, are high-powered bands, which nobody knew about when we started this whole SAS thing. Now, the good news is there are 238 licensees that won spectrum in the auction. That's more than any other auction and more licenses than any other auction. So there's obviously a need for this type of spectrum licensing for the masses. And if you look at it and you take out the ones that spent the most money and got the most market, it's a real interesting potpourri of different use cases and different people—and that was what this was intended to be.

But the cost of providing SAS service on top of that are difficult, which is one of the reasons that we're no longer a SAS provider, but the fact that on either side of the band before we actually went into this was allocated to high-powered operation meant that a lot of people gravitated toward the high-powered operation and may be leaving CBRS, which might not have been the initial intent.

And, you know if we, and I'll speak for our company, had known that there was a likelihood of there being high-powered operation on both sides of the band, we might have taken a different approach to the business case.

So one of the things I suggest in my set of lessons learned is, we need to have longer term planning for spectrum allocation considerations. Longer being not 3 to 5, but 5 to 7 years. And I know that's hard and I know a lot of this stuff is driven by requests for rulemaking and things like that. But the upshot of that is we have people that—and maybe it's incumbent upon the industry to have some degree of perspicaciousness to be able to identify what's going on. But I think we're all in this together. So I think changing the rules in the middle of it is one of the things that we need to work on.

Rebecca Dorch: Well, it's interesting you say that, because one of the things that we're going to be looking at and tackling during ISART 2022 is How do we evolve the spectrum sharing rules based upon data, science, and, you know, scientific decision-making? So we're actually posing How do we learn from ground truth and evolve and improve the rules, maybe adding some uncertainty, which based upon this conversation may not be the best thing to do, is to add uncertainty.

Well you're on one of the panels on the first day, on the industry lessons learned. I am really looking forward to what you have to share on that panel, because we've got folks from different experiences in different parts of the industry for spectrum sharing purposes on that panel.

So Mark, I want to thank you very much for talking with me today and doing this interview and helping us understand the history of TV White Spaces and how it has, kind of, had a thread throughout a lot of the subsequent spectrum sharing proceedings that we've all been involved in over the years.

Mark Gibson: So, my pleasure, Rebecca. Thank you so much for your interest and I'm looking forward to the sessions as well.

Rebecca Dorch: Likewise. Thank you so much.

Mark Gibson: Thank you.

2.2 U-NII-Dynamic Frequency Selection—Lessons Learned

Frank Sanders, Senior Technical Fellow, NTIA Institute for Telecommunication Sciences

Frank Sanders: Hello. I'm Frank Sanders, Senior Technical Fellow at the Institute for Telecommunications Sciences (ITS) the National Telecommunications and Information Administration (NTIA) laboratory in Boulder, Colorado. This ISART talk is on 5 GHz Dynamic Frequency Selection (DFS) Technology Development and Deployment: Challenges That Have Been Met and Lessons That Have Been Learned.

[Slide]

Development of unlicensed wireless access systems, WAS, in industrial, scientific and medical, ISM, bands at 5 GHz began about 25 years ago. The problem with putting unlicensed communications into ISM spectrum at 5 GHz is that primary radar spectrum allocations overlap the ISM spectrum there.

The solution has been to find a technical method to allow spectrum sharing for WAS unlicensed national information infrastructure (U-NII) devices in 5 GHz spectrum and along the way to ensure a spread of WAS traffic loading across the 5 GHz spectrum to reduce aggregate WAS emission levels down to the required levels for fixed satellite service (FSS) and earth exploration satellite service (EESS) compatibility.

[Slide]

When the work began at 5 GHz, there was a precedent that had already been constructed for use in the industrial, scientific, and medical ISM band stretching across 2400 to 2483.5 MHz. There, unlicensed IEEE 802.11b and 802.11g WAS systems were already operating at 2.4 GHz. In that spectrum there were unintentional but relatively high-power microwave oven emissions that were already occupying that spectrum. The microwave oven emissions look a lot like regular radars.

This suggested that a similar spectrum sharing approach might be possible in the 5725 to 5875 MHz ISM Band.

[Slide]

But the parallels were not absolute. The 2.4 GHz ISM band does not overlap any licensed spectrum. This differs from 5 GHz ISM bands that do partly overlap licensed allocated radar band assignments. Between 5250 to 5850 MHz there are allocations for radiolocation and radionavigation radars that include radiolocation on a primary basis, radionavigation on a primary basis, ground-based meteorological radars on a basis of equality with stations in the maritime radionavigation service, and between 5650 and 5725 radiolocation on a general primary basis.

[Slide]

There were also some perceived constraints on 5 GHz WAS. For example, 802.11 device regulatory requirements and band allocations varied widely around the world. This produced manufacturing difficulties for 5 GHz WAS across national boundaries. It was believed that any requirement to produce many different varieties of 5 GHz WAS to meet all of the varying 5 GHz spectrum requirements from one administration to the next would place an undue manufacturing burden on developers.

To address these issues an ITU-R recommendation M.1652 was developed through many ITU-R administrations between 1999 and 2003, notably in Joint Task Group 8A/9B and in Working Party 8B, now Working Party 5B.

The document that came out of all of that work, M.1652, is still the root technical document for 5 GHz DFS.

[Slide]

A purely technical aspect of what had to go into that recommendation was the power level at which the wireless device emissions would cause interference into the allocated radars at 5 GHz. In response to this, ITS in Boulder and the Office of Spectrum Management (OSM), NTIA's office in Washington D.C., jointly launched a fundamental research program into the levels at which RF interference will cause various types of radars to lose targets.

The summary of all of that work is that radar targets tend to begin to be lost when interference levels from non-radar signals in radar receivers are 6 decibels (dB) below the noise level of the radar receivers in question. Substantial losses occur when RF interference equals radar receiver noise levels. This work was documented in separate ITU-R recommendations and also in NTIA technical report TR-06-440.

[Slide]

Some particular features of M.1652 deserve to be noted. These came out of WRC-03. For example, 5250 to 5350 and 5470 to 5725 MHz bands are allocated to the mobile service on a co-primary basis with the radio determination service, provided that devices in the mobile service in these bands use dynamic frequency selection, DFS, sharing technology to protect radar receivers from interference.

WAS and radio local area network (RLAN) operations are not to cause interference to radar receivers. DFS-equipped devices operating at 5 GHz are required to detect local radar signals and avoid the occupied radar frequencies through constant monitoring of radar signals, while also sending and receiving their normal wireless radio traffic.

In M.1652 representative characteristics of 5 GHz radar systems in the band are described. The required thresholds for detection of radar signals for signal avoidance by the WAS systems are determined. Requirements are presented for determining channel availability by monitoring spectrum prior to the use of a 5 GHz DFS channel, and speed requirements are presented for vacating DFS channels when radar signals are detected above critical detection threshold levels.

[Slide]

Domestically in the United States between 2003 and 2005, the FCC [Federal Communications Commission], NTIA, the Department of Defense (DoD), and U-NII industry participants worked together to develop certification test plans and procedures for DFS devices to operate in the 5250 to 5350 and 5470 to 5725 MHz bands.

Prototype testing followed in 2005 and 2006. This was four to five years after initial technical work for development of DFS protocols had occurred. The prototype testing was to involve bench tests with prototype DFS devices that would be sent from multiple manufacturers to the ITS laboratory in Boulder, Colorado. At the ITS lab, radar transmitters replicated radar waveforms as defined in M.1652—which were specially built by ITS engineers—would be put into DFS systems to verify that the DFS systems could successfully detect and avoid the radar signals. Then, later in December of 2005, radiated field testing against actual radars was performed at the McGregor Range next to the White Sands Missile Range, in New Mexico.

[Slide]

In the 2005–2006 time frame, two rounds of DFS testing were initially completed. There were some difficulties with DFS detection of radar waveforms that were noted in this initial testing. DFS performance improved during the second round of testing. Along with NTIA, the FCC and the U.S. Army participated in all of this testing.

Two goals were accomplished overall. First, it was shown that DFS devices could actually detect radar waveforms as specified in M.1652 and the test and measurement set up that could be used by the FCC and later by independent certification laboratories across the U.S. was validated through the actual certification initially of DFS devices at the Boulder Laboratory.

In this time frame, specifically in 2006, NTIA transferred its DFS certification hardware and associated custom-written test and measurement software to the FCC's Columbia, Maryland, laboratory for use in further certification, testing and as noted, for eventual transference to the private sector for ongoing certification testing.

[Slide]

Here's the flavor of what had to be done in this testing. First, there had to be verification on power-on of a DFS system that no DFS emissions would occur for 60 seconds after initial power up.

The system has to remain quiet after the On button is pushed for at least one minute. Any radar signals present when power-on occurs had to be detected within 6 seconds, and radar signals have to be detected 6 seconds before the end of any initial channel check-time by a DFS device.

Then, when the device is running in its normal mode, various synthesized radar waveforms have to be detected in the 5 GHz bands in what's called in-service monitoring. This involves the most comprehensive testing for DFS U-NII devices, and it does not precisely replicate—this is worth noting— any particular exact operational radar waveforms. There are problems with detecting exactly what certain radars produce. What we have to do instead is show that the device can detect across a parameter range of radar waveforms, including a range of pulse widths and a range of pulse repetition rates. Operating across these ranges ensures, first of all, that there's no problem with needing to divulge classified material about radar waveforms. But it also means that the DFS devices cannot be precisely tailored to exactly detect exact radar waveforms, which themselves might vary in different times and places in the future anyway.

And then finally in the certification series, there's a 30-minute non-occupancy test that we have to show is successfully passed. This test is used when a DFS channel has been occupied by a radar signal. Once that channel is occupied by a radar signal, the U-NII device is not to attempt to use the channel again for at least the next 30 minutes.

[Slide]

Here's a quick table of some other parameters. The detection threshold requirement for DFS receivers is either -62 or -64 dBm in the receiver circuitry in 1 MHz bandwidth peak detected; the exact number is specified in the Code of Federal Regulations for certain circumstances. The availability check that has to be employed before any channel can be used is 60 seconds—60 seconds of off time, quietly listening before a channel can be used. And if a radar turns up in that 60 seconds, then the channel cannot be used. If a channel has been occupied and the radar signal is detected in the channel, then a channel has to be vacated and may not have any attempted re-occupancy for the next 30 minutes. The maximum interval that's allowed for the channel move after radar detection is 10 seconds. In other words, if a radar pulse is detected an occupied channel, then that channel has to be vacated within 10 seconds. Within that 10-second interval, the maximum subintervals that are allowed for housekeeping transmissions inside the U-NII device is 200 milliseconds, plus about 60 milliseconds available for various particular operations over the course of the 10-second overall vacation time.

[Slide]

To do all of this, NTIA engineers in ITS in Boulder had to come up with a compliance testbed. This included a radar signal generator and synthesizer that would produce bursts of unmodulated and chirped radar pulses in the subject 5 GHz bands. It had to have a variable- and user-selectable set of options for radar pulse frequency, number of pulses to fire in a burst, pulse width, pulse repetition-interval, chirp—which is linear FM bandwidth—and RF power control for the pulses. A vector signal generator that was programmed by ITS was used to generate these pulses.

On the U-NII side of things, there had to be a monitor for RF activity on a U-NII channel by a U-NII system. This used and uses a vector signal analyzer (VSA) and a spectrum analyzer for both fine and coarse measurements of the RF emissions of the base station and client transmissions over 12 seconds at a time. Both the radar and the DFS systems had to be synchronized so that the press of a button would start the in-service testing and collect data continuously for 12 or 24 seconds on a common time base.

[Slide]

This slide shows a block diagram of the overall testing system. The development of the system and its transference to the FCC initially and to the private sector in the U.S. eventually was a major accomplishment of the overall effort.

[Slide]

This slide shows a photograph of the system as it was assembled at ITS and was used in initial testing at the ITS Laboratory as a prototype.

[Slide]

And so about six years after formal development of DFS protocols began in mid-2006, DFS-capable U-NII devices were finally made available to consumers in the U.S. A wide variety of DFS-capable, 5 GHz U-NII devices were soon certified by the FCC and by independent labs and marketed by several manufacturers. Along the way, NTIA itself undertook random off-the-shelf spot checks of commercially available products employing DFS technology to verify that the DFS functionality was in fact present in the marketed devices and was working.

But in 2008, NTIA and the FCC discovered a certified product that was not detecting radar signals. It turned out that after the product had been marketed, there were post-certification changes that were made to some of the U-NII device's firmware. The changes were not supposed to affect the ability to detect and respond to radar pulses, but, unintentionally, the changes did in fact effectively disable this device's firmware from detecting radar pulses.

It was also discovered through spot checks that there were some additional issues with certification identifications of some devices' responses. Basically, what it amounted to was that some devices that had been certified in the laboratory as being successfully able to detect radar pulses and which did have their DFS functionality intact in the marketed products, were sometimes not detecting some radars in actual field situations.

[Slide]

In particular by early, which is to say January of, 2009, the FAA (Federal Aviation Administration) was reporting interference to its 5 GHz microburst warning weather radars. And the interference appeared to be coming from DFS-capable 5 GHz U-NII transmitters. Subsequent NTIA, FAA, and FCC studies, some conducted in Puerto Rico, others in New York, and which were performed with the help and the cooperation of manufacturing-industry, participants, identified some DFS devices that had passed the certification tests but *were not* adequately detecting radar signals in the field from the terminal-doppler weather radars operated by the FAA. At this point, government and industry worked together to improve the parameters for the certification testing.

While this was going on, further certification testing of new 5 GHz DFS-capable, U-NII devices intended for outdoor use was temporarily suspended altogether, pending development of some revised certification testing parameters. The essence of the problem overall was this: Way back in the formative stages for the technology when inquiries had been made as to the exact technical parameters of the radars that would need to be detected at 5 GHz, there was a disconnect that occurred at the human level between the actual parameters of the radars in the band and the set of parameters that was made available for the testing. This disconnect resulted in the original initial certification testing not always using the actual parameters of radar pulses that were operating in the 5 GHz band. Straightening the problem out lasted from 2009 until about 2010 or maybe even 2011 when we finally were able to implement a revised set of test parameters that unequivocally did cover the parameter range of the actual radars operating in the 5 GHz band.

[Slide]

In terms of challenges met, here's what it amounted to. The first technology for DFS was eventually successfully deployed and is now operational. The 5 GHz spectrum is now widely used by a variety of commercially available DFS-capable U-NII products produced by many manufacturers and shared with a lot of radars. But to get there, close cooperation was required between government and industry.

A substantial effort was required to determine the interference protection criteria, the levels at which radars had to be protected for the incumbent service, that is. And about six years were needed from the initial DFS concepts as they were initially sketched, out to the marketed devices that were eventually sold to consumers. This included time to formulate DFS protocols as embodied in recommendation M.1652; time to develop and verify certification, compliance, testing, hardware and software; and development of DFS protocols that had to be agreed to by government and industry before any DFS-capable devices were built.

[Slide]

Lessons learned from development of all of this included: Timelines that are needed for converting spectrum-sharing concepts into marketed devices can be five years or longer. This includes time that is needed to develop protection criteria for incumbent service receivers; developing engineering spectrum-sharing protocols; developing spectrum-sharing protocols and rules; developing spectrum-sharing compliance certification hardware and software; and performing initial test and evaluation of prototype devices.

Beyond that, government resources may be needed on an ongoing basis to perform spot checks on marketed devices for compliance with spectrum sharing rules in government spectrum bands. Substantial attention has to be devoted to ensuring that field performance equals laboratory performance during certification testing. In other words, this kind of spectrum sharing is not shoot-and-forget. This kind of spectrum sharing requires ongoing spectrum engineering and compliance testing for as long as the spectrum sharing is going to happen. It can be regarded as the cost of this kind of spectrum sharing. It does grow the economy. It does offer opportunities for manufacturers and consumers to use spectrum that would otherwise not be used. But it is a continuous maintenance mode that is required when dynamic spectrum sharing is implemented in any given band.

[Slide]

We conclude with a set of references that may be instructive to anyone who wants to further inquire into the processes involved that we've discussed here, the lessons that have been learned that we've discussed here, and I thank you for your time.

2.3 Citizens Broadband Radio Service—Lessons Learned

Andy Clegg, Spectrum Engineering Lead, Google

Dr. Andrew Clegg: Hello, I'm Andy Clegg from Google, and I am going to do a quick presentation on some of the lessons we've learned in Citizens Broadband Radio Service (CBRS).

So we've been operating for a little over two years now. There are way too many lessons learned to cover in a few minutes. So I've chosen the top few, in my opinion. And, no doubt, some of these lessons can be and are being applied to new and future sharing arrangements, such as the upcoming 6 GHz Automated Frequency Coordination (AFC) Band, the 3.1 GHz band, and others.

[Slide]

So lesson number one is that centralized, dynamic spectrum sharing works. This has been a successful government and industry collaboration. We've worked together to create standards and certification tests to get the commercial framework, um, launched. There are currently six fully operating commercial Spectrum Access System (SAS) administrators and three more are going through tests right now, pending approval of the Federal Communications Commission (FCC). There are more than 230,000 CBRS base stations that have been deployed, and growing. More than 160 base station models have been certified by the FCC for operation in the CBRS band. There's more than 400 client device models certified for operation in the CBRS—so that would be handsets, Internet of Things (IoT) devices, those types of things. The Priority Access License, or PAL, tier auction raised more than $4.5 billion in revenue for the [U.S.] Treasury. It had more than 228 winning bidders, compared to a typical spectrum auction in which the number of winning bidders is small, 10 or fewer. There's more than 4,000 certified professional installers or CPIs, as we call them, who are trained and certified to install CBRS equipment in a manner that won't cause harmful interference to the incumbents. And, after all of that, there have been zero reported cases of harmful interference to any protected incumbents. So, a very good track record of deployments with no reported harmful interference.

[Slide]

Now, one of the things we've learned is that propagation models need updating. So in CBRS, and for that matter, in the 6 GHz AFC, interference predictions are based in part on the Irregular Terrain Model or ITM. ITM is based on the Longley-Rice model, which was created by the Institute for Telecommunication Sciences (ITS) itself in the 1960s, and it used data to create the model that dated to

[Slide]

as old as the 1950s. Yet, you know, we're still making modern spectrum management decisions based on a 60-year-old, 70-year-old propagation model. So in particular, the long distance propagation predictions of ITM, in particular troposcatter, is pretty important to determining the keep-out areas in CBRS, like how far away interference might occur from a Citizens Broadband Radio Service Device (CBSD) into an incumbent. But that troposcatter model has never been extensively validated in terms of frequency and geography and climate and things like that. And that's something that definitely needs to be done.

We also need to take advantage of the latest geodata that we have to improve the data that's fed into propagation models. And, in fact, as I mentioned on the last slide, no reported cases of harmful interference to incumbents has occurred in CBRS. But that could be an argument that we are overprotecting the incumbents, partly by use of overly conservative propagation models like ITM. And so one reason I say that ITM can be considered overly conservative is, you know,

[Slide]

here is a Google reconstructed view of what Manhattan looks like with a lot of tall buildings and trees and all sorts of things. But from a propagation perspective, when you use ITM in an area like Manhattan, ITM has no knowledge of the existence of these buildings or trees and only uses terrain. So, to the ITM model, Manhattan looks completely flat. And so propagation from one part of Manhattan to another in terms of predicted interference would be overly conservative. You would predict way too much interference than actually occurs 'cause you're not taking into account the blocking of the signal caused by the buildings, foliage, and things. So it's just one reason why ITM is

[Slide]

is a very conservative propagation model.

Um, another lesson learned is that the use of aggregate interference in an interference prediction complicates things. So, SASs, when they calculate interference to incumbents, have to add up the contribution of every CBSD or CBRS device base station and has to add up the impact of all of the CBSDs in the area, um, to the incumbent. So one reason that that complicates things is that knowledge about the different CBSDs is distributed among the SASs. I mentioned there are six operating SASs right now, and so a given CBSD is only under management of one of those SASs. So what happens is, every night the SASs have to exchange data among each other about all of the devices under their management in order that the aggregate interference can be accurately calculated. And these data are effectively proprietary 'cause it's all the information about your customers device and you don't really want to share that with your competitors, but in fact that's what happens. The other thing that this impacts is that if a device wants to come online, it may need to wait up to 24 hours, depending on where it's located so that the information about that proposed device can be shared among spectrum access systems and its impact to aggregate interference can be taken into account before giving it a thumbs-up or thumbs-down to transmit. So that's another drawback of aggregate interference.

The calculations themselves can be relatively complex. The computations can take several hours a night for each SAS. And it's because of the number of devices, the number of interference points that you're aggregating to, the fact that, for example, for a sweeping radar, which is one of the incumbents you're calculating compatibility with, you have to take into account the different beamforming directions. It's a lot of calculations that can take a lot of time. And aggregate interference doesn't really necessarily account for such things as duty cycles and orthogonal frequency-division multiple access (OFDMA) and things. So for example, in 6 GHz, they don't use aggregate interference in the calculations there because a typical Wi-Fi access point only has a duty cycle of a few percent. But in CBRS that's not taken into account.

So there are other alternate solutions that should probably be explored. You know, for example, simple multiple exposure allowance—you just add five dB to every interference calculation from an individual device, or some number that's based upon the local density of CBSD deployments in that area updated on some regular basis, monthly or something like that. It's just one idea, but, you know, there should be better ways of doing this.

[Slide]

Another lesson learned is that the environmental sensing capability, or ESC, should be replaced by an informing incumbent capability (IIC). So the way we detect incumbent Navy radars operating in the band is that we have a set of sensors located along the coastline. There's a few hundred such sensors. They're there pointing out to the ocean and having to detect radar activity potentially hundreds of kilometers away. In order to be sensitive enough to detect those distant radar operations, the sensors themselves have to be protected from interference caused by CBRS operating in the area so that they can hear those distant signals. So this creates what we call a "whisper zone" around the sensors in which the deployment of CBSDs is either prohibited entirely or each CBSD has restrictions on how much power it can transmit and where it can point. And given that we have a few hundred sensors around the coast, the total population impacted by these whisper zones is quite large. In fact it numbers in the millions of potential CBSD customers. So it's not a small impact.

We believe that a better approach is to move towards an informing incumbent capability, where the DoD tells us where and when they're operating and we can protect them based upon the information they push to us. And it doesn't have to be in advance. It can be with minutes or even seconds notice, because that's all we get right now. We get about 60-seconds notice through our ESC networks, at most. This has several advantages. One is the DoD controls the information flow to us. We're no longer sensing their actual operations. Instead, they're telling us what they want us to know. It also avoids false alarms from ESC sensors that can sometimes trigger on things like motors or switches or ignition noise or whatever, because a lot of those impulses look like potential radar signatures. And then, most importantly, whisper zones are no longer a factor. If you don't have sensors deployed, you no longer have any whisper zones, and those millions of people are no longer impacted by not being able to deploy CBRS.

[Slide]

This is an example of a whisper zone impact. This is, um, Southern California, basically, from Laguna Beach at the lower right up through Santa Monica, up towards the upper left. And the red areas are areas where you either cannot deploy a CBSD or you're constrained with regard to the total amount of power. And this is not a theoretical impact. This is based upon actual deployments of real EFC sensors in that area. And CBRS customers in these red areas are in fact impacted. The red areas cover over 266,000 people, 120,000 households. And we have similar areas all up and down all of the coast impacting from the Pacific Northwest to California, around to the Gulf Coast. Florida is very heavily impacted because it's so flat. It goes all the way up the East Coast. Manhattan is heavily impacted by whisper zones. And so, you know, in the end, the total population under these red areas is in the millions.

[Slide]

And then finally, in the lessons learned that I have time to address is that coexistence is important within the CBRS service itself. If you consider that up before CBRS, virtually every LTE deployment was in an exclusive use band where there was one licensee, and they operated their own network of base stations, and they could synchronize the base stations, configure them the way they need[d] to in order to manage coexistence among all of the different base stations.

In CBRS, particularly in the lower tier, the General Authorized Access (GAA) tier here, that doesn't require a priority access license, multiple operators share the band. And each of those operators has their own use cases, customers and other requirements that dictate their deployment configuration. And their configuration may or may not be compatible with the base stations that are operated on the same or adjacent frequencies nearby. And so we have to create this concept of what is fair spectrum use. And industry worked on this for quite a while to create a standard or a recommendation on how we treat coexistence among the GAA tier. And we spent a lot of effort trying to come up with it, but we've not come up with any universal definition of fair spectrum use. And so there's still some impacts of GAAs trying to operate in the area of one another and suffering from harmful interference and having difficulty working it out in some cases. You know, [in] most cases the operators work it out together. But there are a few cases that have not gone so well. And we believe that as more spectrum becomes targeted for shared use, that better or, in fact, any definition of rights and responsibilities among the shared-tier users is highly desirable.

[Slide]

So a summary of this, you know, quick lesson on lessons learned is that CBRS is commercially successful and it's the first successful shared spectrum framework in the U.S., or worldwide. The success is due in large part because of the successful collaboration between government and industry. However, as with any new product or service, there is room for improvement.

And we believe that by taking an honest look at lessons learned, like the five I showed here, that CBRS and future shared spectrum frameworks can be refined and optimized to better serve incumbents and new entrants.

So thank you very much. I hope this was a useful, if very brief, insight into lessons learned in CBRS.

2.4 Advanced Wireless Services-3—Lessons Learned

Howard McDonald, Director, Defense Spectrum Organization, DISA (Retired)

Howard McDonald: Hello, this is Howard McDonald, retired Branch Chief from Defense Information Systems Agency/Defense Spectrum Organization (DISA/DSO), retired 31 May, of this year. I was asked to provide an overview of Advanced Wireless Services-3 (AWS-3) particularly 1755 to 1780 MHz in the formal coordination with the AWS-3 licensees. And just a quick disclaimer, this presentation and thoughts and observations are mine and do not reflect DISA/DSO policies.

[Slide]

So what is AWS-3? I have a picture from the Federal Communications Commission (FCC) website that you can refer to that talks about the broad term of advanced wireless services. This particular focus in this presentation is the 1755 to 1780 uplink band within AWS-3. AWS-3 also includes an unpaired uplink band (1695 to 1710 MHz) and the downlink in the paired spectrum being 2155 to 2180 MHz. And there is a requirement for AWS-3 licensees/operators to successfully coordinate with federal incumbents prior to deployment.

[Slide]

And that coordination process is provided via a joint public notice put out by FCC and National Telecommunications and Information Administration (NTIA): DA 14-1023. I've got a snippet here from NTIA's website where one can get that public notice. DoD used DA 14-1023 as an initial framework to build out the business processes and the associated automation used by DoD to respond to formal coordination requests in the 1755 to 1780 MHz band.

[Slide]

And this is a high-level view of the business process and the associated automation for formal coordination. On the far left, you can see the early entry portal (EEP) that's on the open Internet to enable AWS-3 licensees to submit coordination requests. And also on the open Internet is the safe access file exchange (SAFE) capability where DoD would send sensitive information to licensees upon their request as to why sectors in a coordination request (CR) were denied and have that follow-on discussion after the DoD responses are sent back to the licensee via the early entry portal.

The EEP is air-gapped. To the right is a closed environment that DoD has established to process coordination requests. And starting from the leftmost part of the closed environment is the service Spectrum Management Office (SMO), the DoD Spectrum Relocation Management Team (DSRMT), and the contracted engineering cell that does the processing and the coexistence analysis of a coordination request.

All that information exchange between those three entities is done through a DoD AWS-3 Coordination and Management Portal (DACAMP). It's a [Microsoft] SharePoint site that DISA has provided to DSO to exercise this process. There is also a margin data generator, MDG, that apportions the margin and I'll describe this a little later in the presentation to what margin apportionment is. That is also part of this process. And there is the early intra-portal analysis capability that does the validation checking of a coordination request. It does some internal dataset generation that's then provided to the services for their further analysis of coexistence between the proposed LTE laydown in their operations.

The public notice specifies shot clocks. There are five days to acknowledge receipt of a coordination request. That acknowledgment is automatic. In the current process the EEP automatically acknowledges receipt of a coordination request. DoD has 10 days to validate a CR to make sure that all the data fields and the data provided by a licensee is consistent with rules that have been established. And if there are inconsistencies found, those inconsistencies are communicated back to the licensee via the early entry portal. We have 10 days to do that process.

And then after a CR has been validated, DoD has 10 days to do the formal analysis of the coexistence between the proposed laydown and the DoD operation and then provide a formal DoD response letter back to the licensee within 60 days.

[Slide]

I wanted to include this slide. Some may think that AWS-3 is winding down. Yes, a significant number of DoD operations have transitioned out of the 1755 to 1780 MHz band. But there are still operations in that band. The coordination zones intersect roughly $23 billion of spectrum. That's auction value of spectrum encumbered by remaining DoD operations. So there's still a significant amount of spectrum. And CRs continue to be received on a weekly basis through the early entry portal.

Just a note here. This is not intended to define formal coordination. So DSO would have the authoritative statements regarding which licenses are encumbered in any formal coordination request that needs to be submitted.

[Slide]

So I'm going to start drilling into some of the details of how a CR is evaluated.

The first major part is LTE uplink characterization. The DoD started with Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 1 recommendations on how to characterize the LTE uplink. And you can see over time, we went from 100 percent network loading for both urban / suburban and rural to now it's 20 percent network loading for urban and 16 percent rural. There is still a significant simplifying factor here with respect to how a sector is characterized. Currently, sectors are characterized as either urban / suburban or rural based upon census tract. It is not based on the particulars of an LTE laydown. And so there are small cells being received in coordination requests. There's distributed antenna systems. I think roughly 40 percent of the CRs that we've received have intersect distances less than the assumed intersect distance for urban / suburban sectors. And so work continues under the Spectrum Sharing Test and Demonstration (SST&D) program to better characterize LTE. I won't go into details here. Some of the panel discussions and some of the papers that will be submitted for ISART will go into some of these details.

[Slide]

Propagation is another key piece of processing a coordination request. Propagation has two elements. One is a terrain-dependent element that's determined through use of the Terrain Integrated Rough Earth Model, TIREM. Or if it's a ground-to-air scenario, IF-77 [(ITS-FAA-1977) propagation model developed for the Federal Aviation Administration (FAA) applicable to air/ground, air/air, ground/satellite, and air/satellite paths)] is used with no terrain. And clutter is an additive end-point loss added to what TIREM or IF-77 provides us—the basic path loss. So you have a table here of mean clutter loss values as a function of land use/land cover (LU/LC) category. There's also an elevation angle dependency on clutter. And so similar to the LTE characterization, our initial starting point was census tract data. That was a simplified construct and over time via the work of the Spectrum Sharing Test and Demonstration program, we've removed that dependency on census tract data and are using actual land use/land cover data.

[Slide]

Here are some other considerations that we have dealt with and DoD continues to deal with.

So one of the first ones is interference margin apportionment. A DoD operation, particularly airborne operations, see multiple licenses [with LTE operations], geographic multiple licenses. And so the intent here is to provide enough margin to licensees such that licensees can build out their licenses based upon the amount of interference that was apportioned to that license. We use the randomized real network that was provided via CSMAC from their work in 2014. And we had to modify that randomized real network to address—some licensees that didn't have base stations in the randomized real network, for example, and so if you add up the apportioned margin for the individual licenses, they would all add up to the interference protection criteria for a given DoD operation.

Interference mitigation was another aspect. This is more of a retrospective in terms of what we did with our Air Combat Training System (ACTS) and using physical resource block blanking to protect the narrowband ACTS from aggregate interference from LTE. DoD established a standard approach and that standard approach was used to identify the specific physical resource blocks (PRBs) to notch for a given network laydown in operating frequencies of the ACTS. ACTS has since transitioned out of the band. I think this is a mitigation technique that could be used in other bands, particularly for narrowband incumbent systems.

You also have emerging technologies. At that time when the auction occurred in 2014, 2015, 3GPP Release 12 was the release. Right now they're working on Release 18 to include 5G. And so there is an unknown factor here with respect to the use of 5G in the 1755 to 1780 MHz band. What are carrier plans and how would that change the LTE characterization, particularly for those operations that will occur around the indefinite sharing locations for U.S. Army Joint Tactical Radio System (JTRS) deployments?

Then I guess I'll end with the last major piece, which is stakeholder collaboration. Early and often engagement with stakeholders is key to having them endorse and accept the refinements that have been made over time via the Spectrum Sharing Test and Demonstration program. We also know the licensees are significant stakeholders here. And measuring their networks in the wild were key activities to continue to refine clutter loss models and how we characterize LTE.

3. Day 1: Monday, June 13, 2022

3.1 Introduction and Opening Remarks

Eric Nelson, Director (Acting), NTIA Institute for Telecommunication Sciences

Eric Nelson: Good afternoon. I'm Eric Nelson, the acting director of NTIA's Institute for Telecommunication Sciences. It's my pleasure to welcome you to ISART 2022—Evolving Spectrum Sharing Regulation through Data, Science, and Technology-Driven Analysis and Decision-making. ISART is a science and engineering discussion-based conference that brings together leaders in government, industry, and academia, both domestic and international, for the purpose of forecasting the development and application of advanced radio technologies.

We were originally planning to have ISART in-person this year because we recognize the immense value for networking that that provides. But COVID 19 and all its variants gave us pause. It turns out that the latest variant finally made its way to Colorado, and the Boulder area is presently experiencing high rates of transmission. So in hindsight, going virtual was a prudent decision.

That said, I'm pleased to announce that ISART 2023 will return to an in-person format. By hook or by crook. We are already in the initial stages of planning as it will be coordinated with ITU-R (Radiocommunication Sector) Study Group 3 working party meetings. Naturally, given that audience, the topic will be radiowave propagation. With the fully virtual format of ISART 2022, there are only a few logistics to cover.

This year, sessions will be spread out over four half-day–long sessions, which is more digestible considering we're not all sequestered away from the office. Note that the schedules for each day are staggered, though. Those are posted on both the Zuddl platform and the ISART website. Also, in the interest of time, panel moderators will only be making brief introductions.

There is a link from the platform lobby to the ISART website where you can find biographies for all of our speakers and we encourage you to do so. One reminder is in order. If you haven't done so already, please review the tutorials. You can access them from the banner at the top of the Zuddl page. These provide background information, which is of particular value to those who haven't been working in a space for long.

I'll have more to say on that topic in a moment. What I'll call the modern era of ISART began in 2010. And that was something that Mike Cotton really played a large role in. Recognizing that technology itself is just one piece of the puzzle, we bring together a broad audience that impacts decision-making, including engineers, economists and policymakers drawn from academia, industry and government, both domestic and international.

There are already a number of excellent conferences that address spectrum-sharing technologies. They typically solicit papers covering a number of key subject areas. Owing to NTIA's policymaking role, ISART instead centers around a number of key themes. To focus the discussions, the technical planning committee has already taken the liberty of outlining what we believe to be the foremost challenges in spectrum sharing.

In some instances, we go so far as suggesting strategies or solutions. Here's how we're going to address those. Panelists at the end of your session, be prepared to offer recommendations. Organize your thoughts along these lines. A) We have a well-developed idea or solution to the problem, and community consensus is possible in our mind. B) We have a well-developed idea or solution to the problem but doubt that community consensus is possible. C) Perhaps the idea has promise, but more research or input is needed. In that case, consider who might do that work—the academic community, existing stakeholder groups, existing federal advisory committees—or perhaps we should leverage organizations with existing or new funding sources. And finally, D) no good solutions or ideas are apparent. Hopefully we don't run into that one too often.

Participants, your role is to serve as our graduate committee member, so to speak. In preparation, please spend some time familiarizing yourself with read-ahead materials and tutorials. As we proceed, tell us if we're on track. For example, "That's a great idea because..." and fill in the blank. Give us the depth and detail. This isn't Twitter, so we're not limited to 140 characters.

So if you can really explain your ideas all the better. Alternatively, you might say, "I wouldn't recommend that approach..." because again, fill in the blank. Give us the depth and detail. Finally, if you're confused or concerned, ask a question. Using the Zuddl platform, enter your questions or comments in the chat window. Feel free to tap those out as they come to mind.

In the background, each panel will have a curator who will review your inputs and queue them up as the discussions evolve. You can also upvote cute questions you would like to hear the panel address. By the way, if you aren't comfortable posting your thoughts for everyone to see, we understand there are plenty of reasons why that might be the case.

Feel free to drop your thoughts, reactions, comments into a private chat to me and I'll collect those. Also, feel free to provide feedback on our themes. Rest assured, if we can address your input during the sessions, we will be revealing them throughout and following the conference. Finally, following the conference, we will send out a request for feedback. So that would be another opportunity for you to weigh in, perhaps in more detail then.

Our hope is to outline a proposed strategy based on the week's deliberations. So we want to hear from you, particularly if you think we're on the wrong track. That said, a quick survey of ISART topics in the modern era that started with Mike Cotton back in 2010 shows that we have a darn good batting average and we're not just getting on base, so to speak; we're often driving in runs. The announcement of the FCC's 500 MHz Broadband Plan spurred ISART 2010: Spectrum Sharing, which set the stage and put what is a very broad topic in context. Even a cursory examination of NTIA's spectrum chart was enough to motivate ISART 2011: Spectrum sharing between Telecommunications and Radar systems, since it was obvious that radar bands would have new occupants. That conference brought together two communities that historically hadn't engaged each other.

Recent events surrounding radio altimeters simply reinforce the need for more of that. By 2012, dynamic spectrum access was capturing headlines. So that year's ISART explored approaches for real-time federal spectrum sharing. The new incumbent informing capability follows along those lines. The AWS-3 auction was inspiration for 2015. The Commerce Spectrum Management Advisory Committee working groups that hashed out the technical details for the rulemaking did great work, but we didn't tackle all the details before the auction.

So ISART 2015 focused on measurements, models, simulations and technologies for improved spectrum sharing. Not being able to dot all the I's and cross all the T's before auctions is a recurring theme. So this year's ISART will consider how to apply knowledge and lessons learned since then, to update our strategy. ISART 2016: Spectrum Forensics, addressed monitoring, identification and mitigation of harmful interference.

The recent kickoff of the DISA/DSO-sponsored NASCTN CBRS Sharing Ecosystem Assessment (SEA) Program is a tangible example of those ideas being put into practice. With ISART 2017: Spectrum Mining at Millimeter Waves - Digging for Capacity, we explored millimeter waves, the technical challenges they present, and applications that use them. ISART 2018: Navigating Propagation Challenges for Ultra-Dense Wireless Systems, addressed the weaknesses of existing propagation models in dense urban environments.

As I mentioned earlier, ISART 2023 will revisit radiowave propagation. I will make a bold prediction: engineering students contemplating research in radiowave propagation will have long and fruitful careers, and 2023 won't be the last ISART that addresses the topic of radiowave propagation.

Rounding it out, ISART 2010: 5G Spectrum and a Zero-Trust Network, re-examined what spectrum security means. That brings us to this year's topic: Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making. The goal for ISART 2022 is to chart a technical roadmap and gain consensus for specific data-, science-, and technology-driven means to evolve and expedite spectrum sharing, analysis, and decision-making and identify opportunities for continuous improvement in development beyond the current linear spectrum-sharing process.

Over the next four days, we will be systematically walking through the topic. Today, we'll get a high-level overview. We'll hear from the Assistant Secretary of NTIA, Alan Davidson, who can speak to the administration's perspective and strategy for spectrum. Then our opening panel will bring together the ISART chairs and members of the Technical Planning Committee to explain the motivation behind this year's theme and the impetus for the goal of the symposium.

Next, we'll hear from Charles Cooper, NTIA, Associate Administrator, Office of Spectrum Management. Having served at the FCC and now overseeing federal spectrum management, Charles has a wealth of knowledge on this topic. Finally, today, we'll hear from industry. In the

Lessons Learned from Spectrum Sharing panel, we'll get candid feedback from practitioners on the commercial side who have been putting these principles into practice.

The goal is to glean suggestions on how we might enhance, expedite, and improve our processes going forward. On Tuesday, we'll look at economic factors. Starting off, we'll have a keynote on Spectrum Auctions by Evan Kwerel, Senior Economic Advisor, Office of Economic and Analysis at the FCC. Historically, our next panel, Economics of Spectrum Sharing, would have a pre-auction focus.

However, there are a lot of indications that we're selling ourselves short with that approach. This panel will also consider adapting our rules and technologies after systems are initially deployed to yield greater efficiencies and greater confidence in the means to protect critical systems. We'll round out the day with a panel on data sharing and transparency. This is a tough one.

Optimal spectrum-sharing feasibility studies are based on accurate assumptions and understandings of system performance, network density and transmitter and receiver characteristics, for example. Some of that information is proprietary or sensitive. Some of it is not yet known. Yet all of it is essential. On Wednesday, we'll change gears and consider risk assessment and modeling. Opening the day we'll have a keynote address on cost-benefit risk related to national security by Fred Moorefield, Deputy Chief Information Officer at the DoD. Fred has been working in this space for a long time and is an innovative leader, so we look forward to hearing his thoughts on the topic.

The next panel brings statisticians into the fray with a consideration of risk-informed interference analysis. This topic will be covered in two complementary panels. The first will provide a broad introduction to the topic as it's applied in other fields. In the second, spectrum experts from industry and government will consider how risk-informed analysis can be applied to spectrum management.

Then we'll have a panel on model standardization. We can't afford to reinvent the wheel with every new rulemaking. There have to be building blocks we can reuse. Not only because it saves time, but because with time and experience we gain greater confidence in them. Models come in many forms. But we believe the most benefit can come from tackling propagation models first. This panel will consider how to enhance and standardize them and gain stakeholder acceptance.

Finally, we'll close out on Thursday with final considerations and a wrap-up. John Chapin, Special Advisor for Spectrum with the National Science Foundation, will kick us off with a presentation on Fast Interference Management. That day's first panel will consider technical enablers for evolving regulatory processes. Post-auction rule changes can introduce uncertainty, which represents economic risks. That said, if the technology in the framework for assessing it is well engineered and can be demonstrated, maybe it's possible we may actually yield greater confidence.

Finally, we've given the closing panel a different name: the Wrap-up/Roadmap Panel. The panel moderators will summarize the most important takeaways from each of the discussions and consider whether community consensus is possible. As I mentioned earlier, we want to come out of this hour, 2022, with input that can be translated into recommendations and actionable research topics. So we're looking for everyone's active engagement at that point. The symposium Chairs and Technical Planning Committee will have more to say on the motivation for this framework shortly.

But first, it is my pleasure to introduce NTIA's new Assistant Secretary, Alan Davidson, who joined us in January. On Day 1, Alan got engrossed in helping kick off NTIA's broadband program, and that program is coming along well. Alan will have an update for us on that groundbreaking work. We've only been working together for five months now, but that's enough time for me to glean Alan's leadership style and begin to understand his vision for the agency.

First, he values and models excellence, integrity, and kindness. I've seen that firsthand, especially in how he actively listens, questions and encourages, and acts to support our work. When you think about the work that needs to be done in spectrum management, protecting mission-critical systems and services while expanding commercial access, we know we're going to butt heads at times. If we all take that approach excellence, integrity, and especially kindness, we will do well.

I would characterize Alan's approach as something like this: He doesn't use the adage If it ain't broke, don't fix it. That's not in his vernacular. He's more likely to say, "Okay, it isn't necessarily broken, but I'd like us to make it better." At the highest level, that's the whole point of ISART 2022. We've been tackling complex spectrum issues for some time now.

Given all of our lessons learned, we know we can do this more efficiently and effectively. In light of our virtual format, I would suggest that we liven things up a bit. So in lieu of a keynote address, we'll have a fireside chat. Joining him [Alan Davidson] will be NTIA's former Deputy Assistant Secretary, Anna Gomez, who is a partner at the law firm Wiley Rein.

Please join me in welcoming Alan and Anna. Thank you.

3.2 Fireside Chat

Alan Davidson, Assistant Secretary of Commerce for Communications and Information and NTIA Administrator

Anna M. Gomez, Partner, Wiley Rein LLP

Anna Gomez: Thank you to National Telecommunications and Information Administration (NTIA) and Institute of Telecommunication Sciences (ITS) in particular for inviting me to participate in this marquee event. And thank you to Secretary Davidson for speaking today, who really jumped into the fire at NTIA, which has many high-profile matters on its docket, both domestically and internationally. Now, one major matter before you is broadband grants. Last month, NTIA lodged notices of funding opportunities for three broadband programs. 1) $1 billion for the middle-mile broadband infrastructure program; 2) nearly $3 billion for the Digital Equity Act program; and 3) $42.5 billion for the historic Broadband Equity Access and Deployment Program, or otherwise known as BEAD. The BEAD program alone is extraordinary and will provide funding for infrastructure for high-speed Internet access aimed at closing the digital divide for all. It is possible that some in the audience might not be familiar with these programs. So can you give us a brief overview of these important and transformative programs?

Alan Davidson: Thank you for that intro. Thank you, Anna, I should say, for joining us today. It's great to have you back in the NTIA fold for a little while here. And thank you to everybody here: to our organizers and to all the folks out listening today for joining this. This is a very important conference, an important set of topics, as Eric has teed up.

So a great question about what we're doing at NTIA around this broader issue of promoting Internet access. And I will say, you know, we have been talking about the digital divide in this country for over 20 years, well over 20 years. And now, thanks to the bipartisan infrastructure law, the leadership of a lot of folks in Congress and the president, you know, we've really been given the resources in the federal government to do something meaningful, structural, long-term about it.

For NTIA, that is, as you said, we've been given $48 billion—that's with a B—billion dollars by Congress for a variety of programs to promote Internet access and adoption, to really address the digital divide. To think about making sure—it's a very simple, humble mission—making sure that everybody in America, literally everybody, has access to high-speed, affordable, reliable Internet service.

And so that's, you know, it's kind of, it is a daunting challenge. We've got a couple of different programs, this access program, which we're running through the states; a digital equity program, almost $3 billion; a middle mile program, which is kicking off, which we've just kicked off and is what we'll be doing this year. And it's an exciting time. It's an exciting time to be at NTIA, to be doing this work. And I really do think that, you know, just as generations before us brought water and electricity to rural America, built the interstate highway system, we will look back on this moment and say this was our generation's chance to make sure that everybody's meaningfully connected to the digital economy. So this is it's a very exciting time to be working on this. And it's and it dovetails very closely with our broader work on spectrum and other policy issues.

Anna Gomez: That's right. NTIA certainly is, I think, the right agency to be doing this. So what technologies are eligible for funding under these programs?

Alan Davidson: Well, I will say we're taking a real "all of the above" approach. We know that if we're really going to meet the mission of connecting everybody in America, it's going to require a variety of technologies. And the way the program is set up is in fact that different states will have really different approaches. And we know that the needs of Rhode Island or Connecticut are really different than the needs of Montana or New Mexico. So we expect it to vary quite a bit. And so we expect there'll be a full range of technologies from fiber, to fixed wireless, to lower earth-orbit satellites. There's no one-size-fits-all solution. That said, I will say we do have a set of requirements that were put into the law and actually that we've put into our notices as well about what the technologies have to do, what kinds of speeds and latency they have to deliver, what kind of technical features.

And there is a little thumb on the scale, I'll be honest, for fiber, with the notion that it has special properties, as many of us know. Pushing fiber out as far as we are able to, we do think is going to be important to make sure that this is infrastructure we won't come back and have to rebuild five or 10 years from now. But, that said, I think that's only going to be part of the solution. And we know there's going to be a lot of different technology in the mix.

Anna Gomez: Now, you mentioned that spectrum dovetails with broadband, and spectrum is obviously critical to wireless services, both for the efforts to eliminate the digital divide, but also for U.S. leadership in innovation and communications. Over the past decade, NTIA and the FCC have collectively reallocated or repurposed over 7500 MHz of federal and non-federal spectrum to make it available for commercial wireless services and 5G, with over 1000 MHZ of that being mid-band spectrum.

Now, that's a tremendous accomplishment. Of course, as the saying goes, the reward for work well done is the opportunity to do more. Even more spectrum is being asked to be made available for commercial 5G, but there are no longer any easy spectrum bands readily available for repurposing. And so this is yet another daunting challenge for you and for anybody. So what steps are being taken to address this continual demand for spectrum repurposing?

Alan Davidson: Well, it's a great question. The way you've posed it, I mean, there's we sit at NTIA facing these dual imperatives as this coordinator of federal spectrum, as the federal spectrum manager. We know that federal users need to be able to meet their missions, very critical missions—defense, aviation, transportation. At the same time, there is a huge imperative, as you said, if we are going to remain competitive in our economy, if we are going to have these thriving next-generation services in wireless that consumers demand, that our economy demands, we know we need to make sure there's a pipeline of spectrum available. And so we are really trying to take here a long-term vision about how we can be more efficient and effective, about our use of spectrum. And we are working with other federal agencies, trying to develop a strategy here that I think rests on really three key pillars.

One is better coordination among the federal-user community and making sure that we are doing what we can to keep that spectrum pipeline going. The second is trying to use real evidence- and science-based processes as we put together our federal strategy in this area. So making sure that we're science-based as we think about where spectrum may be available, how we think about conflicts and interference and spectrum use, making sure we have a common understanding of those issues.

And the last is really leaning into technology. Because, as you said, the low hanging fruit, as it were, the easy answers are gone. If we are going to meet the needs of both our federal-user community and the commercial sector, we need to be thinking about innovative ways, different bands, different ways of sharing spectrum. And that's where, by the way, this broader community can really help us out.

Anna Gomez: So one thing that you talked about is having a new national spectrum strategy, which I would say is long overdue. What do you foresee as being critical elements necessary to develop a successful national spectrum strategy?

Alan Davidson: Well, I think, you know, it starts with this idea of better coordination. And I do think that we've got some of the tools in place for that. But I think that, you know, making sure that the agencies are speaking together, making sure they're working well with the White House: That's going to be pretty critical. Our working relationship as well with, um, you know, our sister agencies, particularly the FCC, is really important here. And so we're very focused on improving that relationship. We've just launched a spectrum coordination initiative with them as well. I also think it's going to be really important for us to be forward-looking in this in the sense that I think people are hoping for a strategy that's not just about the next few months or the next even next year or two but thinking longer term about how we get all of the relevant stakeholders here—the federal-users, the FCC and commercial community too—involved in developing this strategy and thinking about where we need to be going in the future.

And I keep using the old Wayne Gretzky hockey analogy, "Don't skate to where the puck is, but skate to where the puck is going." And I really do feel we have a big opportunity to work with industry, to work with researchers, to understand where the puck is going in this space and make sure we're moving there.

Anna Gomez: Well, now that you mentioned research, I'm a big fan of NTIA's lab, the Institute for Telecommunication Sciences, or ITS, in Boulder. I love visiting. I understand you recently had an opportunity to visit ITS in person, including the Department of Commerce Table Mountain Radio Quiet Zone, which is managed by ITS. So much of the technical research and work undertaken by ITS is critical to providing science, data, and technical underpinnings for possible policy decisions. And you just mentioned the importance of policymaking that is science-based. How important is it? And I am giving you a softball, I think...

Alan Davidson: Thank you. [Laughs]

Anna Gomez: ...to have an in-house lab like ITS at NTIA?

Alan Davidson: Well, it's very important, Anna. And no, I don't mean to joke about it. It is very important. And the fact is that what we're seeing actually out in the world is what happens when we don't have a good common understanding and common baseline for dealing with disputes or, you know, different understandings of spectrum usage, spectrum interference.

There have been, you know, real examples on the front pages of the paper about conflicts within the federal government. And we do need to avoid those. And I think it's important as we go forward, if we're going to find ways to make more efficient use of the spectrum, of this scarce spectrum resource. If we're going to move spectrum into the hands of the commercial community, we do need to have that common understanding and baseline.

And we've seen what happens when we don't. So I, I was very excited when I got a chance finally just a few weeks ago to visit ITS and our Table Mountain facility. You really see the power when we're doing things like the project we're doing with the Defense Department, testing out 5G interference with their altimeter systems, when you see the work that we're doing with our other federal partners there, there's a huge value in the, you know, kind of cutting-edge understanding of spectrum engineering and technology that we can bring to the table that our community really values and needs. So I think it's incredibly important.

Anna Gomez: So what process changes are needed, if any, to ensure policy decisions are science- and evidence-based?

Alan Davidson: Well, I think, you know, again, it starts with a commitment to coordination. And I do think we have a good framework in place for that. We have working groups and steering groups. We've got a conversation with the outside community. But it's not just about the frameworks. It's really about the common commitment across the federal government to be part of those decision-making processes.

And so, you know, I think there is something, you know, to be said, I think, for ensuring regular order, as it were, as we would say in Washington. Right? And I think you'll see efforts, as we're doing with the FCC, to make sure that we've got everybody buying into the processes that are in place. There probably is more work to do in building our muscles, you know, when you ask about what changes are needed to ensure that we've got it. And it is getting used to and making sure we've got the capacity to have that kind of really strong science-based, evidence-based leadership. And part of it is within NTIA and at groups like ITS, and part of it will be making sure that our colleagues in other agencies appreciate that and have their own ability to engage in that. So I look at the agenda for this conference for ISART 2022 and I think it shows a number of areas where we could improve our scientific understanding and our processes. And I'd look forward to seeing some of the results that come from it.

Anna Gomez: When you talk about building your muscles, one concern that is often raised, when issues around spectrum sharing in particular arise, is how much responsibility NTIA has, yet how few staff it has compared to the impact NTIA has on the economy and, honestly, how antiquated some of the spectrum management tools are. What can you tell us about efforts to address those concerns?

Alan Davidson: Well, I'd say you're right. You've seen it yourself firsthand in the past. You know, we are small but mighty here, is the way we like to think of ourselves and not that small. I mean, we do have, you know, several hundred people here working on these issues. But relative to the impact on the economy, relative to the importance of these issues and just the economic dollarsign impact that we see billions of dollars in auction revenue and spectrum value that can be created if we together do these things. We believe we do, you know, need more resources.

It starts with, I'll just say, it starts with people. I mean, one of the best surprises I had when I came on board as a new assistant secretary was just how incredibly talented and committed our team is here. We need more. We need more folks. We need more, more, more good folks.

And particularly, I think, a diverse workforce of not just here but within our community is incredibly important to make sure that we are thinking about a diverse set of communities that are going to be served by this work that we do. And I think we need to build the field. And, you know, just even in Eric's introduction, just thinking about like, how do we create a bigger pipeline of people coming in to help us think about these hard problems as a community?

You know, this is not going away, right? And you look at these new tools that could be on the horizon. We're thinking about incumbent-informing capability. We're thinking a lot about different spectrum-sharing models. We're looking at new bands that 10 years ago nobody would have been talking about. For the foreseeable future, there's going to be tremendous need for talent to help all of us think through these issues. And I think building that workforce is a community project, not just for NTIA but I'd say across the commercial sector and the academic community as well.

Anna Gomez: Yeah, I could not agree with you more. So, switching topics just slightly: A couple of years ago, the Commerce Spectrum Management Advisory Committee, or CSMAC recommended updating the 2003 memorandum of understanding (MOU) between NTIA and the FCC and in the spectrum coordination Initiative that you talked about earlier, both agencies committed to doing that. And recently, Congress has also begun drafting its own language related to rewriting the MOU. Can you tell us about where the efforts to revise the MOU stands?

Alan Davidson: It's a great question. And this is an area, you know, it can get into the weeds really quickly. But it is you know, this is the important work of coordination that we need to do. So people have gotten very focused on this memorandum of understanding, which hasn't been updated in over 20 years, or almost 20 years. It's kind of crazy, right? And so, a lot has happened since 2003. So one of the first things that the chairwoman and I spoke about—actually on my first day in the office when I spoke to her—was our need to do more to update some of these processes we have. This is a great example of it. We're working to update our MOU. I actually spoke in Congress last week, and the chairwoman and I have committed together to have a completed draft of that update by the end of next month, which is great; and we'll put it through our clearance processes. And then the plan is to work off of that.

And it's just one example of what I think of as the unsexy work of coordination that actually at the end of the day is what will really matter here, right? It's hard work. it's not often seen. But the important work of engineers and policy leaders speaking to each other, coming to common understanding, putting in place processes so that we're coming to a common understanding of how we're approaching different bands, where we see different kinds of interference, how we're building new models of sharing—all of that work, it takes a lot of work, takes a lot of work for the folks who are part of this community and part of this conference. But we're committed to doing that hard work and working with all of you out there to make sure that we're really doing the most effective and efficient thing that we can do with this very, very scarce, and valuable resource.

Anna Gomez: Well, that's fantastic. I'm so happy to hear that. I think a stronger NTIA is great for the country, for the economy, for spectrum management, for broadband, all the work that you're doing. I think that is all the time we have. So I want to thank you so much, Secretary Davidson, for your time today. And again, thank you to ITS for inviting me to do this.

Alan Davidson: Thank you, Anna, for being here. It's great to see you. And again, I'll just say thank you again to all the folks who are participating out there. We need as a nation, as a global community—if we're going to solve these really hard problems around how to make the most efficient, effective use of this really scarce community resource—we're going to need the best thinking we can get. And that's why I'm so glad to be here today and to be here with you, Anna. And thank you to our organizers and good luck to everybody out there on answering these hard questions that have been teed up for us. So thanks.

Anna Gomez: Thank you.

3.3 Panel: Exploring the Theme of ISART 2022

The ISART Chairs and members of the Technical Planning Committee explain the motivation behind this year's theme and the impetus for the goal of the symposium: To chart a roadmap and gain consensus for data-, science-, and technology-driven means to evolve and expedite spectrum-sharing analyses and regulatory decision-making.

Rebecca Dorch, J.D., Senior Spectrum Policy Analyst, Institute for Telecommunications Sciences, and ISART General Chair

Michael G. Cotton, Theory Division Chief, Institute for Telecommunication Sciences, and ISART Technical Chair

Howard H. McDonald, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA), Retired and ISART Technical Committee member

John Chapin, Special Advisor for Spectrum, National Science Foundation and ISART Technical Committee member

Rebecca Dorch: And thank you all for staying with us. We had a little technical glitch there. Eric was going to come back on and introduce the panel, but we had a glitch. So sorry about that. So let me first of all, thank Anna Gomez and Assistant Secretary Alan Davidson for that wonderful fireside chat. It was a great way to kick off the conference and I will tell you, I, for one, am really excited and thankful, frankly, that Assistant Secretary Davidson both embraces exploring ways to improve the processes and particularly supports us exploring this theme that we have here for

ISART 2022, which we initially developed and presented last fall at the National Telecommunications and Information Administration (NTIA).

Spectrum Policy Symposium before he came on-board. So it's awesome for us. So thank you very much, Assistant Secretary. So we have with us on our panel today. Let me make sure I've got my right slides here because I'm using two different machines. So we've got Mike Cotton, who is the Institute for Telecommunication Sciences (ITS) Theory Division Chief and ISART Technical Chair.

We also have on our panel Howard McDonald, who is the recently retired Branch Chief within the Defense Information Systems Agency of the Defense Spectrum Organization, oftentimes more commonly called DISA/DSO. And John Chapin, who is a Special Advisor for Spectrum at the National Science Foundation. And so we are going to share perspectives here on the concept that we're exploring for ISART 2022.

So, if Chris, if you want to throw up my slides, I'll get us kicked off.

So you can go on to the second slide, I guess.

Building on what Eric gave in his opening remarks, also, I'm going to provide a little bit more background on the motivation for the ISART 2022 topic and then the members of our technical panel and Mike Cotton are going to provide some perspectives based upon their own unique backgrounds and their positions—Mike from a federal lab, Howard from a federal agency that uses spectrum, and John as a researcher—on the themes that we're exploring here in ISART 2022. But before I kick that off, I do want to acknowledge and thank very much for their support, the contributions of the other members of the Technical Planning Committee, including Greg Wagner, who is the chief of the Strategic Planning Division at DISA/DSO, and Joy Cantalupo, who is Acting Chief of the Advanced Access Initiative within the Strategic Planning Division at DISA/DSO. And, of course, our Acting Director, Eric Nelson.

Towards the end of this panel, we're going to share three questions that we'd appreciate your feedback on as participants in the symposium. As Eric mentioned, we really do want your feedback and participation. So we've got the Questions and Answers option on the side panel; please put your questions in there. We will answer as many as we can during the course of this panel and during the course of the rest of the symposium.

Next slide.

So as I think Anna and Eric both mentioned, back in 2010 then President Obama set a goal in a presidential memorandum to make 500 MHz of spectrum available for commercial use by 2020. And thanks to the efforts that began then in 2020, in earnest in response to the FCC's broadband plan, the NTIA 10-year plan, and the 2012 report from the President's Council of Advisors on Science and Technology (otherwise oftentimes known as the PCAST Report), and, of course, the commitment of the entire stakeholder community—together, we did as Anna mentioned in her questions that we have enabled the U.S. to far exceed that 500 MHz goal, achieving over 7500 MHz of shared spectrum.

And, as they also mentioned in the Fireside Chat, more spectrum is being asked for by industry and we have more bands that are under consideration for repurposing.

So while we have indeed been really remarkably successful in this past decade using this current linear spectrum-sharing regulatory process at repurposing spectrum, we believe that we can do better and that we can take better advantage of advances in technology and science and of the ground truth data, and ultimately be even more successful with sharing and with spectrum efficiency if we modify the system a little bit.

So the current linear spectrum-sharing process is very broadly generalized in the graphic on this slide. For those who are not very familiar with the current regulatory process, the first series of tutorials for ISART 2022, which are, as Eric mentioned, accessible from the platform and will also then be available after this week on the website, those tutorials in the first series provide overviews of the first three parts of this process: 1) the band prioritization drivers and authorities; 2) the feasibility analysis process as conducted by NTIA; 3) and the rulemaking process at the FCC. And we've also included in that tutorial series an overview of the consultative process through the Interdepartment Radio Advisory committee (IRAC) and a case study on the entire process based upon CBRS.

Next slide, please.

So we've learned valuable lessons learned in this past decade that we've done this spectrum repurposing, lessons that we can certainly apply to improve the process and the outcomes of the process. And I use this slide that we're seeing right now last September, when we first introduced this concept, as these were some of the factors that prompted our suggestion to evolve to an iterative process.

So basically, we posit that the current regulatory process affords little opportunity for adjustments based upon improved knowledge and data, or advances in science and technology. And while a regulatory process that fosters market and regulatory certainty and stability have been really important to commercial interests who pay billions of dollars during auctions for well-defined spectrum rights and lengthy licenses, which in turn reinforce the rigidity of the rules, these same processes can impose some costly constraints on innovation and on spectrum efficiency.

So in each of the areas where recognized limitations in our current approach exist, there are opportunities for improvement and for applied science. The one-and-done linear regulatory process sets technical rules based upon early assumptions and analysis and does not include an easy mechanism or process for revisiting rules based upon the ground truth, on data, on advances, on new models, or advances in science and technology.

Policy and regulatory timescales are both at the same time too fast in scenarios where rules have been set and auctions held prior to a thorough technical analysis to aid understanding of some of the technical and engineering challenges that exist with incumbents in-band and particularly adjacent bands. And they are simultaneously too slow, especially compared to the pace of innovation for particularly software but hardware also. And in employing advances in spectrum-sharing techniques, whether it's spectrum-sharing management techniques or spectrum-sharing technologies themselves, that's difficult in the face of static regulatory processes, slow standards processes, and insufficient funding for test-driven research and development.

The second set of tutorials, is, again, available on the platform. We did we did four spectrum-sharing tutorials based upon a very specific spectrum-sharing efforts: 1) One on TV White Spaces; 2) one on U-NII and the DFS Issue—and I'm sorry about acronyms, I know—Unlicensed National Information Infrastructure (U-NII) radio band and; 4) the Dynamic Frequency Selection (DFS) Issue that popped up in that proceeding. Citizens Broadband Radio Service (CBRS). And then AWS-3, which is advanced wireless services, three with the third set of spectrum was used for that. So there were some takeaways from those tutorials that provided some context and some specificity to these generalized assessments of the current process that I've kind of highlighted here. And just briefly, here are a couple of those takeaways, or actually four of those takeaways.

1) Lessons Learned provide data points that we can build on and use as a sort of future quality assurance check on our processes. And we can also do a lot better capturing, sharing, and leveraging lessons learned from the different spectrum-sharing experiences; 2) Up front, technical research and better understanding of the technical hurdles of sharing are critical to the ultimate success of that sharing; 3) Databases and software play increasingly prominent roles in spectrum sharing, and we can do better in both establishing requirements and conducting testing of software-based spectrum-sharing efforts; 4) And then, markets for both services and products are impacted for good and bad by regulatory changes. And the panel following this one on lessons learned is going to add even more complexity to this topic of lessons learned.

So next slide, please.

So these factors all aligned to suggest that the linear process could be reformulated into an iterative and flexible process. Our initial model for evolving the spectrum-sharing model from a linear process to an iterative process was a continuous improvement model that's very simplistically generalized in the graphic on this slide. The inner circle includes key components of the current linear process but within an iterative, responsive, and evolving context and that incorporates feedback into the process from real-world ground truth data, including interference mitigation and interference resolution issues.

And the outer circle [of the image on the slide] then also represents the evolution of commercial and federal systems, with likely touchpoints that allow for cross-sector dialogue related to industry deployments, system optimization standards and model development, and test and demonstration efforts that actually establish a pipeline for new proven science and technology.

So the idea behind the circular model is to extend the regulatory horizon beyond the first set of regulatory rules to enable the process to be more responsive to technical evolution and more reliant on applied engineering analysis.

So, revisiting assumptions included in the initial technical feasibility analysis after early stage implementation and deployment of the new technology might trigger a reassessment of certain aspects of those rules. Once new commercial systems have begun to scale up and expand deployments, analyzing data from those efforts might also result in another warranted tweak to the rules. So structuring a process that can continually evolve even to stages of market maturity and full system deployment could also enable the ecosystems to be studied, the models and the interference protection criteria to be validated, and encourage lessons learned to be applied to other spectrum-sharing scenarios.

Next slide, please.

So to start to wrap this up, our stated goal for 2022 is to chart a roadmap and gain consensus for specific data-, science-, and technology-driven means to evolve and expedite spectrum-sharing analyses and decision-making and identify opportunities for continuous improvements and developments beyond the current linear spectrum-sharing process. As the Technical Planning Committee grappled with the complexity of what we were proposing while planning this symposium, we had many discussions about terminology and what we meant by *iterative* or *evolving*, and how even simple changes to the regulatory process could have profound impacts elsewhere or unintended consequences. So we acknowledged that we don't know what we don't know. So, hence, we really are quite serious that we want and need input from you, from the other speakers, the other moderators, and all of the audience participants. So you can take my slides down. And to kick us off, we'll start with getting some of the different perspectives on this topic out there from our ISART technical chair, starting with Mike Cotton and then the two of the members of our technical planning committees here.

So Mike, let's go to you first and get your perspectives on our theme from a federal research lab.

Michael Cotton: Okay. Thank you very much, Rebecca. I appreciate that. And, yeah, the approach that I want to take on just this quick overview and is to stay at a high level. And I want to just basically talk about four topics that we like to work on. Stay at a high level; talk about how we're working those problems now at ITS; and then sort of indicate how it's limited and how something like this process could help us move things into doing things in a bigger way.

Next slide.

The first topic is receiver performance and, acronym, sorry, interference protection criteria (IPC) testing. So ITS performs field measurements of real systems, actual systems with hardware in sort of real-world geometries with signals that are both in-band and out-of-band to assess how interfering signals affect those receivers. And you know, those types of tests can be expensive and hard to access and limited in time. But they produce a really important data point for the developments in the process.

We also have laboratory measurements. In those laboratory measurements we'll get a receiver into the lab, and we'll be able to evaluate the front-end, look at the end-user experience, and evaluate interference protection criteria in a quantitative way based on conducted measurements for controlled signal conditions. And that's a very useful way to get kind of broader [information]. We have a little bit more time that we can spend on that.

And then finally, those measurement efforts are backed up by theoretical work, where simulations are run based on communications and radar theory and so forth, and a set of assumptions to help to try to generalize those test results, so we can gain intuitions and reuse those types of data.

Largely, this work is very reactive today because of how fast this process has been going. So we get sent out for the priority of the year and we get out there and do it. It's a large scope of work to get done. And one other thing I'd mention is that we do have a new initiative actually within NTIA, to standardize interference analyses across NTIA. So getting this all together to work and create kind of a tool set to support those types of analysis is going to be better towards automation.

But a longer-term commitment towards systematic testing and modeling of perceived performance in interference environments is a real important thing that this type of long-term work could support.

Next slide.

Antenna characterization is another area where we perform a lot of field measurements out at Table Mountain. We have a turntable out there where we can put the antennas on their platform [such as a vehicle, turn the table], and measure their characteristics in a clear environment. We utilize NIST facilities when anechoic chambers are needed to achieve a greater isolation. You know, antenna models largely that we use in our higher-level analysis are very static and they assume no environmental interaction. There is new planned work to get more into some of the more dynamic and active antennas, but that's just getting kicked off here at NTIA. So a longer term commitment to systematically characterize advanced antennas in the real-world spectrum-sharing scenarios is an important thing that would help the science and spectrum management move in the right direction.

Next slide.

Propagation modeling, as everyone knows, as a lot of people I'm sure know, is a core area of ours. We develop propagation models from first principles, simplifying assumptions, and field measurements. Those field measurements are significant, and we work hard to design the experiments towards gaps and accuracies that need to improve. Model standardization happens at the ITU, for example, and other places.

There is a new mid-band propagation initiative starting at ITS where we do plan on expanding things and doing things in a bigger way, which should expand a lot of our work in the right direction. But propagation models, you know, those are difficult to use. They're mistakenly used outside of their intended scope and inherent set of assumptions. And so it's easy to kind of get inaccurate predictions on that. So to build a prediction capability that's more easily used by non-experts is something that's an important thing to move towards.

Next slide.

And then system deployment models. This is a challenging area where we have obstacles in acquiring accurate and granular data, both for government systems and cellular systems. Measurements are performed. But you know, that's largely anecdotal too. You can measure for a week and maybe characterize the occupancy in a county or something like that and over a shorter period of time. But a lot of times there's larger scales that need to be assessed in this area.

And really the unknowns here make it difficult to do our biggest modeling challenge. And that's aggregate modeling, right? Where we're trying to predict emission levels to reach a victim receiver from a population of trained transmitters. And so the more we can improve this type of modeling where we have better information on system deployments, that would really help us reduce margins and so forth.

Last slide.

Rebecca Dorch: All right. Oh, you have one more. Sorry.

Michael Cotton: One more. Sorry. I'm sure I'm out of time now. I just wanted to mention one last comment on a program we have that's really been growing in the last few years. And it's collaboration with our sister office, the Office of Spectrum Management (OSM). It's called the NTIA Spectrum Management R&D program. And there's two parts to the program. 1) There's a quick-reaction technical support part of it, and that's where, you know, OSM comes to us and basically says, Hey, we got to have this agency interference analysis report, we really need your eyes on it. There's an FCC, NPRM, we'd like to provide comment, can we work on this together, and so forth. So that type of work is kind of like the one-and-done format that we talked about in the linear process that Rebecca referred to. And you know, there's a lot of important science that's discussed, but there's not a lot of science that's *developed* in that space, right? We usually just do it in a very short time frame. 2) The other part of the program is a planned R&D program, and that's the area where we have dedicated scientists working on improving things in the long term.

That's where the science occurs. And there's some sub-bullets there that list the topics. They're largely the topics that we talked about earlier. And I think it's the key topics that we want to hit in spectrum-sharing scenarios. So I guess I might just leave this and suggest that we have sort of the program and the platform for us to support an iterative regulatory process. You know, engage with stakeholders more because that's kind of what it would take for this process—negotiate priorities and create a pipeline for new science and data and technologies to be tested, better understood, and used by regulators.

Thank you, Rebecca.

Rebecca Dorch: Thank you, Mike. That's a great overview of what we're doing at ITS. So let me kick it over to Howard McDonald. So Howard, given your long tenure with DoD DISA/DSO, can you share with us your perspectives on the concept and the thesis?

Howard McDonald: Sure. Quick soundcheck. Rebecca, can you hear me?

Rebecca Dorch: Yeah, you're good.

Howard McDonald: Okay, good. So, as of two weeks ago, I was responsible for the execution of DISA/DSOs AWS-3 transition plan. The details of that are available on the NTIA website under the AWS-3 area. One thing, Rebecca, that that struck me on your presentation was the need for data. And this is an enduring theme within the spectrum-sharing test and demonstration program that I'm going to talk a little bit of detail here.

We collect data on equipment characteristics to include behaviors like LTE power control, resource block utilization, network laydowns. I know Mike talked about some of the challenges with lack of data on those laydowns. The randomized real network laydown that came out of CSMAC was a good start. But we, the spectrum management community, need to replace that with something more realistic.

Obviously, propagation-path false data is key to developing clutter-loss models across land-use/land-cover categories that exist within the U.S. And perhaps near and dear to my heart is the operational characteristics of DoD systems, and that could be used for things like refining interference protection criteria used to protect those DoD systems in, you know, coexistence scenarios. The work that was done, in CSMAC back in 2014 was a good start, to provide an initial set of data but we have come a long way since then.

And that progress is documented in a variety of DSO papers that were submitted for ISART this year. So I would recommend folks that are interested in what we've done and what we are currently doing within SSTD to go look at those papers. So quick perspective, I did provide an AWS-3 tutorial that provides the context for what we're trying to do under the Spectrum Sharing Test and Demonstration (SSTD) program.

I talk in that tutorial about the licensees submitting formal coordination requests in the 1755–1780 MHz band, the LTE uplink band, and the DoD response to those formal coordination requests where DoD approves or denies sectors based upon an aggregate interference analysis. Up until two weeks ago, I think my name was on those DoD response letters. Joy Cantalupo's name I believe is now on those response letters.

So two major objectives of SSTD: 1) To enable coexistence between DoD operations and NATO's AWS-3 licensee operations for temporary sharing during the 10-year transition period. 2) And the second objective is to facilitate less restrictive sharing arrangements for both early-entry and permanent spectrum sharing. The Army's Joint Tactical Radio System (JTRS) will remain in the band indefinitely.

And so we're working on reducing the less restrictive sharing arrangements for JTRS. Then perhaps more relevant to this activity is extending the results of the SSTD activities to facilitate spectrum sharing in other bands and use cases. And we're doing that. We, DoD, are doing that right now in the 3.45 GHz band, looking at what we can take from SSTD and apply to the coordination requests received in that band. A number of technical papers that I referenced were submitted to ISART by DSO and I encourage you to look at those.

One of the key things that might not be made available in these papers is the cross-validation that is done continually as we refine the propagation clutter-loss models, refine how we characterize LTE, etc. And cross-validation includes if we can get the laboratory bench tests to agree with field tests to agree with models and simulations, we've got high confidence that we can integrate those findings into the end-to-end process of evaluating coordination requests and responding with a formal answer to the licensees.

We've operationalized a number of [unintelligible] refinements over time. One major refinement that has not yet been operationalized in AWS-3 is an expanded family of uplink ERP curves that are used to characterize the aggregate interference from LTE handsets or user equipment (UEs). Currently we're using sensors track data to determine which curve—the urban / suburban curve or the rural curve —would be used in those aggregate interference for [unintelligible] working up regional extended family of curves using [unintelligible] line-of-sight distance between the base station antennas that are reflected in the coordination requests. There are still some outstanding requirements that need to be met.

One is characterizing indoor distributed antenna systems (IDASs). The other is what changes may be needed, if any, to address anticipated deployment of 5G services in the 1755–1780 MHz band. I've characterized SSTD as a series of discoveries to include technical approaches, and we have refined those technical approaches over time to develop the models and generate the datasets used when we are processing a formal coordination request.

I'm sorry, I keep saying we. That is, when DoD processes the formal coordination request. These technical approaches and perhaps as important, the collaborative nature of the multi-stakeholder working groups that we've stood up, I think represent best practices that should be considered in other bands. In light of the theme of this ISART and being a bit retrospect, the 1755–1780 MHz AWS-3 band could be considered a low-risk test case for future band sharing initiatives, as [unintelligible—most of the federal systems will relocate out of the AWS-3 bands] by end of FY25 and my personal opinion, an enduring program like SSTD may represent a foundational model for evidence-based iterative rulemaking in other bands.

There is one important topic that we have not resolved to anyone's satisfaction, and that is this concept of interference-margin apportionment, particularly for airborne systems. Those systems have an interference vulnerability footprint that's rather large geographically and cuts across multiple geographic licenses and 1755–1780 MHz. And so, what is the optimal way to distribute the interference protection criteria of a DoD system where the aggregate interference could come from multiple networks operated by multiple carriers?

We have used the randomized real network laydown as a starting point and have improved that over time. But that process that we've taken with AWS-3 I think needs more information to include things like, Are we being fair to all the licensees—there's probably socioeconomic perspective on that—and also the technologies that we're seeing within the commercial world. I think actually that this concept of interference-margin apportionment could perhaps be a future ISART topic because it is a large part of the end-to-end process that we use. So with that, Rebecca, I'll stop and turn it back to you.

Rebecca Dorch: Super. Thank you, Howard,. John, let's quickly go to you. And from a researcher's perspective, can you give us your thoughts? And we'll need John's slides up, please.

John Chapin: Thank you, Rebecca. Thanks, Chris. Delighted to be here and have a chance to chat with everybody today. I'm going to kick you off with a research perspective here. I do want to state that this is my personal opinion. It's not National Science Foundation's perspective and it is not the perspective of the planning committee. This is all up for discussion.

Next slide, please.

So before we talk about where we might go, let's discuss how we got to where we are. The current paradigm of one-and-done regulatory processes was shaped by the technical constraints on radios and other RF devices during the period when the current system evolved in the 1930s to the 1950s.

In those days, the transmit and receive functions of devices were fixed in hardware. They had no local processing or storage. There were no data links for bringing data back from the field or for sending commands forward. Because of these technical constraints, any regulatory change that would require a behavioral change to fielded devices was terribly expensive. Also, real-world assessments were expensive because assessment required sending out a dedicated team with special equipment.

So we ended up in a system where we only modified the regulations in a band in a way that might require behavioral changes to fielded devices once per decades. That is a reasonable and appropriate paradigm given those technical constraints.

Next slide, please.

The constraints have changed. If we look at radios and other RF devices today, most of the transmit and receive functions are flexible. That's true even of mass market cheap devices like cell phones. Essentially, all devices have local processing and storage and essentially all devices are connected to the Internet at some level.

This new technical environment means that, if we do it right, it is potentially affordable to change the behavior of fielded devices in response to regulatory changes. And it is potentially affordable to gather data about the accuracy of things like propagation models, mobility models, and system models, and also to gather data about whether the usage of a band fulfills the vision of the regulatory rulemaking. This technical environment now creates the opportunity to do something different, to do data-based, continuous regulatory improvement. Oh, that may or may not be a good idea. I'm sure there will be a lot of debate here at ISART about that. But let's assume for a moment that in fact it is something we decide we want to do. Then how do we get there? What are the research questions that have to be answered to make this work?

So in the next couple of slides, I'm going to share a list of potential research questions. The goal is to kick off discussion here at ISART and we do hope that the ISART community will participate in setting and prioritizing the list. Okay, so he's already brought me to the next slide.

Let's be on slide four. Slide four, please. Thank you. Slide four, there we are.

The first category of research questions are regulatory and technical mechanism questions. How do you write a report and order that describes potential changes with sufficient precision? This is important because a rulemaking can't say, "Oh, we might change a part of these rules in any way." That just won't work because users of the band need regulatory certainty. For example, system designers need to know what flexibility to build into their devices, and investors need to plan their business models around the range of changes that might happen. So rulemakings need to specify what might change in the future. How do you do that?

A second question: From a regulatory perspective, how do you choose what the range of possible future changes should be? How does the regulator find the sweet spot, considering the potential costs and benefits of the various flexibility options that might be built into the rulemaking? That's a really interesting modeling and prediction problem that needs research.

Lastly, on this slide, what changes could we make to the technical features of our radio devices in our systems, or to the operational methods and the deployments of those systems that would grow the range of changes that are affordable? Because these methods are what would enhance regulatory flexibility. All right.

Next slide, please.

The next set of research questions are on how we do the assessment stage of continuous regulatory improvement. What are the technical methods for gathering the feedback data, for processing it, and for sharing it to answer various policy questions that we might want to assess? Of course, this all has to be done with extreme attention to privacy protection.

Next point: Given that crowdsourcing the data is a critical part of making this affordable, what mechanisms can make the data trustworthy for decision-making? This has to consider both the opportunities for biased entities that may distort the data they collect or provide, and also the challenges created by uncalibrated devices and uncontrolled deployments and so on.

Given that the data is available, who does the assessment? It might be the regulator. It might be the industry. It might be some third party. And how should that entity be funded? Presuming that the datasets coming back from the field will inevitably have contradictions, what are the processes for resolving those contradictions?

Next slide, please.

And the final set of important research questions are policy and economic. Given a band, what's the optimal time between planned regulatory changes? Presumably, different bands will be different. So what factors affect the choice? How do we reduce the potential for regulatory distortion? After all, every regulatory change creates an opportunity for someone to gain an advantage through undue influence or for external political intervention. Changing from the current system that is one-and-done to one where we make a change, say every three to five years in that context, how would we mitigate the increased risk of market distortion?

Continuous regulatory improvement certainly has significant interactions with and implications for other parts of the ecosystem—for example, the business models of spectrum users and the design and payoffs of spectrum auctions. These interactions and implications need to be understood before we can launch into a continuous improvement approach.

Well, finally, while the spectrum regulator gains immediate benefits from a continuous improvement approach, many other spectrum users incur immediate risks while gaining only second-order benefits. So what incentives can be established or identified that make the new approach attractive to the rest of the spectrum ecosystem?

Next slide, please.

So to summarize, it seems clear that there is a technical opportunity for data-based, continuous regulatory improvement, but there are many research questions to address in multiple areas, likely going beyond the ones I've listed here. So we invite the community to help set the list of topics and to prioritize how we should investigate these questions going forward. Thank you. Back to you, Rebecca.

Rebecca Dorch: Thank you, John. So I'd like to pose one quick question to each one of my co panelists, because based upon what I heard from our opening remarks, I think each one of us are coming at this whole idea of evolving spectrum-sharing processes from a slightly different perspective and, well, a slightly different motivation for why we support this theme. For me, my motivation is getting the spectrum sharing right and enhancing spectrum efficiency.

If in one sentence could each one of you go through and see what *your* motivation is? Before we hop over to our next set of polls and questions? Mike, do you want to go first?

Michael Cotton: Yeah, I think I think my motivation is really to develop spectrum-management science, which involves a lot of the topics that we have today. And, like John talked about, there's a big difference in the radio science that was developed 20, 30, 40, 50 years ago and the science that we can do today. And I think that that really motivates me to move from this, you know, this type of science where you need to base it on assumptions and move it towards more data-driven science and things like that. Thank you.

Rebecca Dorch: Howard?

Howard McDonald: Yeah, Rebecca, I'll keep it real quick. My motivation was to drive change in DoD spectrum operations both in United States and Possessions (US&P) test and training scenarios. And you know, a few dB in a globally deployed force that perhaps has to dance with bad guys. That's what motivates me.

Rebecca Dorch: John?

John Chapin: Sure. Well, I want a future in which the radio spectrum fosters continued innovation and sustains vibrant special-purpose uses like scientific research and national defense training. That future requires spectrum sharing that is more sophisticated and more efficient than what we can do today. And necessarily, it's going to also be more complex than what we do today. Due to the complexity, it's going to be harder and harder to get the models and rules correct the first time and if we're only using ex-ante [based on forecasts rather than actual results] analysis. So in my view, the only way to overcome the unexpected interference and excessive separation of unused spectrum that will arise from ex-ante rulemaking is to use real-world assessment to continually and iteratively improve the regulations.

Rebecca Dorch: Thank you, John. So we'd like to get the audience reactions to our theme here.

[new slide]

So our first poll, if you look over on your side, you'll also see that there's a poll up over there. Wait a minute. That is a different question. Oh, that's right. We changed those questions. All right. Can you go on to the next question and hopefully we'll get that one up there.

[new slide]

Okay. So we've got two different poll questions that were put into the poll. We'd like folks to respond now with your first reactions. And then we've got another question about how risky you think this process is and how beneficial you think this process is.

And then we also have an open-ended question that we're going to put up, and we'd like text responses on that. As we as we go through this, we will also then put these questions up in the pulse up at the very end of the of the process or excuse me, at the end of our four days also.

So we I know we are running out of time, but I want to at least get to try and see if we can't get a couple of questions from the audience. Here we have one. And remember, folks in the audience, you can up-vote questions also and they will rise to the top of our list here to help us prioritize what we're doing.

[slide with a two-part question]

So, John, the first question here, can you see that? Do you want to just take it?

John Chapin: Sure. It's from Dr. Ronda Covington, from Transportation, I believe she asks with data sharing in mind. Dr. Chapin mentioned protection of privacy. How are we to protect CUI (confidential, unclassified information) and classified data while also being transparent. That's not one that's answerable in this panel, but it's a wonderful discussion question about the future of spectrum sharing.

I think the feedback question I'd ask is, Is it specific to the iterative or continuous regulatory improvement process that we're talking about; or is it a feature of any spectrum sharing, whether you're using the linear model or the continuous model? And we might discuss whether it's orthogonal to the topic of ISART. Very interesting question. Thank you.

Rebecca Dorch: And I'll quickly answer the second one about if there's any legislative changes that would be believed to be required. I'm going to punt on that one because we have a legislative representative from Senator Hickenlooper's staff that's going to be on one of our panels tomorrow. So I'd encourage us to pose that over to him. There are other questions on here, and we are running out of time. And I am really sorry that we have not gotten to the point where we can answer all these questions. Let's see… Let me try one more, because I think Mr. Cooper said that he might not take his full a lot of time. So Matthew Clark asks a question for Howard. Howard, can you see that question and take it really quickly?

Howard McDonald: I cannot see the question.

Rebecca Dorch: Okay. Matthew Clark says for Howard: On the interference margin apportionment topic, can you say more about what has been considered and what factors are creating dilemmas? For example, an equal interference margin allocation among interfering transmitters is a reasonable approximation to an allocation that maximizes the potential throughput of those emitters. What needs factors aren't being accounted for with that kind of an approach?

Oh, that is a hard question. Can you answer in 30 seconds?

Howard McDonald: So various folks have opined as to what the best approach is, one being Who paid the most at auction? Another being Whoever submits the first coordination request, they should receive most of the margin. Simplistic: If there are 10 licenses that a coordination zone intersects with, well each license gets 10 percent of the total IPC. This really is a complex topic that requires more than 30 seconds to answer.

[End of videorecording]

3.4 Keynote: Spectrum Management Principles

Charles Cooper, NTIA Associate Administrator, Office of Spectrum Management

Charles Cooper: Good afternoon, and hello to everyone online, wherever you happen to be today. I would first like to thank ITS for offering me the chance to update all of you on some of the major policy and governmental activities we are working on here in the Office of Spectrum Management (OSM).

As sister offices within the National Telecommunications and Information Administration (NTIA), the Institute for Telecommunication Sciences (ITS) and OSM work closely with each other on a range of technical and policy related efforts. ISART gives us a chance to touch base on our work together and to gain new perspectives from each other and from all of our participants. So I look forward to hearing the discussions over the next few days, and I welcome the chance to add my views on behalf of OSM. And it's certainly good to be back at ISART.

One of the most important developments that I want to touch on is the Spectrum Coordination Initiative. The good news is that we are addressing the institutional factors between the NTIA and FCC that can lead to policymaking impasses. And by we, I mean both NTIA and FCC, a fact that we should not overlook. Chairman Rosenworcel deserves a lot of credit for this. And Assistant Secretary Davidson, who you heard just a few minutes ago, has responded to that leadership with his own active pursuit of improved coordination and collaboration.

So what does this actually entail? Well, in plain language it calls for more frequent meetings between the FCC Chairwoman Rosenworcel and NTIA Administrator Davidson; reaffirmation of the agencies' roles and responsibilities in spectrum management; commitment to evidence-based decision-making and scientific integrity; and increased technical collaboration.

One of the first items on the list to implement those objectives is to review and update the Memorandum of Understanding, or MOU, that exists between the FCC and NTIA. This MOU provides the framework and impetus for interagency coordination. So the two agencies have formed a joint task force that is actively reviewing and considering changes to the MOU. In keeping with the spirit of the Spectrum Coordination Initiative, the Task Force is exploring ways to increase bilateral meetings, adhere to evidence-based decision-making, and engage in mutually shared long-range planning. The task force is making progress, and as Assistant Secretary Davidson informed Congress last week, he and Chairwoman Rosenworcel have agreed to complete the work on the draft MOU by the end of July.

Another important activity that dovetails with the initiative is the cooperation around developing a new National Spectrum Strategy. Stakeholders are working to put together a forward-looking, collaborative, whole-of-government strategy that will address the needs of federal and non-federal users. A key element in our discussions is how to increase collaboration among the regulators and federal agencies. We are also interested in promoting evidence- and science-based decision-making in leveraging technological advances to create opportunities in the spectrum space. These discussions and the entire strategy development remain at an early stage. As we develop and then implement a strategy, we will consult with a wide variety of stakeholders, both inside and outside of government.

One of the cornerstones of NTIA's approach to spectrum management is to support and incentivize the development of new technologies, particularly in the form of spectrum sharing. Already we are seeing promising signs that innovation in the CBRS-band—that's 3550-3700 MHz—that can pave the way for additional advances in dynamic spectrum access. The Citizens Band Radio Service (CBRS) is taking shape in this band and incorporates a multi-tiered access licensing system that relies upon dynamic protection areas to empower commercial wireless systems while protecting important and critical incumbent military radar operations.

So, this system, which took several years to develop and implement, transformed what has been a doubtful sharing scenario into a viable national CBRS footprint that is utilizing core mid-band spectrum. The CBRS auction, completed a couple of years ago, raised approximately $4.6 billion. CBRS has been extremely helpful in showing how much spectrum management tools can be integrated with new licensing approaches to enable new services, both licensed and unlicensed alike, while preserving existing government missions.

We're not stopping there, of course. The incumbent informing capability, or what we call the IIC, is a concept that is exploring mechanisms for dynamically sharing spectrum among incumbents and new users in the time domain, in a way not possible with current spectrum management practices and capabilities. IIC can move spectrum management out of the traditional man-in-the-middle approach and into the software domain. It could also establish a common dynamic sharing framework that would be scalable across multiple bands.

I want to emphasize the relevance of IIC and other technological innovations in the policy development efforts like the new spectrum strategy and even the Spectrum Coordination Initiative.

First, we have been discussing for many years the increasing difficulties we are experiencing in providing for ever-growing spectrum requirements in both the non-federal and federal jurisdictions. It is becoming harder and harder to manage our way out of these difficult choices in the traditional sense. In the absence of innovative techniques and technologies, we risk continuing to relitigate the same institutional rivalries and spectrum access disputes.

Second, the innovations themselves can spur new equipment development, the growth of new services and ecosystems, and continued U.S. high-tech leadership. So, as we look forward, we embrace technology as an enabler of spectrum access, and we reject zero-sum gamesmanship that posits every spectrum band as a win or lose proposition.

Of course, we have to proceed with a solid foundation of spectrum management principles. That is what we are now discussing within NTIA and our agency partners in the Policy and Planning Steering Group, or as we call it, the PPSG. It's a common set of federal spectrum management principles. So at this point we're positing three basic ones.

Number one, making spectrum-related decisions to optimize based upon evidence, driven by the best available science, and accurate, precise data to include using agreed-upon risk-based criteria when assessing electromagnetic compatibility; [number two, to] develop new systems that can use this spectrum efficiently, with a focus on coexistence and flexibility; and [number three] manage spectrum use to optimize access across users based upon national priorities.

So let me elaborate what we mean by these principles. So with regard to the first one, using agreed-upon risk-based criteria for assessing our decisions: Spectrum-related decisions, especially those addressing equities and protection between users, must be evidence-based and guided by the best available science and data. Collaboration among stakeholders to share scientific and technological information, data, and evidence is central to the development of sound spectrum policies and to the delivery of equitable access for all users across a wide range of heterogeneous uses and use cases.

On the second principle, new spectrum-dependent systems must use spectrum efficiently and be capable of supporting new spectrum-optimizing technologies. Federal agencies should be selecting designs that meet operational requirements while maintaining compatibility in their spectrum environments. This means making greater investments in systems that enhance spectrum efficiency whenever possible. This implies that when we procure or modify systems, we recognize that spectrum has value and we look for systems that maximize spectrum access for other users, including other federal users.

And the last one is, we recognize that spectrum is a national resource. At its root, spectrum belongs to the public, and government agencies need to access that spectrum so they can provide the services that the public needs and demands. Balanced with that, we know that access to spectrum provides consumers, businesses, and local governments the ability to harness the power of the Internet, transforming the way we live, work, learn, and communicate.

To reap the benefits of this nation as a whole, we must have a forward-looking strategic policy based upon national priorities to make spectrum use more efficient and to make more spectrum available for the future needs of Americans, *all* of them.

So, in conclusion, weaving together where this policy stands, we are in a moment in government where we must work together to coordinate not only our strategic goals, but also the institutional practices and processes that must dovetail.

Evidence-based decision-making must lead the way in our planning and discussions.

Our ace card is our ability to support innovation, to leverage new technologies, techniques, and tools into better approaches to resolve spectrum access constraints and dilemmas.

In that spirit, we welcome you back to ISART and we look forward to a free-spirited and a constructive week of discussions and debate in the finest tradition of the spectrum community.

Thank you. And now back to Eric.

3.5 Panel: Industry Lessons Learned from Spectrum Sharing

Learning from lessons of the past should enhance spectrum-sharing implementation and process reform efforts. This panel provides industry perspectives on lessons learned from their experiences implementing spectrum sharing, and on the linear processes utilized for establishing spectrum-sharing rules over the past decade, identifies universal lessons learned, and addresses ways to build upon knowledge gained to enhance, expedite, and improve the processes. Goal: industry recommendations on process improvement and spectrum-sharing parameters. What are the key concerns that industry typically has relative to the regulatory process and implementation of spectrum sharing? Have these concerns been different depending on the sharing scenario (fed[eral]-industry, industry-industry). How has the anticipated/expected technology to be deployed by industry impacted the regulatory process and when is that information typically shared with the regulators?

Moderator: Bryan Tramont, Managing Partner, Wilkinson Barker Knauer

William Davenport, Senior Director, Government Affairs, Cisco

Mark Gibson, Director, Business Development & Regulatory Policy, CommScope

Scott Palo, Associate Director SpectrumX, Charles Victor Schelke Endowed Professor, University of Colorado Boulder

Shalini Periyalwar, Expert Director, Communications Engineering at Innovation, Science and Economic Development (ISED), Canada

Neeti Tandon, Distinguished Member of Technical Staff & Technical Fellow, AT&T

Neeti Tandon: Thank you, Rebecca. Thank you, Chris. So as an introduction, I am Neeti Tandon, and I am part of the technology and the lab organization within AT&T. So my discussion and my presentation point will be more of an engineering perspective to spectrum sharing and so on. So let me start with a rough brief timeline. And it is important to review it.

So historically, if you go back to the ’90s, most of the licensing scheme that was done was based on exclusive long-term licensing with renewal expectancy. And those were the days when the technology was at 1G or 2G station. Think about the technology during the Time Division Multiple Access (TDMA) and Global System for Mobile Communications (GSM) stage. And this industry has evolved a long way since the ’90s and the last 25 or 30 years. And now we’re talking about technology enhancements in 5G. And in fact, now the discussions in the standards body are on features and enhancements for 6G. And this requires a lot of R&D and investments and even equipment upgrades and network upgrades. And that has been possible because of the historically exclusive licensing and spectrum certainty that comes along with it. And most recently the new batch of spectrum that includes AWS-3 (Advanced Wireless Services in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands) and Citizens Broadband Radio Service (CBRS), which also had been very, very successful in its allocation, they are also based on exclusive use. But with some kind of sharing such as geographical or temporal sharing which takes advantage of the fact that not all services are using the spectrum at the same time.

The key to that spectrum sharing is, of course, technology advancements that I refer to in my later slides, but also it requires a lot of careful planning to maximize the use and maximize the spectral efficiency of these shared systems.

Now, looking forward—because part of this whole discussion is a spectrum sharing and a paradigm that it can be for future looking—this will require more incentives and more creativity on our part. And that could be based on decisions that are data driven. It could be the concept of database management, like the Incumbent Informing Capability (IIC) concept that has been proposed in the past, and a lot of data decisions, especially listening to the last [unintelligible] members that are based on propagation model or technology advancement are based on lot of information that resides within the network. So future allocations could require some kind of sharing scheme which is database-driven, but at the same time, the decision-making is made at the edge of the network, like the active Radio Access Network (RAN) proposal that we have proposed in one of the committees.

So in terms of spectrum sharing, we have seen it all, we play various different roles. We have the role of a new entrant with AWS-3 and America's Mid-Band Initiative Team (AMBIT) sharing and CBRS. We also have a role as an incumbent. And that is on the ongoing proceeding at 6 GHz. But even at 6 GHz, besides the incumbents, which we think has to get the full protection, we also play a very, very important role in being the users of this spectrum in an unlicensed format, which is the users of AMBIT. We are actively engaging in new band spectrum shading, actively engaging the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) and the National Spectrum Consortium (NSC) process, which is for the main band at 3.1 to 3.45 GHz.

Next slide, please.

So now going back to the principle, what I do want to touch on is the fact that if you look at the last 20, 25, 30 years from looking all the way from 1G, 2G and all the way to 5G, this industry has led innovations. These innovations are not based on any kind of a regulating mandate, but they are self-driven because the mobility systems work on controlling self-interference and coming up with features. And those features have been very, very useful. And you know what? Even [including] many of the sharing systems and sharing networks across different kinds of systems.

Examples of these innovations include supplemental downlink, active antenna systems, our transmitters and receivers are very well designed, and they're upgraded every five years with the new G they get upgraded. And to give a few examples of supplemental downlink that has been used in the past. AWS-3 spectrum utilization and using it an efficient manner was possible because the industry figured out the carrier aggregation and supplemental downlink. And while the uplink was being transitioned from these Department of Defense (DoD) systems, industry figured out how to use the downlink portion of the spectrum, which is 80 percent of our traffic, for carrier aggregation and so on. So, these are some examples. In the current C-band [in the case of carriers—3.7 to 3.98 GHz], active antenna systems are being used as a mitigation technique, for instance as radio activators or whether it is coexistence with fixed satellite service (FSS). So, the bottom line is that this industry has set up a gold standard for evolving and investing in upgrades as well as in R&D. And it is not driven by a regulatory mandate or so on.

And as to sharing, we totally believe in information sharing. Our standards are open standards set forth in the International Telecommunication Union (ITU) and 3rd Generation Partnership Project (3GPP) documents. One can get all the information that is needed from modeling systems, like from the network layout in urban, suburban, or rural environments, to what the power levels are, channel formats, and in fact even to the position-level and the quality-level of how you can even model active antenna systems. All those parameters are part of open documentation and can be easily obtained through ITU and 3GPP documents.

Next slide, please. Chris, next slide? Okay. Thank you.

So, going back to the principle, especially from an operator's perspective, what are the key considerations for spectrum sharing? One is a sharing regime, even though it is forward looking, and it is creative and innovative, it should have a technical feasibility to it. And technical feasibility is very, very much band-specific, and very much use-case specific, so a one-size-fits-all kind of technical rules. I don't think would work. But a technical feasibility that is band-based and as well as what the systems are sharing is the path to the future.

The Federal Communications Commission (FCC) rulemaking has to be clear on what the coordination mechanisms are, what the technical rules are, what the spectrum rights are, and also the FCC rulemaking must be clear during the rulemaking or through some other kind of a notices. Also, the enforcement process should have the clarity there.

Of course, there is a lot of feasibility analysis that needs to be done. And the feasibility analysis has to be with the right set of parameters, both for adjacent channel as well as for both channels using an International Mobile Telecommunications (IMT) [generic term used by the ITU to designate broadband mobile systems] system, both as the transmitter and the receiver, along with the other federal systems or satellite systems and so on. The rules should encourage timely deployment. And also there should be an environment for sharing information.

And these things have been done in the past. If I look at this cluster-agent information that was used for AWS-3, it was very, very helpful in reducing some of these coordination zones, especially for the AMBIT systems. I do want to close my presentation by giving an example of how all these features have been taken into account by the FCC in the rulemaking. I'd really like to applaud the FCC in the C-band rulemaking, especially with respect to coexistence and sharing between 5G and the FSS systems. So based on the state-of-the-art receivers and filters, the FCC did come up with a minimal guard band space. They did define an interference threshold, from power flux-density (PFD) or power spectral density (PSD). And to get back to the point on aggregation, the PFD and PSD was defined on a per-operator basis, which is very much easy to implement, especially in the operators' network.

And using those sets of rules and principles, the operators would invest in the state-of-the-art antennas, state-of-the-art propagation models. Use mitigations, which are part of 5G like muting and nulling, and so on in order to coexist with the FSS. And also the enforcement for this coexistence has also been kind of an old model that has been set up because currently there are just two users. And if there are some issues, both the parties can easily work together either modifying the antenna characteristics or doing power reductions or using some other mitigation techniques.

So a model has already been adopted by the FCC for sharing the spectrum efficiently and in a timely manner, because it does give encouragement and incentives to both the parties to resolve interference issues, has been what the FCC did in the C-band proceeding, especially with respect to the FSS.

So that’s my presentation. And I think I’m out of time now.

Rebecca Dorch: Thank you, Neeti. Let me just hand it over now to Mark Gibson from CommScope. Mark, do you want to give your opening presentation, please? We’re still working on getting Bryan Tramont back in [to moderate].

Mark Gibson: Okay. Well, I hope we get there sooner or later, but that’s great. Thanks, Rebecca, and hope to see you soon, Bryan. Okay.

Next slide, please.

So I’m concentrating my talk on, you’ll see.

Next slide, Chris. Thank you.

So I’m concentrating my talk really on the database-enabled sharing, AWS-3, and then the other parts of that 3 GHz band and pulling out lessons learned from that. And most of those items are the subject of tutorials. I know Howard did one of them. I know Andy Clegg is doing one of them. I did one of them actually on this. And so a lot of the background is there. So I won’t get into a lot of those details. So I’m going to address these things as it relates to the lessons learned on some of the things we can do going forward.

So for example, TV White Space started in 2004 and everybody thought it was going to be the next big thing. In fact, at one point they called it super Wi-Fi. And so the FCC selected 10 database administrators, which is basically as many database administrators as showed up. And that typically is the way the FCC does it. They very rarely downselect in these areas, mostly because the bar is fairly low.

Then, about five years into that, the Middle Class Tax Act was passed, which reallocated the upper portion of the TV band to mobile, which is great, but that took away about 200 MHz, or 210 MHz, to be accurate, of spectrum from TV White Space. It actually did two things. It took away spectrum that could have been used for TV White Space and a lot of the TV stations that were up in that upper portion of the spectrum, which was about 614 MHz, were relocated down into the lower portion of the spectrum, which was up from 54 up to 608 MHz with big chunks out in the middle. So what that did is it basically effectively removed a lot of the TV White Space. And frankly, it really didn't make it super "Wi-Fi" anymore.

What ended up happening was all of the database administrators that had participated kind of left. The last one standing for a while was Google, and then Google left and RED Technologies took over. And RED is actually based out of France. And they're doing this for France and for Europe and also, in part, for Canada. And Microsoft was using it for this project called Airband, which ended up meaning that the band, as opposed to having broad super Wi-Fi capability, was really a niche player in rural and underserved areas. And so today there are fewer than 300 TV White Space deployments out there that are being managed, at least in the United States.

Now, there are several international applications for TV White Space. And in fact, Microsoft did a lot of work in the early mid-2000s to evangelize this in parts of third-world countries—parts of Africa, parts of the Far East. So that indicated that the application was a really again, more of that type of an application. And, I should have mentioned this earlier: From start to finish, from the time that the public notice came out inviting proposals to be database administrators to the time the public notice came out granting full commercial deployment, it took three years, which is a fairly long time. So lessons learned from TV White Space are 1) the band was plagued by regulatory uncertainty, and I think we heard this in the last panel that that's an issue. 2) The FCC database testing delayed the rollout because the FCC did the testing themselves, and we'll probably get to that in the rest of the panel. And, 3) they really never addressed enforcement. And you'll see that as a theme running through this as well.

So next slide, please.

So the next one was or is CBRS. And CBRS is still active, certainly. And, full disclosure, our company was both a TV White Space database administrator, and a Spectrum Access System (SAS) administrator and will be an administrator hopefully for Automated Frequency Coordination (AFC), which is 6 GHz, which I want to talk about that in a moment.

So this band was established in 2015. Again, 10 administrators were established or selected from five, I'm sorry, six in the first round and four in the second round, which they called Wave 1 and Wave 2. We've been in commercial operation now for about two and a half years, with over 230,000 devices deployed. So this is much more successful than TV White Space was. We've had to share in this band. TV White Space was not federal sharing. It was actually commercial sharing primarily with TV stations or TV receivers. Here we're sharing mostly with commercial interests as well as the DoD. And this is really the first dynamic sharing that has occurred with the DoD. And so we had to build these sensors.

So the FCC, as I said, picked 10 database administrators, four sensor organizations, the companies called Environmental Sensing Capability, which are the radar detectors that sense the shipboard radar operations off the coast. And so that's in play right now. Now, the National Telecommunications and Information Administration (NTIA) is considering, I think you saw this, the Incumbent Informing Capability (IIC) which we as industry strongly support for lots of reasons. Among which are that the Environmental Sensing Capability (ESC) sensors are a really a lousy way to share spectrum because the main issue with the ESC sensors is they need to be protected from interference from the band. And the band is full of devices. As I said, there are over 230,000, and the device deployment needs to make sure that it doesn't interfere with the ESC sensors, which brings up what we call whisper zones, which is another way to call it basically protection zones around the sites. And that's sort of an anathema to sharing when you put something in the band that has to be protected. So we think the IIC is a really good idea to alleviate that.

The other issue, two other issues, were that it took four years from the bookending public notices to certify databases. There was a government shutdown in the middle of that, which was one of the reasons. And a lot of this we were figuring out as we went along. And, due to the leadership of people like Rebecca and Institute for Telecommunication Sciences (ITS), we were able to get it done. And we're comfortable that the databases are really doing what they need to do. However, speaking of regulatory uncertainty. On either side of the CBRS band are two high-powered bands. On the band below is the 3.45 GHz band that can operate at up to 30 some thousand watts per 10 channels.

And on the upper portion is the 3.7 GHz band, which can actually operate to twice that for 20 MHz channels. And so the maximum power in the CBRS band is 47 dBm or 50 watts. So it kind of makes an inconsistency across those band segments, which complicates sharing and also makes the business prospects slightly different.

So again, lessons learned here: There were issues again with regulatory uncertainty because when we all entered CBRS we weren't aware in advance of the 3.45 GHz or 3.7 GHz bands being considered. The certification process was long and complex. This was brand new. Our TV white piece was out there. I think it was complicated by the DoD just wanting to be careful about this, which we all understood. And there was also this issue with the SASs role in enforcement, which we've actually had to try to address in specific situations. And I'm sure we'll talk to that as we move forward. And then finally, this notion of the IIC, the Incumbent Informing Capability, allowing incumbents to tell database systems when they're operating as opposed to having to sense.

We think that's very forward thinking and will hopefully replace ESC sensors.

Next slide.

So in the next slide, we get into the AFC, which is actually ongoing. AFCs have not been identified or certified yet except there have been 13 AFC administrators that have showed up. Don't know if we're doing a lessons learned on this yet because it's brand new, although there are some lessons learned. And in this situation we're sharing, this is full commercial sharing with primarily microwave systems. And in fact, I think it's exclusively microwave systems.

There are other segmentations of the band which facilitate sharing, but the AFC addresses sharing in certain portions of the band—Unlicensed National Information Infrastructure (U-NII) radio band 5 and 7—for those that are familiar with those U-NII designations. So that's what the AFC is for. Wireless Innovation Forum (WInnForum) and the Wi-Fi Alliance have been working in parallel on the specifications and recommendations. This is congruent work that is a separate but is expected to come together shortly to provide the FCC information on how these things should be tested.

One of the things that came out of this effort was the FCC directed a multi-stakeholder group, which is a sort of nondescript group of people that have interests here to study enforcement, primarily and other things. But it's actually centered on enforcement. And this has caused a lot of consternation in the context of what enforcement looks like, because you have people that represent interests from incumbents, you have people that have interest from the new unlicensed entrants, and people that have interest for AFCs and others. And so we're hashing through what enforcement looks like. And actually there's a document that's being developed very shortly that should be made available to the commission [FCC]. And so lessons learned here so far is that the Multi-Stakeholder Group (MSG) interaction has been difficult. Just in terms of What is the mandate, what are the timelines, and how do we do what we do?

Another Lesson Learned is we really need clarity on the certification and testing, and we also need to better address enforcement. Again, that's my thread. The

next slide please,

deals with AWS and I broke these into the AWS-1 (Advanced Wireless Services in the 1710-1755 and 2110-2155 MHz Bands) and AWS-3 (Advanced Wireless Services in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands) because, essentially, it's the same spectrum. It was just made available a different time, mostly because of the DoD systems in there, the commercial systems are almost exclusively microwave, and this is a service called BRS, which is the broadcast radio service in the 2.1 GHz band. A little bit of spectrum there. However, and I think you've seen this, I think Howard [Howard McDonald – Day 1, June 13, Panel: Exploring the Theme of ISART 2022] alluded to this and others. In AWS-1 the theme that runs through these in terms of lessons learned is how industry engages with federal users in the context of What are you doing, how do we share? And so in AWS-1, it was left up to the new entrants as well as anybody that had an interest to engage with the DoD directly, one on one.

And by the time that engagement happened, one of the first things that was going on was to better understand how to share. And in the context of those discussions, this notion of a portal was developed to facilitate data exchange, and it was never a part of the rules. It came in after the rules were established.

And this portal actually allowed for the sharing of data between commercial systems and DoD to effectuate coordination, which is what the Commission required. The other thing too is AWS-1 band saw the creation of the Commercial Spectrum Enhancement Act, which is part of my lessons learned. And so, in AWS-3 one of the lessons learned from AWS-1 going into AWS-3 is we need a better way to engage the federal-commercial users.

And so CSMAC was used, and I think you saw this in a previous discussion. CSMAC is the Commerce Spectrum Management Advisory Committee. We were able to make that, and Bryan [Bryan Tramont, moderator of this panel] and I were in the middle of that. We had some scars from that effort, but it was very good in enabling the sharing of discussions between commercial users and the DoD. It was primarily DoD but there were other agencies as well, but it was primarily DoD. And I won't get into all the details around it. We can talk about it if we need to, but it was really a good facility to facilitate discussion. The problem was though, by the time we got into those discussions, a lot of the initial analysis had already been done regarding the feasibility of sharing.

So what we did in that content in those discussions was revisit some of the baseline parameters and then redid sharing and in so doing, and Neeti mentioned this, we developed this trusted agent concept which allowed us to get access to Controlled Unclassified Information (CUI). And so by virtue of signing these Non-Disclosure Agreements (NDAs), we were able to get into a little bit more detail of what these systems look like to better address how sharing should be done.

So lessons learned across both of these was: Was there lack of clarity on funding of the early relocation? The portal was an afterthought, but we didn't know that then. There was no additional funding for NTIA for [these] efforts. You'll see this as sort of a thread through these last two. And we really need to confirm operating parameters early.

Next slide.

And now this slide deals with 3.1 [3.1 to 3.45 GHz band] and 3.45 [3.45 to 3.55 GHz band]. And again, we're all familiar with these bands. In 3.45, which preceded 3.1, I won't get into the sharing situation, but I think Neeti talked about this. AMBIT, which was the America's Mid-Band Initiative Team, was developed sort of in secret, so to speak, to facilitate sharing of information. There was some commercial involvement, or industry involvement, but by the time it was open more broadly to industry, the concept of the Cooperative Planning Areas (CPAs) and Periodic Use Areas (PUAs) was pretty much already established. And that discussion was done under the NDIA, the National Defense Industrial Association. And by the time it got there, we were really wondering, What are we doing, because that concept of CPA and PUA had already been established, although there was some facility to share baseline parameters and information.

And so one of the lessons learned that's really good to see here is the portal that was developed in AWS-1 and AWS-3 is being used now, and in fact we're in that stage where the portal is being developed until September.

And again NTIA helped all of the … manage all the federal interactions with transition planning and cost containment, and the same in 3.1. So as we get into the 3.1, that band right now has not even been allocated. It was part of the broader thing. So it's sort of been somewhat allocated. There are a couple bills that describe that we're supposed to be looking for 200 MHz.

The NDIA and CSMAC sharing is now done under the National Spectrum Consortium (NSC) under a group called Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group, which I don't remember what PATHSS stands for, but it's basically … it's a work group under the National Spectrum Consortium to study. Neeti and I are part of that. And the great thing about that that we were never able to figure out how to do in CSMAC is we have a facility to have the security clearances that are held by the contractor for NSC, which is ATI (Advanced Technology International), that allows commercial and federal discussion and sharing of information under a classified domain where we can really get into a lot of the details on how these systems operate and then can drive better sharing discussions. So we go to the next the last slide. I'll characterize all of the lessons learned sort of in this last slide.

Next slide, please.

So for the lessons learn summary, it appears that each new sharing endeavor sort of has been treated as new. And I think what we need to do is do more like what we're doing here, which is have official lessons learned.

It would have been a great at the end of all of these rulemakings if the FCC had conducted an informal and formal Lessons Learned Notice of Inquiry (NOI). NTIA did this after AWS-1 and that's what led to some of the changes for AWS-3. The engagement that's going on for PATHSS is excellent in terms of the ability to allow for much more close discussion between commercial and federal entities.

I really think this is what we wanted coming out of CSMAC. But what we did in CSMAC was we actually focused discussion on this. And a lot of the recommendations coming out of CSMAC actually were addressed by the NSC. We think, and this is only our company's suggestion [CommScope], that NTIA really needs to be funded to support a lot of these commercial sharing and relocation efforts, because the CSEA [Commercial Spectrum Enhancement Act] does not accommodate NTIA's efforts.

But NTIA's efforts are foundational and critical to this. They do a lot of studying behind the scenes. They create the transition plans, or at least they make them available. They are interacting with federal-commercial inside and they're really pulling this effort out of hide. So if we can fund NTIA to do this, that'd be great.

Longer term spectrum allocation planning is really needed. That sort of speaks to itself. And then also enforcement needs to be studied in the realm of the commercial dynamic spectrum sharing systems. It's kind of really being left as an afterthought. A lot of this being made up as it goes along and we're kind of concerned that it's going to come back to the industry to figure it out.

So we'd like to see more study of that. So with that, I think Bryan is back. I guess he's not. Okay. Back to you, Rebecca.

Bryan Tramont: No, I'm back. You're all good here.

Mark Gibson: Yes, sir.

Bryan Tramont: It's been a rocky journey. I've never had this much trouble. You don't usually push me onto the stage. I usually just go running on. Very glad to be with you all. I apologize for the technical difficulties. Yes, Mr. Davenport, our esteemed director of Government Affairs (GA) at Cisco. And before we go, though, Mark, for the record, the PATHSS stands for Partnering to Advance Trusted and Holistic Spectrum Solutions.

Mark Gibson: Thank you, Bryan.

Bryan Tramont: I don't know why that didn't just fall off your tongue.

Mark Gibson: Yeah. It is a cute acronym, though. PATHSS.

Bryan Tramont: It is. It is, indeed. All right, Mr. Davenport, newly minted at Cisco. After a long career in a variety of spectrum roles, we turn it over to you next. Bill, are you there?

Bill Davenport: I am sorry I had to refresh. You disappeared on me, Bryan.

Bryan Tramont: Seems to be a theme for me today.

Bill Davenport: Well, I guess I'm up.

Bryan Tramont: Yes, you are, indeed. If that's all right.

Bill Davenport: Perfect timing. Well, hi, everybody. Thank you for inviting me to ISART. I really appreciate [inaudible]. [I worked for the FCC] as a long time employee of the commission. And I was Commissioner [Geoffrey] Starks' chief of staff in wireless legal advisors. So I'm in a new role now and I'm very excited about it. I think in the interest of time, I'm going to kind of skim over a couple of the slides that are coming up.

So can we just move forward to the next slide, please? Okay.

Yeah, I think many of you most of you are probably very familiar with Cisco. So the bottom line from this slide really is that Cisco sells to both telecom carriers, wireless carriers that use licensed spectrum, as well as to enterprises that use unlicensed spectrum. And so we have an interest in spectrum sharing from sort of both sort of camps in terms of both licensed and unlicensed.

Next slide, please.

I think others have talked about the 6 GHz band. The thing that I want to flag is the automated frequency coordination system (AFC).

So why don't we go to the next slide.

So as I mentioned, others have talked about AFC. It's a huge new endeavor the commission has adopted spectrum-sharing database-driven coordination systems in the past, and others have talked about that. But AFC is taking it to a whole new level. Never before has a sharing mechanism incorporated an existing user base, an existing ecosystem of devices that are already in the market. We're talking about millions, billions of users, frankly, and ultimately hundreds of millions of devices that could be part of this this AFC system.

Not every 6 GHz device needs an AFC, the commission approved devices that are going to use lower power that don't have to connect to an AFC to be able to operate. But the power levels are relatively low. And so I think for a lot of use cases, particularly in the enterprise standpoint, they're going to need to use standard power.

And so that means connecting to an AFC, which means that the AFC is critically important to, really, the full growth of the 6 GHz band. Right now, the commission is reviewing AFC applications and really trying to develop what process should apply for testing of the AFC and also apply to the devices that connect to them.

Others have mentioned enforcement and that is something that is definitely top of mind with respect to the AFC, because historically and speaking as someone who worked in enforcement for a long time, the FCC has approached interference issues from the standpoint of identify[ing] the source of the interference, using direction, finding or whatever it might be, and then going out to the source and saying, turn it off or fix it or do whatever you need to do to fix or stop the interference problem.

With the AFC, the commission hopefully will be pursuing enforcement from more of the AFC standpoint where there's an interference issue and the commission goes to the AFC and says, hey, there's a device that's operating in a frequency that's causing interference, move them to another frequency. And so that will alleviate the interference issue rather than sending out field agents to basically engage in whack-a-mole, trying to find the source of the interference.

That's particularly important for the reason I stated earlier, which is that we're talking about millions, billions possibly in devices that are going to be involved and operating on this band. So it's really important that the FCC gets this right. And we appreciate all the hard work that the FCC Office of Engineering and Technology (OET) has spent in developing the system and working with us on testing.

But it's also really important that they move in an expeditious manner because we have a lot of people that are waiting for this technology, a lot of investment that is sort of on hold and at some point and, as I think Mark talked about with TV White Space, the more delay there is, the more complicated the rules are, the more concessions are made to operating a device in a particular band, the harder it is actually for the band to be successful, for the sharing regime to be successful. So we're optimistic that we will be hearing soon on this front. But I just want to emphasize the importance of acting relatively quickly and allowing this process to move forward.

Next slide, please.

So these are my initial thoughts. You know, this is based off of, you know, I've been at Cisco for a hot six weeks, maybe. So most of this these thoughts are really mine drawn from my time at the FCC. And just as an observer and sometimes participant in policymaking. So the first thing spectrum policy has to be future proof. I don't think that this is necessarily a huge insight, but it's something that I've been very focused on in my new position because I'm seeing how the 6 GHz decision really was anticipating technology that doesn't exist yet.

You know that that we're not only talking about 160 MHz channels in the 6 GHz band via the current and the most recent generation of Wi-Fi. But ultimately, we're talking about 320 MHz channels in Wi-Fi 7, which is only a couple of years away. So that kind of policymaking is really important, and it's something that the commission needs to emulate in future decisions.

Second thing, regulatory leadership is critical. Once again, not exactly novel insight, but I think the important thing is that the commission and other policymakers really need to be capable of making the hard decisions. You know, there's always winners and losers in every spectrum proceeding. And there's lots of...

Neeti Tandon: I'm so sorry. [unintentional exclamation that's not even visible in the video]

Bill Davenport: Sorry. Oh, okay. I was just going to say that it's very complicated, technical and policy arguments. Financial interests are at stake. Ultimately, agencies can't kick the can down the road forever. And it's really important that they stand up and actually make the hard decisions and deal with the fallout.

Next one.

Don't sit on your spectrum rights. You know, after I wrote this, I actually thought about it a little more and I would probably retitle that more as you know, that incentives are changing. One of the things that's happened in the last couple of years with the FCC is that the commission is starting to look at spectrum policy from different standpoints. Like, for example, the receiver performance notice of inquiry is reexamining the role of receivers and really thinking about whether or not receiver, design, and performance needs to be more rigorous and more protective of spectrum in the future, as opposed to simply complying with our current interference environment and avoiding interference to others.

Relatedly, the commission is also looking at in some proceedings at how they can encourage spectrum efficiency from that [inaudible]. This is sort of changing over time. And I think that these proceedings are really kind of like a bellwether for a new attitude with respect to spectrum policy.

And then lastly, FCC and NTIA resources. Both of these agencies always need more money, always need more time and more people. But one of the things, and Mark alluded to this earlier as well, I think that with these hard spectrum policy decisions, really having an objective party that can actually do the technical analysis for the agencies and cut through the advocacy, because you can have great engineers on both sides because they always have a pool who can do technical analysis on behalf of the federal government and the agencies can then use that analysis for their decision-making.

Hopefully, I didn't get cut off. I saw my screen kind of flat flicker for a little while, but that's basically it. And I'm looking forward to the conversation.

Bryan Tramont: Thank you, Bill. And although it's government's loss, the American people's loss, we're excited to have you on the commercial side and as a member of the Cisco team.

I want introduce Scott next, who is a satellite entrepreneur, as well as a professor of aerospace engineering at CU and he joined our panel this morning, so he gets extra gold stars of appreciation from the entire ISART community.

So with that, Scott, we expect you go for your 10 or 20 minutes, whatever you were able to plan during the course of the afternoon.

Scott Palo: All right. Well, thanks, Bryan. And, you know, as a faculty member, we operate on 50-minute time blocks. So you just have to bear with me. I sent a few slides over. They may not have come through. If not, I can just start going extemporaneously. But I did want to say, you know, as way of introduction, this is a panel on industry lessons learned from spectrum sharing.

As Bryan indicated, I'm not in industry. I'm a faculty member. And I will also say I don't know that I have a lot of lessons learned to provide from spectrum sharing, but I think what I do bring is a perspective of the satellite, the emerging satellite industry, and in fact, the emerging new space commercial SmallSat industry, which I've been involved with.

And, you know, for those that aren't aware, there's been a significant evolution in the commercialization of space over the past decade or 15 years. And really that's been driven by the reduction in launch costs. It had been previously, that there was a significant barrier to entry to getting onto orbit that really limited that market to folks with deep pockets and that has evolved significantly.

In fact, the most recent BryceTech satellite report indicated that in 2021, 94 percent of all spacecraft launched were small satellites. And in fact, in the past a decade, there were approximately 6,000 small satellites launched. And in the last year, there were approximately 2,000 small satellites launched. So you can see that the rate of launch of small satellites is increasing significantly. The emerging entrepreneurial business cases have been growing dramatically. Obviously, folks are familiar with StarLink and broadband, but there are a lot of other small satellite companies doing space-based imaging, synthetic aperture radar, IoT (Internet of Things) devices, and, you know, the list goes on.

And so I think one of the things I just wanted to bring to the discussion here is maybe less of a retrospective and more of forward looking perspective that there is a significant evolution in small satellites with regards to space and all of those systems are using spectrum. I think there is a, you know, an opportunity here as we're leaning forward to think about how we can share, how we can evolve. And obviously, with new space mostly being startups and new entrants, there is an interest to have the ability to have access to build their business models and to share. So I just want to sort of raise that as an opportunity.

And then I also wanted to make a quick plug. I'm also excited to be the associate director of SpectrumX, the new National Science Foundation (NSF) Spectrum Innovation Initiative. We have a team of 27 universities and are working on workforce development and also working on interesting spectrum problems, such as the spectrum-sharing problems we're discussing here. And so we're happy to engage more on those discussions in the future. So thank you, Bryan.

Bryan Tramont: Oh, there you go. Thank you, Scott. Really appreciate you jumping in today. And last but not least, we have Shalini Periyalwar, Expert Director, Communications Engineering at Innovation, Science and Economic Development (ISED), Canada. And I recently had the opportunity to visit the ISED facility in Ottawa. It's an amazing place doing wonderful work.

I commend it to all of you and we're curious about some of the lessons learned across the border. So with that I will turn it over to you, Shalini.

Shalini Periyalwar: Hi, everyone. Good afternoon. I am, as Bryan points out, from across the border. I will present some of our experiences in spectrum sharing in Canada.

Next slide, please.

So we are the Spectrum and Telecommunications Sector (STS) within the Ministry of Innovation, Science and Economic Development (ISED). So we are a department that is directly reporting to the ministry, and we are not an arm's-length agency.

We are responsible for both federal and non-federal use of spectrum. So although we call ourselves ISED, we are actually a department within ISED. And we also collaborate with other government entities which is the Department of Defense, public safety, transport, environment, health, etc. And within our mandate, we have everything from Applied Research, which is done at the Communications Research Center, to International Negotiations.

We have people at the ITU and other international bodies. We set policy, including auction and licensing. We do the legislation regulation and implementation, including certification, compliance, enforcement, etc.

Next slide, please.

So in terms of spectrum sharing lessons learned, I'll start off with a lot of the aspects of spectrum sharing. Lessons Learned for us is coming from TV White Space because, unlike the U.S., we didn't have CBRS, we didn't have any of the other technologies in place. So our lessons learned is primarily from CBRS, from a spectrum-sharing perspective with a database-driven spectrum sharing model.

So what we've learned is that we need to ensure that the ecosystem is already available and in play in large markets. We are a small market, and it's difficult for us to attract new technologies into our domain because our market is very small. So we believe we have to be fast followers and we need to keep our standards harmonized as close as possible to bigger markets.

Our experience in TV White Space is similar to that of the U.S.. We introduced TV White Space in 2011 in Canada. We had a database administrator designated in 2017, but it only became operational in 2021 actually. And we have about 50 TV White Space devices operational primarily for rural and indigenous remote communities.

With respect to spectrum-sharing technology being portable across bands, we don't believe so. It's not a one-size-fits-all solution. There are various tools that we need to have in the regulatory toolbox. One of them is database-driven spectrum sharing. It's working well in TV White Space for now, and we are definitely looking at implementing it in the 6 GHz band very soon.

In addition, we are looking at technologies such as automated spectrum management, data-centric decision-making, and so on, that we can leverage as items in a toolbox for implementing spectrum sharing in other bands. Specifically, I would say whether we implement spectrum sharing with license-exempt users or with licensed users, I think the approaches we take will be different for these two cases.

With respect to data itself, we believe that high quality data is crucial for efficient spectrum management. So improving data quality, where the data is adequate, accurate, and up to date is an ongoing task for us. And we want to make sure we can do everything from our perspective as a regulator to minimize interference issues. However, the onus falls also on the incumbents who are in the band.

If they don't give us good data, we cannot do much. So we are trying to persuade the incumbents in the band, particularly in the 6 GHz band, to give us good data, to keep the data up to date so that we can work with reliable data. And we also believe that leveraging complementary datasets that inform spectrum policy and standards setting is very helpful to us.

Next slide, please.

And for example, here we have looked at a complementary dataset because we are hearing a demand for a possible mix of business cases. It could be rural operators, it could be forestry, agricultural oil, oil and gas, mines, etc. And in the rural environment, yes, of course a band may be used by commercial-mobile or maybe licensed commercial-mobile, for example.

However, they are not as ubiquitously deployed as they would be in urban areas. So for us we wanted to get a better perspective as to who are the potential rural users, particularly for private network services, and where are they? Are they overlapping each other, or could they be sharing spectrum on a spatial basis? So that's one of the reasons why these datasets have been informative in helping us set spectrum policy.

Next slide, please.

And similarly, with respect to urban use cases, we can see that we have a variety of potential users. And although 5G is expected to be covering these areas really, really well, there's a high demand for services and we're hearing a demand for a mix of traditional mobile service as well as other stakeholders who have an interest for private wireless network services. So getting this type of mapping with overlays of new datasets and other complementary datasets is very useful for informing our policy.

Next slide, please.

So, what's next? In terms of database-driven spectrum sharing? We are currently in consultation for the standards for 6 GHz standard power use with AFC, and we have allocated 950 MHz of the band between 5075 to 6825 MHz for use with standard-power devices in the AFC. We are also looking at better use of data-centric approaches to spectrum sharing, whether it is using these approaches for getting clean data or whether to make decisions on policies and standards.

So we are also looking at policies and mechanisms for 5G small and private network operations where we are examining, and we've now consulted on unused license commercial mobile spectrum being shared for such types of services. We are in the decision phase right now. And we're also potentially consulting for a new licensing model for 3900 to 3980 MHz in the mid-band as well as in the millimeter-wave bands.

Thank you very much for your time. And that's it for my end.

Bryan Tramont: Thank you, Shalini. Thank you very much. And we're going to go to some questions now and I beg our panelists to go a little bit over, since we are always having technical difficulties. I want to bring everyone in on the lessons learned that your fellow panelists raised earlier. But before I do that, Shalini could I bring you back for one moment.

You mentioned the Canadian model is often to be a fast follower. And I suspect you look around the world on things that you want to follow and maybe things you don't. Have you seen anything that maybe hasn't been discussed elsewhere in the world that might provide some interesting lessons learned in modeling for purposes of spectrum sharing going forward?

Shalini Periyalwar: Well, I think the U.S. has been very, very much a leader in spectrum sharing. But we cannot always mimic the U.S. model simply because we may have other incumbents in the band. For example, we didn't take on CBRS because we had no radar use, right? But we are following what's happening in Japan and in Korea and at Ofcom [Office of Communications in the United Kingdom], for example, and BNetzA [Federal Network Agency (German: Bundesnetzagentur or BNetzA) is the German regulatory office for telecommunications and other services] with the German regulator and so on, just to see how they are approaching spectrum sharing.

For instance, we did hear, and we did contemplate whether to allow database administrators to come in externally. And we were even speculating as to whether based on our TV White Space experience, are they going to come in? Should we set up our own database administrator role in case they don't show up, right? Based on the challenges that we faced with TV White Space. So that's something that we did contemplate and looked at Japan. Japan is looking at doing its own database administration. South Korea had contemplated it. So we did look at other regimes.

Bryan Tramont: Very good. Thank you for that. So anybody want to jump in? This is our jump ball, if you will, on other panelists' lessons learned, anything you might disagree with or want to drive home? We are trying to reach some common ground here over the course of the next few days on lessons learned for policymakers and other interested parties to use going forward. Any reactions from folks?

Mark Gibson: I'd like to make a comment on what Bill said, because I think it's very germane and it went by pretty quickly. He said that it's the first database-enabled sharing for which there's an installed base, and I think that's important. I don't know that you can control what you go into, but you know the Wi-Fi Alliance has estimated that probably by 2025 or 2026 there'll be over a billion Wi-Fi 7 devices. Now not all of those will be on the AFC.

But what that indicates is that it could be that the AFC is the first situation where we have a sharing endeavor that we're trying to make lightweight, and it will be established pretty much in the band, and it won't be messed with much. So I thought that was a very good point that's worth mentioning because for TV White Space there was no installed base and same for CBRS, it was called the Innovation Band and there was no installed base. So that's a very good point I just wanted to highlight.

Bryan Tramont: Thanks, Mark. Neeti, do you want to comment on this?

Neeti Tandon: Yeah. Thank you, Bryan. So in terms of lessons learned, traced back to AWS-3 and CBRS and being more forward-looking, I think these sharing methodologies, which are more analytic-based where you have a central database with some exclusion zones based on arcane models without any relevant data, those were okay, and it worked in the past. But moving forward, you have to go into more efficient spectrum-sharing techniques, and you should use technology as an advantage. Use 5G or 6G features of the technology as an advantage to enable sharing and enable much more efficient use of the spectrum.

Bryan Tramont: Excellent. Anyone else want to jump in on that topic? If not, I'm going to bring Bill back because now that you're out of government, you seem to talk a lot about the need for speed. So having worked at the [unintelligible] level of the FCC and having been in the enforcement bureau, what do you see as the major things that slow down decision-making? Are there any things that are structural that could be changed going forward, that would be a Lesson Learned here?

Bill Davenport: I think I can hearken back to the point I made earlier about the need for objective analysis. I think that one of the things that I saw over and over again was that parties come with very sophisticated, very detailed technical analysis of their position on spectrum policy. You know, 6 GHz is a great example. You know, when you have the unlicensed interests, cable on one side, and NAB (National Association of Broadcasters) and the carriers on the other side, and they present very detailed analysis of all the technical considerations associated with one outcome versus another.

And that can take a lot of time to try to work through from the commission standpoint. You know that the people in FCC OET are excellent, and they work very hard. But, you know, it would be very helpful, I think, in terms of decision-making to have something that they can refer to that is from another agency as opposed to a party that has an interest.

So one of the things that I mentioned, and I think Mark alluded to this as well, is just having NTIA receiving the resources. And specifically from my standpoint, the Boulder lab actually I think would be a great target for, a great candidate for, increasing resources. They can provide that objective analysis that I think would be really helpful in making policy decisions more rapidly.

Bryan Tramont: I suspect Charles Cooper wouldn't be all that disappointed with that. So if makes it to the end I think we might be winning this panel. Anyone else on that particular topic on the need for speed and ways in which we could expedite policy-making? Mark, do you want to comment on this one?

Mark Gibson: What Bill said actually is interesting because there's a bill that's been put forth. There was a hearing on it a couple of weeks ago that I had the chance to testify at, which is asking for more money to fund ITS support projects like this for spectrum sharing, and also for NTIA to support IIC development. So, I mean, I couldn't agree more with funding to these agencies because these agencies have excellent people, they have excellent capabilities, to do this in [unintelligible] of everything else. If we can, you know, make these sort of a center of excellence, to use a trite expression, I think we'd all feel much more comfortable that we have someplace to go to where we can get some sort of ground truth.

Bryan Tramont: Great. Thank you for that, Mark. I want to pull in Scott. I don't want him to miss out on all the fun here. To talk a little bit about what the unique challenges are in our complex satellite-sharing environment that are distinct from a lot of the kinds of sharing experiences that we've talked about here. Scott, do you want to talk about some of those unique challenges? And I'll probably bring Mr. Davenport in on this one because he has some satellite-sharing experience as well. So, Scott?

Scott Palo: Yeah, I think it's interesting maybe to think about how do satellites fit into the sharing architectures, right? For the most part, when we talk about sharing architectures, we focus on terrestrial sharing architectures. And so, when you look at satellites you have the geostationary satellites that are fixed over a region. But there's been a rapid evolution of non-geostationary satellites. So spacecraft that are very transitory come over a region. They persist for a few minutes, maybe 10 minutes. And that's a very dynamic environment.

And when you think about the spacecraft, there's also different operational use cases. There is the command-and-control, which you need to have robust for health and safety of spacecraft. And then, there may be data backhaul that you've got some more flexibility with. And then I think the other thing that maybe doesn't get the attention that it maybe should is the scientific use cases of spacecraft. Spacecraft are used significantly for gathering data for weather forecasting.

You know, passive radiometry and those systems are sensitive to terrestrial emissions. So then the thought is about how do you manage maybe a noncommercial use case, which is often harder to engage in the conversation, with some of these challenges? So I guess I'm more asking questions to the experts here than providing answers. But it's some of the challenge that I see emerging.

Bill Davenport: Yeah, certainly Scott has raised a lot of interesting questions. I think I would say that I alluded in my remarks to the issue of sharing among satellite operators as something that the FCC is taking a fresh look at.

Historically, the commission has approached the use of spectrum in certain bands through the mechanism known as a processing round, where somebody applies to operate a satellite constellation in a given band and the commission says, "All right, well, now that you have an application from someone, is there anybody else that's interested in operating in this band?" And not long after the commission starts to grant approvals, there's sort of a race to launch your satellites into the band first, because ultimately the person, the entity, that's there first gets priority in many respects. That can provide perverse incentives as far as spectral efficiency, because if you're the first one up there, then you get protection. So there's sort of an incentive to launch a satellite that maybe is not as spectrally efficient, so you can have more space, you know. It's similar to the issue, as I mentioned earlier, about receiver performance, where less resilient receivers historically have received more protection than maybe some of us would be comfortable with.

So I really am heartened by the commission's actions on both of those fronts to kind of take a fresh look at, you know, maybe we need to have incentives at the front end to encourage receivers, encourage transmitting parties to start their operations from a more spectrum efficiency standpoint so that for future spectrum uses there's room for basically more folks over time.

Mark Gibson: And let me add one more thing, Bryan, to what Scott said. You were mentioning the passive systems. WInnForum (Wireless Innovation Forum) has an initiative that actually is chaired by Kevin Gifford. If you're not aware of it, you might talk to Kevin, or I could talk to you about it after the fact. It's called passive and active spectrum sharing, where we are studying how we can effectively share with those systems.

And this started back in November, I believe. We've had some fascinating presentations from folks that use passive satellite and passive sensing to study fascinating things, you know, cosmos and all that stuff. And so Kevin is driving this along with Andy Clegg and several others are participating in. The next step, then, is to transition into How can we effectively protect them because they are across all the spectrum.

So I would recommend if you're not aware of it, talk to Kevin.

Bryan Tramont: Oh, great. Thank you, Mark. I do think as we've just touched on, the satellite-to-satellite sharing regimes are more complex than they often get appreciation for and have not had as much academic work done around them. And I think that's super interesting. And the incidents of satellite terrestrial sharing are littered with some fairly unsuccessful models, unfortunately to date, including 12.2 to 12.7 GHz. And so there's some interesting work to be done there as well.

I do want to invite our audience with a few minutes left, if you have questions, please do put them in the chat. We would welcome those.

One thing that I think everyone's touched on in various ways, shapes, and forms is to quality of data and the importance of having access to quality data early. So I want to throw open to the group, I guess, first: Are those problems different for commercial users versus for government users? And B, are there paths to solving the data problem that we can think about as a Lesson Learned? It looks like Neeti is going to jump in on this one. Thank you.

Neeti Tandon: So, as I mentioned in my presentation, the quality as well as the resolution and as well as the level of detail for IMT systems, which is one of the partners in the sharing regime, is the public information. Of course, in the sharing agreement, you have to get information for all the systems, including aviation and radars and satellites and so on. So I would invite the regulators, and that's where the role of the regulators come in, to identify what are the important parameters in the sharing environment and try to disclose that either in a public setting or to anonymous data or to some kind of a trusted agent. And this current AFC [?] process and the PATHSS process that has been set up is also a good way to identify that kind of a shared data.

And another important point in sharing data is not just for the extent of a feasibility study, but it does give confidence to different parties, and it helps in reaching a consensus. And an example of that could be, I mean I can give several examples, getting access to the shared data either in the EMBRSS [?] (Emerging Mid-Band Radar Spectrum Sharing) process or in the C-band for radio converters or even in the 6 GHz CableLabs study that was used as a basis of technical sharing rules. But the study was redacted. The regulators have to find some form or shape on How do you anonymize the data and restore the confidentiality but just make the information available as needed.

Bryan Tramont: But if I can go back to this point, it felt like you're ready. Two threads there. One, certainly is the confidentiality and anonymizing the data. Another thread that has been brought up, I think is the incentive of the various parties involved to share it or not share it. I can see how there could be certain structures available for the confidentiality.

How do you think we tackle the incentive problem for parties to share the data early so that these regimes can be developed in the first instance, particularly in cases where they might not be enthusiastic about having other users in the band?

Neeti Tandon: So again, these incentives have to be self-driven. I go back to my example on the C band with FSS. It was a timely transition and even working while the transition is happening, working on a co-channel and an adjacent-channel basis. The incentives are there in the rule set so that the two parties can get together and create incentives for sharing the data as well as coming up with mitigation techniques. So I think it should be an arrangement and incentives should be done in the rulemaking. That is an arrangement between the two parties that drive towards the sharing of the data.

Mark Gibson: Well, I can add to that based on our experience, Bryan. You know, the data, we sort of live and die in data. And so what we've come up with is ways to get through that. So for example, in a previous panel, McDonald [Day 1, June 13 - Panel: Exploring the Theme of ISART 2022] referred to what we did in AWS-1, or maybe it was AWS-3, which is this thing called the randomized real network laydown [McDonald said that came out of CSMAC]. And Neeti referred to the trusted agent. So what that was, it was a cellular laydown that was provided by one of the mobile licensees, one of the major ones, to us actually, CommScope or CommSearch at the time, and I believe it was their broadband Personal Communications Service (PCS) laydown [in the 1850 to 1990 MHz spectrum range] because it was close to the AWS frequencies to randomize the locations because that's probably the main problem that people have.

And that data was used extensively for the analysis that I referred to in the deck. So I think a couple of things. One is being able to come up with creative solutions around some of the concerns that Neeti talked about. And then, the trusted agent. If there's some entity, and, again, I looked to NTIA and ITS, we actually provided them information as well in CBRS. So, coming up with creative solutions to make data available. If it's adequate or good, excellent doesn't need to be the enemy of the adequate. And then find a creative solution to just make the data available.

Neeti Tandon: And to that point, I would like to add is between randomized real data that we have shared, as well as the layouts that are available in your 3GPP documents. Because they do come up with network settings and distances and assumptions on antenna heights and so on. That should be enough to drive these studies and to get efficiencies in spectrum sharing.

One reason to share the state-of-the-art data is that the data from the network perspective is always changing. So how often do you want the data? And it may create overhead, which may not be worth the hassle that it creates. Right? I mean, the network is evolving all the time.

And if you have a sufficient information on the network layout either from randomized real data or from some 3GPP network deployment practices and so on, that may be enough to do feasibility studies. And data at a much finer resolution may create more overhead than it may be worth.

Bryan Tramont: Thank you. So I want to pull those back on the enforcement part because a few of you brought that up, obviously any spectrum management regime doesn't work unless there's effective enforcement. Some of these more complex sharing regimes we've talked about, I think particularly require enforcement. But have there been enforcement issues to, or is this something we're seeing around the corner instead? And then, do we have the tools ready if things go sideways, when we have multiple regimes across the world, across the landscape, are we ready?

Mark Gibson: Well, I know Bill has a point on this. I keep talking, but we have some experience in CBRS. There were some enforcement actions. And Bill is I'm sure aware of this that early on in the process, after the SASs had been identified, the FCC sat down with its enforcement bureau and said, okay, now we got to deal with enforcement. What are we going to do?

How are we going to use these SASs not to facilitate enforcement, but in the whole enforcement picture? And what we arrived at was a process for data exchange. And we've used that process. A couple of the field offices have contacted SASs to get access to data in an agreed-to format to do some interference sourcing on potential interference sources.

Now I think, as it turned out, that it wasn't CBRS. It was other things. But that's a good example of how the process works. And it really worked. It took us SAS administrators sitting down with the Enforcement Bureau with the appropriate regulatory oversight and coming up with a process that did not put SAS s in the position of being bounty hunters for their own customers, which is, I think, a big problem we've got to be aware of. And that's going to happen I think in the AFC in a big way. So that was one way that it's worked.

Bill Davenport: Yeah, I think the FCC has the tools that it needs to be able to do enforcement in the spectrum-sharing context. You know, as Mark alluded to with respect to the CBRS, we also have the examples from the 5 GHz band where there was some sharing of unlicensed operation with weather radar operated by the FAA.

And there were a number of enforcement cases that involved those operations where field agents were able to use direction-finding equipment to identify the sources of interference and to ultimately resolve the issues. But as I mentioned in my remarks, my focus really is on the AFC as a problem solver rather than leading to any kind of enforcement action against parties.

So it's really more about if there's an interference issue, working with the AFC to move the offending device to another band where it's not going to cause interference. I think that is probably going to be more useful because we are talking about so many more devices. It is just not, I think, realistic to expect that there's going to be enforcement actions brought against parties causing interference. It's really going to be more about resolving the interference. And then preventing it from happening in the future.

Neeti Tandon: So Bryan, if I can add a comment here, especially with respect to 6 GHz and listening to what William has to say and yet I'm speaking as an incumbent. As an incumbent on

6 GHz with fixed microwave lengths. So this problem of enforcement will get impounded in 6 GHz because as William mentioned, there are millions and millions of devices.

So as an incumbent, the incumbents have to feel confident in the enforcement process. So there has to be a clarity on identification and reporting. Spectrum rights for the incumbents have to be protected. Whether it is with respect to 6 GHz or whether it is with respect to 3.45 GHz flag or 4 GHz, incumbents have spectrum rights that have to be protected either through AFC or through some kind of enforcement mechanism.

And another important point is, the reason dialogue happens in industry is that there is a tendency to build these fortresses, the services. And one of the reasons could be because there is no confidence on the enforcement process. So once you have some confidence, then the parties would be much less restrictive and would be more open to an agile scheme.

And that can be updated as things move along. So beyond the confidence building due to having the right set of enforcements, we've come a long, long way for spectrum sharing.

Bryan Tramont: Shalini, can I bring you in for one second just to share a little bit about how enforcement works in Canada. So folks have a little bit of international perspective.

Shalini Periyalwar: Sounds good, thank you. Yes. As I'm listening to this, I agree that there are concerns from the incumbent side and there's also concerns from the AFC administrator site. So in Canada, the responsibility for dealing with the enforcement or dealing with the interference issue does lie with ISED first and foremost. So, if you receive a complaint, it's usually our regional offices.

And as Bill pointed out, they do the field testing to see where the interference is coming from. But there's potentially two reasons why there is interference. One is, the licensee has not uploaded the correct data and we are relying on incorrect data to provide the protection, the exclusion zones. And if that's the case, the onus is on the licensee to make sure that they've given us up-to-date data.

So we can't always blame the interferer or the dynamic spectrum access (DSA) administrator as a source of interference. So we are looking at the incumbents, the administrators implementing the correct exclusion zones, as well as the device that is the interferer. So we are open to being open minded and saying we will take responsibility to make sure we're having these conversations between the licensee, the incumbent licensee, the DSA administrator, and the potential interferer and try to figure out what's going on and then practice enforcement accordingly.

Bryan Tramont: Right. Thank you for that. All right. We're going to have one final question and then we will wrap up, considering I've got at least one email saying wrap it up already. No, [laughter]. One of the concerns that folks have talked about is the importance of regulatory certainty. I've also heard threads of it's important to adapt the rules as technology changes and what have you, which could arguably undercut certainty.

Is there a way to balance those two principles? Is there a need for a standardized period of review of rules? Every two years, four years? I'm making up a number. Or is it better to rely, I think, on the current system, which looks to the marketplace to come to the regulator to update rules or change things. How do people feel like we should be balancing those two things. No takers on the philosophical question.

Okay, here we go. Thank you.

Mark Gibson: Yeah, I mean, given that I was the one that raised it. I think the examples that I raised were ones where, you mentioned it, the marketplace came back and said we have a better way. And so I think the issue is more looking at the implications. I don't think anybody is going to say to people, look what the C-band generated in terms of revenue. No one's going to tell the people that spent $82 billion on spectrum, "No, we want to do CBRS." That person would probably be run out of town on a rail, so to speak. But I think once a decision is made, there needs to probably be a better way to... And the rulemaking process is not really the way to do it.

It has to happen at a higher level, almost at a policy level. So I don't know. Those are the problems. And Bill may know from his time at the commission a little bit better, but those are the issues we have. Now I think with AWS and 6 GHz we got a lot of clarity. But I will say as an example, and here's some regulatory uncertainty, the industry is struggling over very niggling parameters on how to do propagation.

However, the FCC put propagation models in the rules. So it's kind of like being halfway there. And maybe they want industry to come up with that or not, I don't know. But those are an example. If you're going to go in part of the way, go in all the way. So there's a middle ground here, but I'm not quite sure where to find it.

Bill Davenport: I just—Go ahead, Neeti.

Neeti Tandon: So, Mark, I kind of tend to differ with you a little bit on the piece concerning the propagation parameters. There is a difference in setting up a regulatory framework and technical rules versus standardization. 3GPP or IEEE (Institute of Electrical and Electronic Engineers) provide the standardization and the FCC cannot be in the role of setting up standardization. So they have to come up with a framework and they have to provide incentives to all the parties in the industry to come up with an agreement. And even if an agreement cannot be reached, FCC always has the flexibility to step in. And it doesn't have to be a rule change. It could be through indirect incentives, or it could be through a [indiscernible]. There are a lot of levers that the FCC has without doing any rule changes.

And rule changes should be the last resort because that's what gives the certainty into the process. And that certainty gets into the use cases and the standardization into equipment manufacturing, and so on. So yes, the regulations should be evolving. They cannot be static and 50 years back, but there are a lot of other levers the FCC can pull rather than just doing a rule change.

Bryan Tramont: Bill, are we good [indiscernible]. All right, Bill, we're going to let you take a pass then. All right.

Bill Davenport: I'm sorry, Bryan. You broke up for a second. I'll be really fast. My view ties to something that has come up already, which is really the idea of lessons learned reports is something, or a look back after a certain amount of time. I think that's a great idea. It's something that actually my former boss, Commissioner Starks, proposed in other proceedings. I think it would be incredibly helpful.

And the second thing is, like I said earlier, when you set the rules, you need to account for all the different spectrum uses in the band and in adjacent bands and really set expectations about the level of protection that everyone's going to be entitled to, as well as encourage spectral efficiency from the get-go when you're authorizing use of a band.

Bryan Tramont: Great. We let Bill have the final word. Thank you all, to all of our great panelist. Scott, thank you so much for jumping in today. We really appreciate it. I apologize for the technical problems that made us run long, but I look forward to everyone joining us tomorrow. I will turn it over to Eric. Thanks, everybody. A great job!

Mark Gibson: Thanks.

4. Day 2: Tuesday, June 14, 2022

4.1 Opening Remarks

Michael Cotton, ISART Technical Chair

Michael Cotton: Good morning. Good morning ISART community. Welcome back for Day 2 of the conference. A couple of things that I want to talk about in terms of logistics. First, there's a Q&A tab on your right. We'd like to see more questions from the audience. Just so you know how that works. We curate those questions, and we post those questions to the panel, and so the moderator can ask the panel those questions. And also the panel can reply via text, so please ask questions.

Second, if you're a speaker, please, if you haven't shared a connectivity check, please go ahead and join backstage early so that we can do a little connectivity check on our end. It's just some of the simple logistics we need to work out so that we can have things move more flawlessly. Avoid VPN, if you can as a speaker. And if you're a government employee, especially, and you have some challenges in your network, please go ahead and consider working from and connecting from home. I know it's a little late today, but maybe for future reference. So Charles Cooper's presentation will be re-recorded. Apologies for all the gaps yesterday in the in the video, but we're going to rerecord that and post that for everybody's viewing.

So with ISART this year, we're tackling the theme of continuous regulatory improvement. As a lot of a number of the speakers indicated, the FCC and the NTIA, we're always scrambling on kind of the problems of the day. So one of the goals that we tried to bring for ISART is for us to think forward, right? And really one of the purposes of the conference white paper was to think 10, 20 years down the road on some of these concepts. So please, you know, have that be a theme as you're viewing some of the panel discussions. And I also challenge the panels to think that way, too.

We also promote diversity. You know, we aim to promote diversity for, you know, equality and inclusion, and also in thought. And so, you know, the way we achieve that diversity is to introduce across disciplines. So Eric discussed yesterday a little bit how in 2011 we brought in the radar community into ISART and we had this kind of cross-dialogue between disciplines, between the radar engineering people and the communications people.

And the thing that that I learned about that was that, you know, there is a common language, and, in that case, it was mathematics. And so if you just kind of look and try to talk across those disciplines, there's a lot of value there. So this year, you know, the focus that we would like to add is the cross-discipline of economics.

And so today we're going to have a keynote in that field and have an Economics of Spectrum Sharing panel. And then also later on in today's agenda we will have a Data Sharing and Transparency panel.

4.2 Keynote: History of Spectrum Auctions

Evan Kwerel, Senior Economic Advisor, Office of Economics and Analytics, FCC, and 2021 Paul A. Volcker Career Achievement recipient

Michael Cotton: So we're going to kick off the economics segment with a keynote by Dr. Evan Kwerel. Evan is Senior Economics Advisor in the Office of Economics and Analytics at the FCC. He was a recipient for the Paul A. Volcker Career Service Award for pioneering the use of competitive spectrum auctions to allocate the public airwaves for sound, data, and video transmissions, helping fuel the digital revolution while adding more than $200 billion to government coffers.

So I love this story. It really demonstrates the leadership, vision, and tenacity, you know, really required to overcome skeptics and a lot of obstacles that, you know, we as government civilians really face. So this story is really inspiring. So if we could bring Evan online. How are you doing, Evan?

Evan Kwerel: I'm doing fine.

Michael Cotton: So, welcome to the main stage. So, I gave a quick introduction. I really appreciate you being here with us today, Evan. I'm very proud and honored to have you here. And you can take it away and provide your keynote. I will be providing some questions to you in the end. Okay?

Evan Kwerel: Okay.

Michael Cotton: Thanks, Evan.

Evan Kwerel: Okay. Thank you, Michael, for the introduction. I'm honored to speak to you today. And I want to thank Mike Cotton and Rebecca Dorch for inviting me. Mike and Rebecca asked me to speak about lessons for making meaningful policy change, based on my experience as a champion of innovation at the FCC. I want to start my talk with a lesson about the importance of implementation.

Lesson 1: Implementation. It's not enough to have a good idea; you also need to find a way to implement it. This question is one of the reasons I left academia for government. In government, you have far greater leverage to implement the good policy idea. Now I'm going to provide a personal history of an important innovation in spectrum policy–the introduction of spectrum auctions–pointing out additional lessons as I go along. I originally had 10 lessons, but now, due to inflation, you'll have to suffer through 11.

The idea of auctioning spectrum licenses was first proposed in 1951 by a law student, Leo Herzel, in an article in the University of Chicago Law Review. He proposed auctioning TV licenses to resolve the debate over color television standards. The idea got far more prominence when the Nobel Prize–winning economist Ronald Coase expanded on it in his 1959 paper "The Federal Communications Commission," published in the *Journal of Law and Economics*. That paper proposed a comprehensive use of markets to manage spectrum rights, of which auctions were just one piece. Coase's broad vision has guided much of my work at the FCC.

This brings me to Lesson 2: Good Ideas. You don't need to have an original idea to make a difference. But you do have to recognize a good idea and be able to adapt it. In choosing ideas you should weigh both the importance of the idea and the likelihood of implementation. The idea of spectrum auctions didn't originate with me. Nevertheless, I made a difference by contributing to the adoption of spectrum auctions and the use of innovative auction design.

What makes a good policy idea? You should consider both the importance of the idea and the likelihood of implementation. If you care about making a meaningful difference, you should choose ideas with high expected values of pursuing. That is, try to maximize the increase in social value from implementing your idea times the increase in probability of implementation from your working on it.

Now I turn to a brief history of spectrum license refinement. To understand why auctions are a good idea, one needs to know the alternatives. So I will now discuss three methods that were used to assign commercial spectrum licenses before auction.

From 1912–1927 (under the Radio Act of 1912) a first-come first-served method called "priority-in-use" was used. With the passage of the Radio Act of 1927, the Federal Radio Commission (1927–34) used "comparative hearings" to award licenses when there was more than one applicant for a license.

Under this method, which the British colorfully call "beauty contests," the FCC established criteria for choosing the best party to hold a license. Applications were assigned points based on how well they met the criteria. Hearings and court challenges could take years and were costly for both participants and government.

It was often difficult to distinguish among applicants, and winners were frequently chosen based on trivial differences. Some people have also asserted that it was a highly political process used by politicians to extract favors, such as favorable television coverage from parties seeking licenses. But based on talking to people who administered it, I don't think it was. In 1982, Congress granted the FCC lottery authority to select among qualified applicants.

Lotteries were not used until 1984 after cellular licenses in the thirty most valuable markets had already been awarded. Lotteries turned out not to be a panacea for several reasons. First, lotteries caused socially wasteful expenditures by applicants seeking to obtain valuable licenses for free. The FCC received more than 400,000 lottery applications for the least valuable cellular licenses. Hazlett & Michaels (1993) estimated that between $500 million and $1 billion was dissipated in such "rent-seeking."

Second, lotteries did not award licenses to the parties who valued them the most. Resale re-assigned licenses to parties who valued them more highly but assignments were still not as efficient as in a well-designed auction. Third, lotteries created windfalls, often for parties with no interest in providing cellular services. A frequently cited example was a group of dentists who won a cellular license for Cape Cod and sold it as soon as possible.

Finally, lotteries raised no revenues.

Shortly after the FCC started using lotteries, I told the Deputy Chief of my office that I wanted to write a working paper on spectrum auctions. He told me not to waste my time because auctions will never happen. I ignored his advice and pitched my proposal to the Chief of the office, Peter Pitsch, who enthusiastically supported it. The working paper, "Using Auctions to Select FCC Licensees," coauthored with Lex Felker, was released in 1985. After that, Peter convinced Chairman Fowler to take up the cause. Fowler proposed that the FCC seek legislation to authorize spectrum auctions, and he was able to get a congressional hearing in 1986.

It wasn't until 1993 that Congress granted auction authority to the FCC. The legislation required that the FCC use auctions to award licenses when there were competing applications. Auctions cannot be used for license renewal, or for broadcasting, or for noncommercial licenses. Congress required that the FCC begin the first auction within one year of the signing of the legislation. An incredibly short time to implement the new government program.

So what were the factors leading to the passage of auction authority? I think the most important factor leading to auction legislation was the development of cellular technology, which greatly increased the demand for spectrum and the value of spectrum licenses.

The increased value of spectrum made auctions, a significant potential source of new revenue. And new revenue was especially important to the White House and Congress at the time.

In 1993, the new Clinton administration was under tremendous pressure to find new sources of revenue because the 1990 PAYGO, or pay as you go, act required new expenditures to be financed by new revenues.

A high demand for cellular licenses also made more visible the defects of lotteries.

It pains me to admit that the arguments that economists made about allocative efficiency and dealing with inefficient rent seeking were probably compelling for few, if any, members of Congress. The most compelling argument was that auctions would raise new revenues. And Congress wanted the money.

The main source of opposition to auction legislation was stakeholders, like broadcasters who didn't want to pay for using spectrum. Other licensees also saw auctions as a painful cost to them. But broadcasters had the most political power at that time. Broadcasters feared that auctions, even if not permitted for them, could lead to acceptance of the idea of paying for the use of spectrum by other means, such as high license fees.

What lessons can be learned from this?

Lesson 3: Persistence. If you believe in your vision, be both persistent and patient. It took nine years from the release from my 1985 auction working paper co-authored with Lex Felker to the first FCC auction in 1994. It took 15 years to the conclusion of a broadcast incentive auction from the release of the 2002 paper on two-sided auctions that I co-authored with John Williams and 25 years for the release of our 1992 working paper on voluntary reallocation of spectrum from TV broadcasting to mobile use.

Lesson 4: Patrons. To achieve significant policy changes you need a patron. A patron has the trust of key decision makers and confidence in you and your ideas. Peter Pitsch and Don Gips were my early patrons at the FCC. Chairman Fowler had confidence in Peter Pitsch, and Chairman Hundt confidence in Don Gips. Later when was I was trying to sell the idea of the Broadcast Incentive Auction, Paul DeSa, then the Chief of OSP, was my patron with the ear of Chairman Genachowski.

Without a patron, there is little chance for someone like me without significant formal authority to drive major policy changes. I never had the authority at the FCC to require anyone to do anything. The only authority I've ever had is moral authority.

What do you need to acquire a patron? I can think of three things. 1) You need good ideas, 2) ability to sell them, and 3) access to the patron.

I've already discussed Ideas in Lesson 2, but the other two points each warrant a lesson.

Lesson 5: Selling. A good idea is of little value if you can't sell it to your patron or directly to a key decision maker. And this requires good communication skills and an appreciation for the value of the time of your audience.

Lesson 6: Access. Without good access to your patron or key decision makers, you probably won't get far no matter how good your ideas and your ability to sell them. Good physical location facilitates good access. In selling and implementing the concept of the Broadcast Incentive Auction it was helpful that my office was just a few steps away from the offices of Paul DeSa, Blair Levin, who was the head of the Broadband Task Force, and, later, Gary Epstein, who was the head of Broadcast Incentive Auction Task Force. There is another lesson closely related to the lesson on selling your ideas.

Lesson 7: Timing. You need to opportunistically seize the right moment to sell your proposal. After proposing a two-sided auction in my 2002 working paper, I tried to sell the concept as a solution to specific problems. I got close twice, including one time getting the support of Chairman Powell, but in the end to efforts always failed because of a lack of clear legal authority.

When the Broadband Task Force was created in 2009, I saw another opportunity. I devised a way to use a two-sided auction to reallocate spectrum from TV broadcasting to mobile use. I sold my patron, Paul DeSa, on my proposal and he sold Chairman Genachowski. The 2010 National Broadband Plan included my proposal and sought legislation, which was enacted in 2012.

Now let me talk about my role in implementing the first FCC auction. When Congress gave the FCC auction authority in 1993, I was far from an expert in auctions, but I knew more about spectrum auctions than anyone else at the FCC. So I was tasked with developing a proposal for the design of the FCC's first auction. This is another illustration of Lessons 2 and 3—getting ahead of the curve and identifying good policy ideas and persistence in following that vision. In our 1985 auction working paper, Lex Felker and I said that ideally spectrum licenses should be auctioned simultaneously because the interdependence of license values. That is, the value of a group of licenses is often worth more than the sum of the value of the individual licenses in the group, and bidders also want to be able to switch to other licenses when the price of the license gets bid up too high.

But in 1993, when I wrote the auction design section of the auction notice of proposed rulemaking, I didn't know how to design a simple simultaneous auction. So I proposed a sequential auction. It never occurred to me that it was feasible to auction licenses simultaneously. At the time, it seemed that doing so would require a combinatorial auction in which the winning bids were determined using a complex integer programming algorithm.

But then Preston McAfee, consulting for AirTouch, and Paul Milgrom and Robert Wilson, consulting for PacTel, proposed similar novel simultaneous auction designs. The format went a long way towards achieving the benefits of simultaneity without the complexity of a combinatorial auction. The mechanics of their proposal were relatively simple because the auctions were a series of rounds in which individual licenses were up for bid at the same time.

Both proposals were brilliant, but I thought that Milgrom and Wilson's proposal was the best. Only their design had the elegant feature of a simultaneous closing rule. The Milgrom-Wilson Plan still needed some important details filled in, such as developing a mechanism to ensure that the auction would end in a timely manner. I worked with Milgrom to develop the activity rule, which provided bidders with an incentive not to hold back until late in the auction.

Then I wondered, given a tight deadline, whether I should recommend something simpler for the first auction and proposed the Milgrom-Wilson design for a subsequent auction. Thinking about the way bureaucracies work, I concluded that no, we should use their design right out of the block because of the precedent. It wasn't just getting the auction right for its own sake; it was getting that first auction right because it was going to set the precedent for every auction after that, for a very long time.

So here are another three lessons. Lesson 8: Flexibility. Be flexible on your means while staying true to your principles and goals. The design proposed by Milgrom and Wilson was clearly better than what I proposed in the Notice of Proposed Rulemaking (NPRM), so I embraced it.

Lesson 9: Collaboration. When you're dealing with a big, complicated problem, such as designing and implementing FCC auctions, you need a tremendous amount of collaboration. Making significant policy changes is a team sport. All my major accomplishments involve collaboration with numerous colleagues, agency leadership, academic and other consultants, and industry stakeholders. The scope of collaboration matters. It is not enough to get the policy right within the confines of your discipline, whether it be engineering, law, or economics.

Successful innovation at the FCC has required extensive collaboration among lawyers, engineers, computer scientists, operations researchers, software developers, project managers, government contracting specialists, and economists. Who you collaborate with also matters. Having a few close collaborators who are creative and share your vision can make all the difference for policy innovation. My major achievements would not have been possible without the close collaboration of FCC electrical engineer Tom Williams and Nobel Prize–winning economist Paul Milgrom.

My last point also spotlights the value of collaboration with brilliant people outside of government. We need more of that if we want more innovation in government. Lesson 10: Precedent. Once a program is implemented, if it is reasonably successful, it is very hard to change. So, try to pick the right basic structure of the initial implementation, and then incrementally improve on it.

Now for my last story and final lesson. To help decide which auction design to implement, Chairman Reed Hundt sent Don Gips to ask staff two questions. 1) First, he [Gips] asked me, "What is the best auction design?" I said, "I think Milgrom and Wilson's simultaneous multiple-round auction design is absolutely the best," and explained why. 2) Then he [Gips] asked Karen Wrege, whom the FCC had hired to help implement the auction, "Can we implement it?" And Karen said she was convinced that we could. Once Chairman Hundt committed to the Milgrom-Wilson design, he devoted the necessary resources to mitigate the risks and maximize the likelihood of success. Innovating in government requires that agency leadership is willing to take risks. Implementing a novel auction design with complex features is not only hard to do, it is also very risky.

When I first proposed, we used a brilliant but never before used auction design. The head of my office said, "I don't want it to be a beta test site." Fortunately, Reed Hundt was willing to take a risk. This leads me to my last lesson.

Lesson 11: Risk Taking. Innovation in government is too rare, in part because it requires taking risks. All involved, especially agency leadership must be willing to take more risks to try a new idea. The FCC's decisions in 1993 to move forward with an original auction design, and again in 2012, with the Broadcast Incentive Auction, were giant risks.

That ends my brief personal history of FCC auctions and some of the lessons I've learned. Thank you for listening.

And now we go to questions, and could someone please put up the summary of my lessons for successful policy innovation?

[Slide with lessons displayed.]

Okay. So now we move to new questions. So the first question is, "Do some bands of spectrum lend themselves to beauty contests? For example, air marshalling radars air need wavelength that work well with identifying plane [?], so that spectrum should be only used for radar use."

I think the issue here has to do with allocation of spectrum and spectrum assignment. Allocation is the use of the spectrum, and the assignment is who gets to use it. And until the Broadcast Incentive Auction, which determined how much spectrum—the split allocation between TV broadcasting and flexible use, including mobile services—until the Broadcast Incentive Auction, spectrum auctions were really used only for assignment and not for the allocation. And I think the question you're asking is, Should we use auctions more generally for allocation, especially in complicated cases?

And the answer is, probably not. I mean, I think you might use it within a restricted range of allocations, such as the Broadcast Incentive Auction, where you had two users—broadcasting and mobile services. And there was an expectation that we've already made a decision that we needed more mobile use, but there was the question of where you draw the line. And so it made sense to use auctions to draw that line. But it wasn't like we're going to use auctions to decide whether we're going to allocate something for radar or for mobile use. So the answer is No.

Next question here, "Will auctions continue to draw billions of dollars of investment?" Okay. Well, I've made it a practice not to speculate on the number of dollars raised in auction, even though I am an economist, you know, my focus generally has not been on how much money an auction will raise.

But let me just say this, I mean, in order to raise billions of dollars in auctions, you have to be auctioning a significant amount of spectrum. And I'll give the Pai administration credit for emptying the auction the spectrum cover. They did an enormous job of getting a lot of spectrum out there. There aren't that many auctions. There isn't that much spectrum that's in the cupboard. There's not much low-hanging fruit. And to mix a metaphor, there's not much low-hanging fruit in that cupboard. So I don't know that we're going to see a lot of dollars coming in the near future. But you didn't hear me say that because as I said, I don't think about how much money is coming in.

Well, these are hard questions.

Here's one but it doesn't finish, and it looks like an interesting question. "How is the auction of shared spectrum affected the," and I don't see anything more of it to get any votes. So let me at least try to answer the question. Licensed spectrum rights holders have a financial incentive to use their holdings efficiently. Unlicensed spectrum users have the option of inducing the FCC to give them more spectrum.

How have these disparate incentives played in technology development over the last 20 years? It's really hard to say. Just on the first point. It's not just . . . the fact that that the licenses have been auctioned doesn't in itself provide incentive to use holdings efficiently. It's really related to the fact that the spectrum is exclusively allocated for exclusive use. So if we had, you know, beauty contests or lotteries assigning the spectrum, if it assigned it to the same winner, they would have the same incentive to use the spectrum efficiently, because neither the benefits nor the costs accrue to other people. The problem with unlicensed spectrum is, you know, something with the tragedy of the commons that people don't take into account, the fact that their additional use reduces the amount of spectrum available to others.

And how is it played in technology development? Well, I don't really know, to be honest, but one issue is, you know, I think that when you don't have to pay for it, there's a certain amount of rent-seeking to get unlicensed spectrum. So there can be a substantial incentive to lobby to expand the band instead of figuring out ways to use it more efficiently. But, you know, since it's hard to do, I don't know how that all balances out. So let me just say that I think we need both. I think there's a place for both licensed and unlicensed and I'm out of time. So let me stop you there. Anything else?

Michael Cotton: No. Evan, thank you very much for your time. I know it's, I know it can be a challenge to get all these diverse questions and challenging questions. But I really appreciate the inspiring words and the lessons learned on what it takes to plan and execute policy innovation. I really admire your work, and congratulations on the award.

Evan Kwerel: Well, thank you very much.

4.3 Panel: Economics of Spectrum Sharing

All the best of intentions and plans to develop a flexible framework that allows for an iterative approach to regulatory and licensing rules must also work for industry by creating additional spectrum value and maintaining sufficient certainty for business to operate. This panel discusses both the potential obstacles and opportunities for changing regulatory approaches to develop an iterative regulatory approach that might maximize the value and use of the spectrum over time. Could it be possible to generate more value from spectrum by allowing for some flexibility in sharing rules after licensing? How important is stability to companies' long-term capital expenditure decisions, including decisions to spend billions at spectrum auctions for licenses with expectations of renewal rights to access spectrum long term? Are shared, opportunistic, or unlicensed spectrum access models more consistent with an iterative/continuous regulatory improvement model? Could there be a regulatory approach that would allow for adjusting license rules to enhance the value and use of the spectrum once licenses are assigned? Could there be opportunities for moving towards shorter term investments in the telecommunications sector? Are there competitive assignment approaches that could work for shorter term licenses and investments? How would spectrum valuation—and consequently auction revenues and SRF contributions—be impacted?

Moderator: Giulia McHenry, Chief, Office of Economics and Analytics, Federal Communications Committee

Carolyn A. Kahn, Chief Spectrum Economist, The MITRE Corporation

Sarah Oh Lam, Senior Fellow, Technology Policy Institute

Edgar Rivas, Legislative Assistant, United States Senate, Senator John Hickenlooper (D-CO)

Gregory L. Rosston, Gordon Cain Senior Fellow at the Stanford Institute for Economic Policy Research and Director of the Public Policy program

Martin Weiss, Professor of Telecommunications, University of Pittsburgh

Michael Cotton: We are going to transition over to the Economics and Spectrum Sharing panel. That panel will be moderated by Giulia McHenry. Giulia is the chief of the Office of Economics and Analysis at the Federal Communications Commission (FCC). She also worked at the National Telecommunications and Information Administration (NTIA), and I had the privilege of working with Giulia on a project there. And I can tell you that she brings a ton of great leadership and energy to whatever she does. That energy and leadership was brought here to this panel, and she helped bring this very talented and diverse list of panelists here. I can honestly say that in my planning for the conference, I was stuck on these papers by these authors more than any other papers that I saw across the agenda. So, I am really excited to see this panel. And with that, Giulia, take it over.

Giulia McHenry: Thanks, Mike. Well, thank you for inviting me to plan this panel and to moderate this panel with you. It has been a pleasure to work with you again. And I always miss you from the FCC. So thank you all for joining us for what I think will be a vibrant panel. And I am truly excited to see everybody here.

I have worked in various ways with everybody here and it's really exciting to see them all on a panel. So without further ado, we are still waiting for one person to join us, but we're going to kind of dive in and get started and hopefully they will join. There are six people. Statistically, I think we're going to have some technical difficulties. So if that's it, then we're good. So I'm going to start by introducing everybody and then let everybody kind of present their thoughts and ideas for a few minutes and then we can kick it off with some Q&A.

So first, I want to introduce Martin Weiss. He is professor of telecommunications at the School of Computing and Information at the University of Pittsburgh. So Martin is really our self-described spectrum anarchist on the panel, and that's probably the way to think of him. But he's also a wonderful person to work with. So he is the associate director at the Center for Governance and Markets at Pittsburgh and the lead of the Research Working Group on Economics and Policy at SpectrumX. So Martin is both an anarchist and the leader.

Moving on to probably one of my favorite Ph.D. J.D.'s., Sarah Oh Lam is a senior fellow at the Technology Policy Institute, better known as TPI. Sarah has both her Ph.D. in economics and her J.D. from George Mason. And many of you may know Sarah from the TPI podcast *To Think Minimum*. You will recognize her voice from those. And Sarah has also written extensively and published a number of really interesting papers on telecom law and economics, regulatory analysis, and technology policy. I think, as all of the panelists now know, Sarah is prolific and very quick, so I'm excited to hear her ideas.

We are still waiting for Edgar Rivas, so I will introduce him when he gets here.

But Carolyn Kahn is chief spectrum economist at the MITRE Corporation. Carolyn works across government, industry and nonprofit organizations to help solve the most difficult spectrum problems for a safer world. Her research has included developing whole-of-nations solutions, including in areas of broadband delivery and adoption, 6G spectrum valuation, spectrum, macroeconomic modeling, risk informed sharing and management and Open Radio Access Network (O-RAN). And I can tell you, I worked with Carolyn both on the Commerce Spectrum Management Advisory Committee (CSMAC) together, along with Greg, but also when I was at NTIA, and she is wonderful to work with and she probably one of the only people you know who will have both the industry and the agency perspective. So we're really excited to have her.

Finally, he probably doesn't need any introduction, but Greg Rosston is the Gordon Cain Senior Fellow at the Stanford Institute for Economic Policy Research and the Director of the Public Policy Program. Greg is also a professor of economics and continues to teach a variety of economics and public policy courses. And actually was with us here in D.C. this summer, or this spring—it felt like summer. Greg served as the deputy chief economist at the FCC, where he got to work on both implementing the Telecommunications Act of 1996 and designing and implementing some of the first ever spectrum auctions that we had here in the United States. And in 2011, he was also the senior economist for transactions for the FCC on the proposed AT&T–T-Mobile transaction. That was fun.

So, with that, I think we have everybody introduced. So I'm going to turn it over to folks and I am hoping that others know how to get your slides up because I don't. We're going to start with the anarchist right now, starting with Martin. Kick it off.

Martin Weiss: So, thanks Giulia. Thanks for the wonderful introduction and thank you to my fellow panelists for joining me. It's really an honor to be on the same stage with each of you. So just briefly, this idea of spectrum anarchy is a concept that we developed at the Center for Governance and Markets a couple of years ago.

Next slide, please.

Martin Weiss: So what is it? The idea here is a radically decentralized spectrum use regime, and I think it's leveraging a couple of things. One is the realization that there is a huge heterogeneity in supply-and-demand spatially and temporally in radio spectrum. And the question is how to leverage that. I was struck by John Chapin's comments yesterday, you know, by kind of challenging us to think about radio systems that are now much more easily changed, ex post. Even thinking about what Evan was just talking about in terms of unlicensed spectrum, how it leads to tragedy of the commons. Well, it can, except that we can also govern spectrum differently. There's a huge literature on common pool resource governance that we've been trying to apply to spectrum and spectrum anarchy is essentially the branding term that we use to address a lot of that. And so what we're talking about is spectrum management that's biased towards local governance. And of course, it's a project from our Center.

Next slide, please.

So why do this? Again, there's a huge degree of unevenness in spectrum use and time, space, and frequency. But the way we formulate a policy, again, this is general and I'm sure you can think about counterexamples, but we tend to have a think-local act-global policy posture where we make global decisions about local problems. You know, you think about, for example, the radar altimeter issue. It's an issue that is specific to particular regions around airports, and we should be careful not to make a broad policy prescription based on a very local problem. Other localities may have different priorities and different problems. And so we should allow for the heterogeneity of different kinds of solutions. And spectrum anarchy basically asks us to act locally but think globally. I mean, again, spectrum, depending on the frequency band that you're in, does have global allocative problems. Again, I won't make the point again because I've already made it and this jibes with what John was talking about yesterday. And I think as we think about mid-band and higher-frequency bands, we do have, you know, fairly constrained propagation environments. And so this idea of, of local first is, is much more reasonable.

And finally, I think there is a lot we can learn from what I call unassigned spectrum. Unassigned spectrum is those bands that don't have spatial licenses. So it's amateur radio. It's unlicensed bands. It's some of the radar bands, some of the scientific bands. These all have a way of governing themselves. I think we can learn from that.

Next slide, please.

So why wouldn't you want to do this? Well, when you have a lot of local governance, it's hard to quantify risk. And so it may be a detriment to investments in a particular area. The spectrum anarchy at least initially assumes that, you know, we're all cooperative users, and we all know that that's not the case. We have radio pirates. We have other kinds of people who want to disrupt spectrum use for a variety of reasons. And you have to have a mechanism for dealing with that.

Another big incentive problem is, you know, when you have these differing local solutions, you have a potentially large number of different communications regimes. And for carriers that gets costly. And so, you know, the question is, how do you balance cost against benefit in these areas? As Edgar and Evan reminded us, how can we get revenues from this, right? And that's something to be determined. And I think the last thing is we've never done it that way before. So why should we do it now?

Next slide, please.

So basically, let's free spectrum and I'm going to co-opt the Occupy movement and, you know, let's start occupying spectrum in different ways. Thank you very much.

Giulia McHenry: Thanks, Martin. I really appreciate it. You make a compelling case. So with that, I'm going to move on to Sarah. And I think Sarah has slides as well. There we go. Great.

Sarah Oh Lam: Thanks, Giulia. And thank you to the panelists. I'm also excited to be on this panel with everybody, people who are experts in the field. Today, I'm going to talk about a proposal or just thoughts about how to make spectrum licensing more iterative, like Giulia teed up. And so I thought, well, the experimental license program is flexible and local, like Martin was talking about. So today I'm talking about what it would look like to have markets in experimental licenses.

Next slide, please.

So the question is how to make spectrum more flexible and more iterative and faster for reallocation and clearing. And so, just as an overview, right now, the current pipeline for spectrum is, it's pretty robust, but it can be better. There have been auctions for flexible use licenses that have had billions of dollars of interest by market participants. Auction 110. Auction 108. Different mid-band bands have had a lot of interest and have released flexible-use spectrum. There's a Spectrum Pipeline Act that mandates finding another 30 megahertz for flexible use, and then there's a spectrum relocation fund that is supposed to help with relocation costs and clearing for federal spectrum. So I think this is kind of the landscape currently and we're thinking, well, how do we make it faster? How do we find more spectrum?

Next slide, please.

So there's room for just new ideas. And in my next slide, I have some an idea for expanding the experimental license program. So, in the experimental license radio service, there is a subcategory of STAs, Special Temporary Authority licenses. And they're quite flexible and they're small, they're local, but they're also encumbered, so, they can be interfered with—interference is possible.

And so next slide, please.

There are a few scholars that have done studies, mostly from Martin Weiss's group. Martin, I had already cited that Bustamante paper a lot. That was kind of the, those two papers were kind of core to this discussion draft paper that I wrote. And you had forwarded me that paper. I was like, Oh, yup, because I think one of your students and scholar, Pedro Bustamante, whom I haven't met yet, but he did a survey of the experimental program and found a lot of interesting statistics that experimental licenses have been issued over pretty much every band in the ITU (International Telecommunication Union) spectrum table. And that's like 74,000 different frequencies. Most of them have been in the middle bands that are kind of most valuable and on the Ultra High Frequency (UHF) band. These licenses I believe can happen on federal and non-federal spectrum, on incumbent bands. They're very short term, so they're limited. Special Temporary Authority (STA) authorizations are limited to six months. The experimental licenses, broadly, are allowed to be licensed up to five years, and the majority of Experimental Radio Service (ERS) licenses are issued for two-year terms. And in chatting with other folks who are familiar with these licenses, like, within NTIA and Interdepartment Radio Advisory Committee (IRAC), there are few companies that are repeat players and they're getting a lot of value out of the experimental licenses that are free, and they're using them for video broadcasting of sporting events and NASCAR and award ceremonies.

So next slide, please.

There is a subset of users who are using it for presumably commercial uses. But then there are a lot of companies that are using it for R&D purposes, like Boeing, Lockheed Martin, Raytheon. In the 3.1 to 3.3 GHz band, when they were clearing it for auction, they had to clear experimental users that were there as well. And so in the report, in order and further notice for proposed rulemaking for that docket in 2020, there is a description showing that they had to clear some of the users that were there experimentally. So this chart, this table shows just a little bit of what's happening that on this valuable band, there are all these like smaller users that are legitimately on the unused space through the experimental program.

So that's really interesting to me as an economist because that shows that there's market demand, that there are actually uses for short term spectrum licenses that are encumbered and that can accept interference. Now, you're not going to build a national network based on these really short-term licenses. So, you know, in my proposal to create a market for these, you know, you might not see billions of dollars from wireless carriers. But what you do see is that there is like robust demand, robust in my mind, meaning like a lot of different players and a lot of different places and creative uses. So that indicates to me like, oh, there could be a market here. And what components are needed for a market, like fees and payments?

Next slide, please.

And so my idea is like to create markets and to do that would require some statutory authority to have intermediaries. So in this discussion paper, I call it a Spectrum Exchange Act that would authorize exchanges by private firms—firms that can be managers that can interact with the facility. And then the companies would register with the facility and be able to broker these bids and auctions. And there would be a method of having pre-approvals or attestations about interference between the licensees and incumbents before they approached the facility.

So a lot of like contract and legal infrastructure to make it possible to have even more transactions than currently. I mean, a critic might say, like, You don't need that much infrastructure, because what's wrong with the current program? Like, the FCC can handle the current throughput. But I think,

next slide please,

if you add some fees and a little bit more certainty about just expanding the program, you might see increases in transaction volumes.

And then another building block to this proposal would be allowing the federal spectrum users to get monetary fees or revenue for usage of federal spectrum. And currently that's prohibited under the Miscellaneous Receipts Act. But Congress could write into a statute the authority for the government to receive receipts for spectrum. And then I just say, you know, to handle all this, those transactions, Congress could create like a federal spectrum contribution company. Like a USEC (United States Enrichment Corporation) or a Fannie Mae or some sort of intermediary to handle the money that goes back to the federal government.

So rather than getting all stuck in in NTIA or IRAC or Treasury, there would be like a separate entity that could handle the bookkeeping and accounting and, and the other things like spectrum valuations, like the intangible asset valuations that are very specialized and difficult. So anyway,

next slide,

and that's about it. That's a new idea, something to noodle over. And I have a discussion paper that will be posted soon. Thank you.

Giulia McHenry: Thanks, Sarah. That's great. And like I said, she's prolific. I really appreciate the discussion paper. I think it'll be fascinating to see. So, since we now have Edgar here, I'm going to quickly introduce Edgar and then let him talk a little bit.

So, Edgar Rivas is a legislative assistant in the U.S. Senate for Senator Hickenlooper, who's from Colorado. And Edgar is the Senator's principal advisor on all things Senate Commerce, Science and Transportation Committee, including technology, telecommunications, cybersecurity, privacy, space science, trade and Transportation issues. Speaking of George Mason, Edgar received his Bachelor's in international relations and his Master's in public policy from George Mason as well. So with that, I'm going to kick it over to Edgar to bring us back to reality. I don't know.

Edgar Rivas: Thanks Giulia. And thanks, everyone, for having me here. And, you know, obviously, with the Colorado flag behind me here, you know, we're so thrilled to be part of this conference and we're so proud to represent the NTIA and Institute for Telecommunication Sciences (ITS) in Colorado. And, you know, as everyone has mentioned already, you know, telecommunications is such a dynamic policy arena. And, you know, I'm biased in saying that I think it's one of the more dynamic portfolios to have as a staffer on the Hill. So I'm really thrilled to be speaking to you all today about all things spectrum. Again, it's such a such a hot topic in the telecommunications world today, as has already been touched on. And I'll just be very brief with my opening remarks, then we can move on to Q&A and have a lively discussion.

Spectrum is so critical to supporting the scientific community and research, you know, in the development of advanced communications and 5G technologies. And we'll see when we get to 60 down the road and other everyday applications that, you know, we really rely on. And I think that just underscores the importance of the demand has skyrocketed for spectrum, both on a license and unlicensed basis in recent years. Which is why we're here today to discuss how can we develop a regime where, you know, we are sharing and coordinating and researching spectrum in a way and managing the spectrum in a way that we're maximizing its value for all users, both federal and non-federal.

And I think some of the proposals that have been brought forward today are really, really fascinating. And I'd love to dig into those in a little bit throughout the discussion and throughout the conference. But one thing, obviously, from Capitol Hill that we are thinking about is What are the statutory and regulatory requirements that need to be paired, harmonized, together to allow us to really maximize our value of spectrum and our use of spectrum in a cohesive way?

It's no secret that, you know, passing legislation through Congress takes some time. And revitalizing these regulatory frameworks to adapt to the needs of federal non-federal users, you know, is also a time- consuming process. But we need to be sure that the policies we're putting in place in the frameworks that we're implementing are able to be adaptable over time to keep up with the dynamic pace of which we're needing to use spectrum.

I think two other points, I'd love to kind of close my remarks with are, you know, obviously NTIA and with what ITS does is very fundamental to all these tricky questions. But in particular, on the research side, you know, what are the frameworks and what are the guardrails that can be alleviated, if you will, so that we can be doing more proactive research into propagation models and identifying, you know, what the appropriate use of spectrum bands are.

And then on the coordination side of the equation, you know, how can we establish these frameworks in a way that we're building trust between NTIA, FCC, and obviously all the other federal partners who use spectrum? You know, I'll take this opportunity to applaud the work that NTIA and the FCC have been doing in recent months to really, you know, reaffirm the commitment to spectrum coordination and planning.

And I think that's a great first step. And I you know, like I said, I'm over the moon to be part of this conversation because I think the outcomes of this conference will help build on that framework and foundation to allow us to use spectrum to the maximum extent we can. So, I'll end with that and then I'll take it back over to Giulia to lead us into the Q&A.

Giulia McHenry: Thanks, Edgar. I really appreciate your comments. And I think it actually it's nice that we're now going to turn to Carolyn, who I do think has also kind of been thinking quite a bit about that, the line between federal and commercial and how we can work better together. So with that, I'll turn it over to Carolyn. And I know she has slides there.

Carolyn A. Kahn: Great. Thank you so much, Giulia. And it's great to be a part of this panel and really great perspectives sharing. So, I was very excited about ISART's theme this year and I'm trying to build a upon it and have a few upfront remarks about evolving economic and policy mechanisms to support spectrum sharing and then look forward to the discussion afterwards.

So next slide, please.

So there's tremendous technology developments underway, but these must be coupled with economic and policy innovation in order to be successful. So we have spectrum repurposing that's governed by executive and legislative mandates, such as the Commercial Spectrum Enhancement Act, which established the Spectrum Relocation Fund, or SRF. The SRF reimburses federal agencies for some of their cost to repurpose spectrum.

There's also legislation that explicitly mandates spectrum repurposing, like the Spectrum Pipeline Act and also MOBILE NOW. But this current process of repurposing spectrum from government to commercial users is unsustainable. And spectrum sharing is a more flexible and sustainable approach, but it must be supported by economic and policy mechanisms.

Next slide, please.

So, some thoughts on economic and policy mechanisms. We could implement something that's a more agile approach, as put forward in the ISART call for proposals. And so agile approaches are used in other contexts, from software development to acquisition systems engineering and testing, and a more agile approach could potentially be applied to spectrum policy-making. The goal would be to build upon and improve where we are today; so, to improve our current processes without adversely impacting safety or risk.

And we have some tools that we can, you know, start to build and the community is starting to build, which is solid engineering data, robust objective data, that can be leveraged in conjunction with modernized IT infrastructure. This could help at least to improve and accelerate our current processes, again, without the adverse impacts. One way to go forward with doing this is starting with initial decisions that are known not to cause adverse impacts and then follow that by more detailed engineering analysis, even policy pilots, tests, experimentation, and then issue iterative policy that's more refined or targeted.

But such a continuous regulatory improvement model must be supported by economics. And so we heard some of the other panelists talk about increasing spectrum sharing in the transaction. So I agree that it would be helpful to increase the fungibility or that exchangeability of spectrum access. This could be done by more fully reimbursing for costs of repurposing. The SRF, for instance, could be extended to incorporate increased operating and support costs for spectrum repurposing. It could be expanded for other costs of repurposing as well, such as pre-auction costs prior to a band being identified for reallocation of sharing, greater standards development costs, subsidizing equipment replacement. And there are other costs that would be helpful to reimburse to at least make it equal to where some of the incumbents and federal agencies are now.

In addition, modernizing spectrum access. So excess SRF funds could be applied to innovation and research and development to modernize spectrum access, to provide for upgrades, such as more advanced technologies like transmitters and receivers. It could also stimulate innovation through incentives.

So we've talked about some incentives, some of the other panelists did, but the SRF, for instance, could be further reformed to provide incentive to motivate greater spectrum efficiency, such as designating a percent of auction proceeds or leasing revenue to federal agencies by providing cost reimbursement or by providing cost reimbursement for increased capability or increased efficiency to support greater reallocation of sharing.

We can also support secondary use and leasing, which could be implemented perhaps on a voluntary basis, where stakeholders agree, and could help enable shorter term transactions that reduce risk. So from the lease-source perspective, it would provide an opportunity to generate an additional revenue stream to offset a portion of auction fees, for instance, and from the leasee's perspective would provide an option for shorter-term spectrum access at a lower cost, which then could potentially open up the market to a greater number of and a more diverse set of participants.

Next slide, please.

So just some final considerations that I wanted to put forward, for the community to consider implementing agile policy development as put forward by this ISART as well as spectrum IT modernization: To consider ways to increase the fungibility or that exchangeability of spectrum access to more fully reimburse costs of repurposing. To support secondary spectrum use and leasing. And to foster a whole-of-nation approach—so, to make decisions in terms of what's best for our country as a whole, as opposed to individual stakeholders and their incentives.

So in the short term, we can work now to build the foundation in order to do this, to build robust databases, acceptable methods, modernized infrastructure and efficient coordination processes. We can consider reforming the spectrum relocation fund and supporting shorter term transactions on a voluntary basis, and develop and clearly articulate shared national objectives, so that we can come together and the community can work together towards these common national objectives.

So, bottom line is agile economic and policy reform is needed to move with the speed of technology advances. And thank you so much. Back over to you, Guilia.

Giulia McHenry: The unmute button gets me every time. Thank you, Carolyn. It may be that I've been talking a lot about agile development this week in other contexts, but I think that has a lot of appeal and it's really interesting. Okay! So we are going to turn it over to Greg to wrap all these amazing ideas up and start making sense of all this. So, Greg, take it away, please. And I don't think you have slides, right?

Gregory L. Rosston: I do not have slides. I'm from Silicon Valley. So I don't have slides. I want to thank you, Giulia. And thank ISART for putting this on. This is great to be here with the great panel. I think our panel is really diverse, not only from viewpoints, but, you know, Sarah came up from our previous talk as an organization group to come out with a paper. Others had slides, and Edgar and I came up with bullets. So we have a diverse set of ways to present.

So overview. Kind of the first thing to think about when I think about sharing is that sharing means a whole lot of different things. Sharing can mean, and essentially, I think we all have the same goal, to maximize the value of the use of spectrum. And maximizing the use of spectrum is different than maximizing the *value* of the use of spectrum. First of all, I think economists want to maximize the value of the use of spectrum. Some other people want to maximize the use of spectrum, which may be very different. But also sharing—if you have lots of different networks sharing, it may be that you get a lot less use and a lot less value of use than if you have highly centralized networks that may be very efficient at using the spectrum and reusing the spectrum and doing handoffs and other things like that. So economists kind of say it depends on the costs and the structure and what's going to happen in the future with respect to innovation, competition, and access. So we need to figure out what is the goal of sharing and how we do this and what are the alternatives?

So this kind of brought me to something. So Edgar pointed to the Colorado flag behind him. I'm going to point to the rural West Virginia barn behind me. And thinking about you have service in some areas where spectrum may not be used as often. And this may be an oxymoron, but I want to go back to what Martin said and maybe what I'm going to propose is controlled or rules-based anarchy, which may be somewhat of an oxymoron. One idea I've been thinking about is transitioning team spectrum rules from a use-it-or-lose-it perspective, which is what we have right now for license spectrum, to a use-it-or-share-it system. So currently the spectrum system is like the patent system where licensees have the right to exclude usage, period. A patent holder can use its own technology and importantly prevent others from freely using its know-how in its patents. So exclusive-use spectrum confers similar rights. So in that rural barn area, even if a licensee doesn't have systems there, and that barn owner could use spectrum or a community around there could use spectrum to provide service, it's not allowed to if it doesn't have the license and someone else does have an exclusive-use license.

So patents are our system enshrined in the Constitution to provide incentives. Article 8, for those of you who are not lawyers other than Sarah on the panel and maybe some of you in the audience who are not lawyers, the Constitution says that Congress shall have the power to promote the progress of science in the useful arts by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries.

So economists think incentives are important. So some reward for invention is really good. And that's part why the patent system has survived and people have invented. But moving towards spectrum, I like to think more of land as an analogy. We don't give exclusive rights to land as an incentive, but more to make sure the owner can enjoy the use of the land. That someone else doesn't degrade the land, doesn't degrade their enjoyment of it, doesn't take away what they can do with it. And we can think about that with spectrum in that you have the right to use your spectrum, but if someone else is using it where you're not using it, that doesn't degrade your usage of the land—or sorry, you're using the spectrum. So use-it-or-share-it with transition essentially from a right to exclude to a right to use. And that may be a very different way of thinking about how spectrum is. And we might think about transitioning to a different standard that's aligned with giving the right to use this spectrum, but only exclude others if they're going to interfere with the licensee's primary right to use. So it's important in this transition or thinking about this that rules matter and pretty clearly enforcement matters. So you need to make sure that if I don't provide service to this rural West Virginia barn when I have my exclusive license and you start doing it, that if I decide No, this is a good idea, I can say, "No, you've got to stop, and you have to stop." And that's where enforcement matters. And companies are going to respond to these changes and rules and expect enforcement. And one of the things also is that the FCC is thinking about receiver standards right now. Essentially, we need to define harm. How much transmission of somebody who doesn't have the license is going to cause harm and what's the standard we have for that? That's going to be really hard. So that was kind of the proposal I wanted to think about and to tie things up. And in some sense, this also ties back to what Martin said about act locally in that flexibility for rights is an act locally policy and so will user sharing be an act locally policy. So I think I'll stop there and let us get to the discussion.

Giulia McHenry: Thank you, Greg. That was great. I really appreciate it. Actually, you did a great job of wrapping it up and bringing it full circle. And I have to say, the diversity of this panel is going to make my job really hard. So I've been sitting here debating with myself where to kick it off. And I do think I want to sort of touch on a few themes just to acknowledge them and recognize that there are a lot a lot of amazing ideas here. And recognizing that spectrum policy has always sort of operated with a set of tools. And I think there are a lot of ideas, of potential tools here. So I don't want to dismiss any of it.

But, you know, I think the original concept, which I didn't talk too much about in beginning, is this idea of Are there iterative approaches to licensing and assignment that might do a better job of finding—as an economist, I think of—value from the spectrum?

I think Greg made a very good point: There's a difference between usage and value in a lot of cases. There's a sense, I love this theme, of local, which is, you know, national policy doesn't always do a great job of ensuring that there's usage locally and there's a lot of room for improvement there. Thinking of the ideas of temporary licenses and uses of the spectrum that—and I agree this concept of harm is a really important one—maybe doesn't necessarily harm other users at the same time, that it does have potentially some economic value for the future.

And also Carolyn's thoughts bringing in the more how can we create a framework to have an iterative approach whereby rather than by establishing rules and running forward for decades, we're thinking along the way and trying to understand what could be the best compromise or sharing or solution to a band, recognizing that we don't necessarily get it right on the first shot with one whack.

And, Edgar, I think, you know, bringing us all again back to the reality that there's very little we can do without both FCC and NTIA having some authority. And that authority comes from your boss along with his colleagues and we have to do this all within a framework of laws and statutory responsibilities.

So thinking about all of these concepts, I am going to sort of take the out of starting to ask questions round robin. But also please feel free to raise your hands and chime in because I think there's a lot of dialogue that I want to be able to have here. And none of you can kick me under the table. So I'm going to go a little bit off script and start asking questions that maybe you didn't put in your list of questions you'd be willing to answer. So please feel free to tell me to back off and ask a new question, if you want.

So, Martin, I want to kick it off with you again. Like I said, I love this idea of thinking locally about how we can use the spectrum better at a local level. Has your team given any thought to how this might fit into a frame? You know, sort of, you know, how you can fit anarchy at the local level within the sort of larger statutory framework to create more value?

Martin Weiss: Well, we don't have a lawyer on the team, right. So I can't say that we thought about that in depth. I will say, though, that, you know, Greg's comments reminded me of this: that there is a framework that, at least as a non-lawyer, I'm generally aware of, and that is usufructuary rights, right? Where you have the right to use something as long as you don't diminish somebody else's use of it.

I've actually spent a little bit of time trying to find experts in this in the U.S.—and I haven't yet tracked that down—because I think that would be a useful legal framework. It's not necessarily a statutory framework, though. So, I guess, you know, I like the idea of use-it-or-share-it. I think that's a useful framework going forward. But again, I like, you know, some of the other proposals that were made.

The other thing, you know, while I have the floor, I just kind of wanted to put it out there and excuse me if I'm digressing a little bit, but as we think about the spectrum sharing, I think it's really important. I mean, we spend so much time thinking about the incumbent, what the incumbent does and shouldn't do and can do and can't do. We have to think about the entrant. The people, or person who's the sharing party, right? Why should they share or under what circumstances would they share? I mean, I thought about this problem a bit and had a student who did a dissertation in that area. You want to think about it, but you think about the decision problem that you have. I can, you know, use unlicensed, I can share, I can go for a license. You know, how does how does that play out? Because I think as we as we think about sharing, we have to think of the counterparty as well. And I want to urge my panelists to consider that.

Giulia McHenry: Thanks, Martin.

Gregory L. Rosston: Can I jump in? I think you're absolutely right, Martin. For example if, you know, if it came for the spectrum incumbent to use it or share it, it could cause incentives for the incumbent to over-invest, to try to prevent competition or prevent somebody else from using it. So you're right. You need to think about the effects on both sides of this.

Giulia McHenry: That's a very good point.

Sarah Oh Lam: That's like water rights, right? That if you use it, you don't affect other people. I believe that.

Martin Weiss: Well, I was thinking more of land rights, right? So if I go, you know, like in England, you can hike on people's land as long as you don't damage crops or whatever. Where this came into my awareness was with some of [economist] Thomas Hazlett's work here in Central America where they were using this usufructuary framework specifically for spectrum. But again, I'm not a lawyer, and I'm really certainly not a property rights lawyer, so I can't really speak to the where and how and when it applies. If you can point me to somebody who is, I'd really love to talk to them.

Giulia McHenry: Thank you, Martin. Anybody else want to chime in?

Carolyn A. Kahn: I can jump in. So, I mean, I think if realistically we could put it into practice and implement it and still, you know, protect the critical safety missions and not cause any safety issues or risks, you know? It sounds like a good path. I think also kind of the situation we're in is, you know, spectrum was originally allocated over 100 years ago. So we have these incumbents that are very invested, a lot of systems in place. And so how to accommodate these new users with all of the emerging technology, which is really drastically changing, nothing like how it was, you know, over 100 years ago. And, you know, there was a question also in the keynote about different systems with different physical properties and how can that be considered in this whole kind of framework. But here we are with a lot of systems in place. And so it is very challenging. And, you know, I think there's a lot of great ideas in the spectrum-sharing technologies and, you know, wanting to get it right with the economics and policy to go with it.

Giulia McHenry: I agree. The diversity of users is really interesting. And I think particularly when we're thinking about sharing federal to commercial, you know, it's certainly a major concern. So thank you all. Unless anybody wants to jump in, I'm going to turn it to Sarah and ask her a similar question, which is How do you see, and I know you sort of generated this proposal right now, so I know it's not fully fleshed out, but how would you see something like temporary or short—very short—term licenses with relatively few rights, how would you see sort of a secondary market for those fitting within the bigger framework of, you know, of commercial, of FCC and NTIA commercial-federal spectrum use?

Sarah Oh Lam: Well, so this is kind of an idea to think about, to noodle over, markets and STAs. I think what is interesting to me is that there's so much demand. I have an RSS feed that you know sends me all the experimental licenses as they're registered. They're from sorts of users. They're in local places, they're small, they're hyperlocal, they're very small, like one day or a week. And they're limited to places like, campuses. They're not at the census block level. And so on the one hand, I wouldn't expect actually there to be a lot of competition for particular licenses. It seems like everyone just wants a little piece and of their own and permission. I mean, in that proceeding, you saw like Boeing has one campus, Raytheon has another campus. And so they're not really overlapping.

And so I think there is a question in the Q&A like, Would it be expensive for researchers to want that access if it's not free anymore? And, I mean, I would suspect that if there are no other bidders, that it would be pretty low of a price. You'd have to set some sort of way for the incumbent not to, like, really charge a lot. I mean, I can imagine there being a market with high transaction volumes, but maybe low monetary amounts. But then when you add it all up, like, there would be more access and more information.

And so then in the paper and I'll post, I'm happy to share my discussion paper, it's just very new, so I haven't fleshed it out yet, but I think these little amounts of spectrum, you know, they're encumbered. Like I don't think they would be auctioned off for billions of dollars, but it would satisfy the demand for flexible use, quick access, and also it would allow for price discovery. It would allow for discovery and testing of new devices. And you could actually see like where people are using spectrum and how much. And so it would be another dimension of gathering data. And I think what was interesting to me in looking at the STAs that are actually being issued, yeah, they're all over the dial and they're all over the federal and non-federal users. And so talk about comprehensive and then relatively low impact. Like, if there is catastrophic interference risk, it's very limited, like, to a small amount.

And then the experimental program, it's also like very transparent. The licensees are supposed to register their equipment with the FCC—the exact transmitters, the time and use [what they're using it for]. So in a way, it's also like if you're doing something super secretive, you might not want to take advantage of this program. So I think there's potential there for markets. And thinking about it, I do think there would need to be a lot more infrastructure to handle those kinds of transactions. But in terms of reality, there have been talks about spectrum exchanges for a long time. But I do think there are a lot of analogies between spectrum and securities, like finance. It's very abstract. You know, they're abstract instruments that allocate risk and capital. It's really all, like, contracts. So it made sense to me that it would be in that kind of framework of law.

Giulia McHenry: Excellent. Thank you. Martin. Looks like you have your hand up.

Martin Weiss: Yeah. I love the idea. Sarah. I have to say, I love, you know, first of all, price discovery. I think that's something that we're really missing in the spectrum arena. There was a question in the Q&A about secondary markets. And I think partly they're hampered because there is no price discovery. It's not like we can look and see what the futures price of meat is. I think in the STA world, part of the motivation would be time, right? So it takes, you know, let's say 23 days to get a license. Well, you know, maybe if you have an event that needs to happen tomorrow, you don't have the 23 days. And so it may be a temporal type of an arbitrage that you can do for that. I mean, that might be a reasonable justification for a market like that.

The other thing I wanted to say while we're talking about these markets is that spectrum markets are difficult because different frequencies have different characteristics. And so there's not perfect fungibility between different bands.

We did a paper a few years ago where we were trying to explore, you know, maybe having some kind of a way of translating one band to another, the value of one band to the value of another. And it's kind of imperfect because, you know, different frequencies cover differently. They have different capacities. And so you may want to use different bands for different purposes. So it's actually a fairly complicated topic. I mean, we can get into it, but I think that would be really going down a rabbit hole here.

Giulia McHenry: Excellent. Anyone else? Okay. So I'm conscious that we only have 10 minutes left and this could go on for a long, long time. So one thing I just want to ask Edgar before we get to far along is, when you're thinking about new legislation and when you're thinking about how can we use the spectrum more effectively, particularly in context where maybe revenues are not eye opening, what are you looking for in terms of priorities to think about what we can get authority to do? You know, what are the priorities of your boss when thinking about these things?

Edgar Rivas: Yeah, no, I think it's a great question, but our—

Giulia McHenry: Uh oh. Can anybody else hear Edgar?

Edgar Rivas: Can you all hear me?

Martin Weiss: No.

Giulia McHenry: Try again.

Edgar Rivas: Are you all able to hear me now? Perfect. Sorry about my technical issues, but no. I think with when the Senate is considering spectrum authorities and reauthorization of upcoming deadlines, I think there's going be a lot on the table for us to noodle through. I think obviously in the near term, as I mentioned earlier, I think building upon and codifying the new coordination framework that the NTIA and FCC are working on is front and center. There's legislation to basically put that into U.S. statute and kind of put the MOU into place and update it periodically, I think that's a key facet of that. When it comes to auction authority, however, I think one of the things that will really drive the Senate, and this is just my own opinion here, is seeing how the agencies are able to, you know, really agree upon a standard set of frameworks for developing a propagation model to inform which spectrum bands are identified as, you know, eligible for unlicensed, eligible for a license basis, or even something as we were just discussing here with STAs, certain bands, as Martin was mentioning, have different capabilities and frequencies. And I think one add-on I would add to that is the type of mission or use that a user is trying to use a piece of spectrum for. Going back to our earlier discussion in this conversation, you know, if an incumbent agency is using spectrum only periodically for certain types of observation missions, for example, those may offer different opportunities for sharing versus something that's a bit more continuous and ongoing, such as the GPS system and kind of maintaining those types of communications on the battlefield or wherever else it may be.

So I think there's a lot on the table for Congress to consider. Another thing that I think will be really important for Congress and this is the upcoming debate I believe we will have, is whether or not we will follow previous legislation and simply, you know, condition in statute certain amounts of spectrum to be made available, say 500 MHz or whatever else it may be. Or, if we go the alternative route and say one specific band of spectrum will be auctioned off on a license basis by a certain date. And I think both routes that could be taken offer different considerations for Congress to consider. But I think in the near term, as I mentioned, I think the big focus will be codifying the interagency framework for coordination.

And then one last thing I'll end on is on the Spectrum Relocation Fund, I know there's a lot of talk about ways to modernize that, ways to allow that to be used for more proactive ways of research. You know, I think there's a lot of interest that's growing in that arena on Capitol Hill. Frankly, I think, the notion that the SRF is really only used when a federal incumbent is being asked to move, you know, I think that obviously presents its own challenges that we're all, I think, cognizant of. You know, why not transition it into something called like, the Spectrum Research Fund? It does not have to be just tied to relocation, but it could just be tied to research on a go forward basis that, you know, allows for all the great things that ITS and other agencies are capable of doing, bringing that to the forefront.

So, you know, I think that would be my response to what the Senate's priorities are. But obviously, there's a lot to consider and I think, you know, these considerations of secondary markets with STAs and other types of ways to modernize the way we look at spectrum is really going to be fascinating in the next few months. And as I mentioned, Congress has a short deadline coming up, so we will be entering these discussions very shortly.

Giulia McHenry: Excellent. Thank you, Edgar. Anybody want to respond or tack on? All right. So we have 5 minutes left and two distinguished guests. Carolyn, we talked a lot about the short-term in terms of implementing a more agile approach, what we can do. What are your, do you have sort of the long term goals as well in terms of where do you think, how we can use an agile development process for spectrum rulemaking?

Carolyn A. Kahn: Sure. So, um, in an agile process doing things more iteratively, decisions would be put forward quicker. So it could accelerate things. It wouldn't typically be the final decision, but it would be maybe a win-win decision or like a low-hanging fruit kind of decision that could be refined over time. So this would hopefully in the long term, it would accelerate in a good way and also make the decisions better and give the chance to... I mean, that the hard work still needs to be done. So, you could put forward the easy decisions that, you know, there's confidence across the community on. And then having more time to do the hard work, the engineering that so much of this is based on and even doing economic and policy experiments so that when the future decisions are made, that they are based on sound engineering stakeholder input and, you know, plus backed up with robust data and IT modernization could just help support that effort.

Giulia McHenry: I like that. I think that's consistent with how Edgar is coming out in terms of supporting the research pieces and the toolbox to support this. So wonderful. Thank you.

So, Greg, I'm going to give you the last word. And you can either reflect on everything we've talked about so far or talk a little bit about how your approach to use it or share it might work and whether there's an assignment framework that might work with that.

Gregory L. Rosston: Sure. First, one thing is that [economist] Scott Wallsten, also of TPI, has done work on secondary markets for spectrum and that he's found lots of transactions for uses of spectrum. So there is in his mind, in his work an active market for spectrum and for secondary markets. And obviously with auctions we do have some primary market values of spectrum. And so I would encourage you to look there.

As for how I would think about trying to implement use-it-or-share-it, it seems to me, not surprisingly, as a part of the team that helped develop the auctions, that I think you can still do auctions with the rights changed from an exclusive-use-right covering, for example, the entire license area to a right-to-use covering the entire license area.

People would bid differently based on that. You would have to ensure that there was going to be enforcement when you wanted to go ahead and use it in an area. And so that would be relatively easy.

One of the things that I've advocated for, and I think economists tend to hate, is buildout requirements. A buildout requirement is something that, you know, again, using the land analogy, if I buy a plot of land and I don't put an apartment building on it, I may be waiting for five years because I think I need to develop the capital or maybe the technology of steel is going to change or something else is going to change. And I want to keep this land vacant for a little while until I can get the right design or something like that. So, the same thing might be true of keeping spectrum vacant for a little while until demand develops or until 6G is available, something like that. So I may want to wait, but while I'm waiting, someone else's use does not degrade the spectrum. It's not like they're digging up the land or doing some other problem. So the use-it-or-share-it would be okay. But you wouldn't want to say to somebody, well, you're going to lose the license if you don't build out. So I think you'd want to get rid of buildout requirements.

And now there's a legal question. You know, it's very easy for economists to sit here and say, yeah, go ahead, get rid of buildout requirements for licenses going forward. What do you do about for all the licenses that have already been issued with buildout requirements? Probably as an economist with rules, you say, well, you guys paid less for those because you had buildout requirements. Now, if we let you do it, there's a windfall and you need to think about how do you deal with those kinds of different issues. But I think that the way of putting use-it-or-share-it going forward is relatively straightforward within the system. Again, subject to enforcement—so enforced anarchy, Martin.

Giulia McHenry: I like that, enforced anarchy. On that note, we unfortunately are at time, and I unfortunately have a hard stop. I know that there are some questions in the chat, and I think it makes the most sense answer those as folks wish because I think that Q&A sort of stays, maybe. Mike might know the answer. But thank you all. This has been really a fabulous panel and you all have so much to bring to it. And I'm so impressed with all the ideas on the table, and I really appreciate all of your ideas. And hopefully we have given the broader conference and things to think about in terms of how to make this work from an economics standpoint and thinking about evolving sharing. Thank you all. It's been a pleasure. I hope to one day soon see you all in person. But in the meantime, it's a real pleasure to have you all here. I appreciate you all taking the time. So thank you very much.

Sarah Oh Lam: Thanks, Giulia.

Martin Weiss: Thanks, Giulia.

Gregory L. Rosston: Thanks, Giulia.

4.4 Panel: Data Sharing and Transparency

Availability of spectrum data is limited because (1) proprietary constraints exist to maintain IP and competitiveness, (2) government data policies and restrictions exist to ensure national security, and (3) data acquisition is expensive. This causes (a) long time delays and conservative assumptions in spectrum management analyses, and (b) limited progress in data science applied to spectrum. This panel explores administrative, technological, and system solutions to data sharing and transparency. What spectrum planning analyses and processes would immediately benefit from improved data sharing and transparency? What types of data sharing and transparency strategies can help us overcome the current barriers faced by spectrum analysts/researchers? Do we have concrete recent examples of where data sharing and transparency has been improved? What were the key mechanisms that enabled these improvements (e.g., governance changes, open data, open code, etc.)? Can these examples be replicated in other areas, or further expanded in terms of scope, such as across models, frequencies, applications, use cases, and enhanced across time and space?

Moderator: Edward Oughton, Assistant Professor of Data Analytics, George Mason University

Kaushik Chowdhury, Professor and Associate Director of the Institute for the Wireless IoT, Northeastern University

Eli Cohen, Deployment Strategist, Palantir Technologies

Ian Fogg, VP Analysis, Opensignal

Paul Tilghman, Senior Director of Azure Spectrum Technologies, Microsoft

Gregory Wagner, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA)

Mike Cotton: So, thank you very much, Economics of Spectrum Sharing panel. Sorry about the delay I'm getting online here. I really appreciate the great conversation and discussion there. I might invite the panelists to go back to the Q&A and answer those questions during the rest of the conference because you guys didn't get all those. Okay. So now we're going to transition. We're going to skip over the break because we had a little bit of a delay there for me.

And we're going to jump right into the next panel, which is a panel on Data Sharing and Transparency. And I met the moderator about a year ago, Ed Oughton, because he basically rewrote one of our propagation models in order to do his analysis. And he's been a great leader in terms of developing this panel. So, Ed, thank you very much for your leadership here, and take it away.

Edward Oughton: Thank you very much, Mike. So my name's Ed Oughton, and welcome to this panel on Data Sharing and Transparency. Today, we're going to look at some of the solutions, or administrative, technical, and system solutions that hopefully can allow us to do more data sharing and improve transparency in order to improve spectrum management for the future. So I'm hoping that this session is going to be somewhat dynamic and interactive.

We have a very esteemed panel of guests who are going to come speak today, and what I've asked them to do is to provide initial three to four minutes of opening statements, essentially on the topic of this panel. And then we're going to go into a kind of interactive session. We have some topics that we'd like to cover. I very much encourage you to post your questions in the Q&A so that we can hopefully get to those.

And then at the end of this session, I'm going to basically give the opportunity for each of the speakers to say some final concluding thoughts on this particular topic. So without much further ado, I'm going to just cover three initial slides just to provide a little bit of background context.

So if you could go to my slide that would be great. Thank you. Next slide, please.

So we know as a community that there's a lack of spectral data out there and there's a variety of reasons for that. So there's national security issues with sharing the data. There're privacy issues with sharing the data. We know it's expensive if you and I want to go out and collect data. Because many of our colleagues in industry are operating in a very competitive environment, it's also challenging for them at times to kind of share the data that we might be interested in. It can kind of jeopardize that position within the market. So it generally means that we do not have the kind of data that we might see other industry where data is increasingly ubiquitous.

This basically means that we end up with long time delays in how we allocate funds across the spectrum. And it also means when we carry out analysis where we want to look at the implications of maybe management of the spectrum, we end up using what could be conservative assumptions in those modeling efforts, in the simulations and this analysis of the data, etc. Additionally, it also kind of slows the progress that we kind of want to put forward, as Mike expressed in comments yesterday about this kind of spectrum data science future that we all hope that we can kind of engage in. And that's kind of going to change the landscape for us as researchers, maybe some kind of deductive theoretical models to actually using more empirical inductive data where we can use some of those advanced statistical techniques that will take advantage of the many things like [unintelligible], etcetera. So why does this particular context matter and how do we overcome it?

Next slide, please.

So it's kind of cliché to say it, but I just wanted to emphasize that all models are wrong, some models are useful, and we're all using models and simulations in order to assess spectrum options. And ultimately, there are inherent uncertainties in the models that we use. We all rely on, at times, assumptions. At times we rely on monumental assumptions.

So really what I want to emphasize here is that hopefully the better future that we're envisaging actually consists more of sharing models, being able to plug and play different models for comparisons, being able to kind of recognize that none of our models are perfect. We are far from that. But by kind of sharing and understanding what's in each of those models, we can push the state of the art further forward.

Next slide, please. So whereas the previous quote was really kind of a generally statistical statement, this one here from Ben Monk, who was long before my time in this field, at the Electric Science Laboratory at Ohio State, makes this really interesting quote, which I enjoy. It's kind of adopted from a classic Einstein quote, but he says that computer simulations, nobody believes them except those who perform them. Measurements, everyone trusts them, except those who make them. And I think that's really kind of poignant. And actually, it's just kind of a good way for us to kind of address this panel today, because it's kind of an assumption from the outside that our models are kind of perfect, and the reality is that we are a long way from that. And one way that we can improve how we make decisions using these models is by kind of understanding the limitations of them, sharing better data, and being more transparent about our decisions.

So I don't want to get in the way of our esteemed panelists. I'm very much looking forward to introducing them. The first person I'd like to put forth to provide some initial statements is Greg Wagner who is director, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA). So, over to you Greg. Please take it away.

Gregory Wagner: Thanks Ed, and I appreciate it. And thank everybody for spending some time this afternoon. I wanted to focus today on some of the concrete things that we've been able to do in the department to begin chipping away a little bit at this question of data transparency. And I want to just hit three things very quickly at the outset.

1) Some of the work that we're doing in the 2025 MHz band with the Electronic News Gathering (ENG) community; 2) some of the AWS-3 work that Howard McDonald talked about yesterday in his opening remarks; 3) and then some of the work under EMBRSS [Emerging Mid-Band Radar Spectrum Sharing] and specifically PATHSS [the National Spectrum Consortium (NSC) Partnering on Advancing Trusted and Holistic Spectrum Solutions SD task group] that was mentioned yesterday.

So on the Spectrum Management/Coordination System (SMCS) or the 2025 to 2110 MHz work, the Department of Defense is kind of sharing that spectrum with the Electronic News Gathering community. Here, we were able to kind of understand each other's concerns in the band a priori. And not necessarily a priori from a rulemaking point of view—I'll come back to that point in a minute—but a priori in the sense that the broadcasters were keen to share with us the concerns that they had about the department entering that band and sharing it. And the department was also keen to understand those concerns. And we were able to establish a memorandum of understanding (MOU) that set out a framework for sharing some parametric data about each other's operations. This also set the stage for some joint-level testing at both the bench level and the field level, with an eye toward kind of doing some models, predicting some results, and then comparing those results against what we see in the field. And then kind of turning the nerd knobs on everybody's system to find out where things kind of experienced interference. And then understanding each system's response to that interference so that people could make a judgment about whether that was something that could be worked around operationally, for example, or something that was truly going to be a challenge. And we were able to construct test reports in a way that allowed a version of those test reports to be shared with the broadcast community in the case of this band. So they could actually see in black-and-white our results. So that's one, I think, concrete example.

A second one: Howard talked a lot about the Spectrum Sharing Test and Demonstration program (SSTD) yesterday. So I won't dwell on that too much, except to point out that it really did foster a collaborative environment where the department could understand how the carriers were using this particular spectrum, and we could get visuals—and I don't mean a set of curves. There is a series of papers, in SSTD that were submitted as part of ISART. You'll see all the curves there and those are those are cool and all. But the reality is we were able to turn No's to Yeses with some of that data. So we were able to wring out that initial conservatism that we had to assume in from the outset of AWS-3. But then we were able to back it back out again over time.

And then the last item: Mark Gibson mentioned this yesterday in his opening remarks, but that's the EMBRSS and specifically the PATHSS effort where the Department of Defense (DoD) CIO has provided a forum where candid discussions at levels appropriate for national security type dialogues could be had to increase understanding of systems and their behaviors in the bands of interest in the case of EMBRSS, 3100 to approximately 3450 MHz. So just a few observations I want to make on that and try to tie it back to some of the things we've heard about earlier.

So, John Chapin talked a little bit about, or implied a little bit about, scale. So these are great, I think, exemplars or pathfinders for us to be looking at. I'm not sure about the scale, though. So in the case of the 2025 MHz, it was just a few pieces of DoD equipment. And we took a crawl-walk-run approach, and we're just in the crawl-walk stage. So we, as my colleague likes to say, we broomed away the complexity to later and we started with the easiest cases. So promising results where they scale out to systems that start to look like war-fighting equipment remains to be seen. And then in the case of AWS-3, you know, that assisted effort has been going on for years. It's a very big effort and it's been going on for a long time now.

So, Ed, your opening comments hinted on the time scale there. This takes human resources, it takes financial resources, and it takes temporal resources to make something like that work. And so whether they can scale to machine-type speeds or even calendar-type speeds, reasonable calendar-type speeds, the national security question is always going to be a challenge for the department.

As Howard said, you know, we have to dance with the enemy. And it's not just the type of power that we output, or the output, as it's a system capability. It's how we use the equipment as well. And then we have the further challenge of when we get enough equipment and enough information together in one place and the aggregate or the ensemble, we have to think about what that means from a national security perspective. Again, the CIO is working this challenge now. I think up they've got a solid start with PATHSS and we'll have to see how that develops going forward. And the other observation I'll make is with some of these bands, particularly in 3450 MHz and potentially 3100 MHz, you know, we have a 5G use case rolling out for the first time in these [bands]. Some of the use cases we're seeing with 5G are different than the past.

So can we use some of these techniques like SSTD as we extend into these new 5G use cases? I don't know yet. We still have some thinking to do in that space. But you know, all of these things have worked. They've worked on, you know, time scales on the order of months to years. And it's taken time to gain confidence and trust.

How these would all then work in the ISART thesis of this, more of an iterative, regulatory framework, I don't know. I think SSTD has shown us, that we can wring out conservatism so we can make some conservative assumptions up front and then wring those out over time. I think that what we're doing in the 3450 [MHz band] right now in terms of preparing for a sharing apparatus in that band and the idea of driving that conservatism out going forward will be another great test case.

We'll see what that band looks like, perhaps at ISART 2023. And you know, again EMBRSS and PATHSS have given us some indication of what a kind of human-based conversation approach to data sharing and data transparency [looks like]. So I'm really looking forward to hearing from the other panelists and tying this back into this notion of an iterative regulatory fabric with all of the concerns that we heard about in that end.

So thank you.

Edward Oughton: Thank you very much. And it's very exciting for me now to introduce you to Kaushik Chowdhury, who is professor of electrical and computer engineering at Northeastern University. We would very much like to thank Kaushik for being a super-hero coming in today on short notice to attend this panel. Thank you very much for that. We look forward to your initial statements. Thank you.

Kaushik Chowdhury: Thank you for having me here. So I'm going to present a different kind of a talk, and this is going to be more on what exists as a community resource that academics like me can use. And also point out to some methods and techniques which I think can overcome some of the privacy issues that are plaguing the sharing of datasets.

So next slide, please.

So I'll leave my introduction aside broadly, but I've been involved in a number of these different large-scale projects, both supported by Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF) and Intelligence Advanced Research Projects Activity (IARPA). And many of these datasets are key. And when I talk about datasets, they are generally IQ datasets and sometimes sharing them becomes a big problem. So we recognize that there needs to be a venue where researchers can go and collect datasets for themselves and then do a machine-learning type of work on them.

So I just want to highlight one of the projects which is sponsored by the National Science Foundation is called RFDataFactory. And we just kicked it off—in fact, we made a workshop. And you can click that link and you'll see the program that we just concluded last week. So this is a platform for accessing and sharing RF-centric datasets. And what we have done here is that we have made available datasets.

We have provided a sort of a concise way to look up datasets of interest. We have made available software tools and APIs that sort of democratize the action of collecting datasets for yourself. As well as radius tutorials where we train the community on how best to create datasets and how to use standardized metadata representations for them, etc.

And I'd also like to connect very quickly with some of the other interesting sources of datasets. So one of them is, again, the National Science Foundation's PAWR project—the Platform for Advanced Wireless Research—that allows you to go ahead and capture these datasets at scale, as well as the Colosseum, which started out under the Spectrum Collaboration Challenge by Paul here who will probably speak right after [me]. But then just since transition as a community research resource, but from a competition environment, now you can go in and use it in a research environment and actually create very rich and different scenarios with the datasets. I'll show you some examples of this in just a bit.

So next slide, please.

So what datasets are available under RFDataFactory today?

So if you go to the website, you will find a classification diagram like this. And as you click one or more of these, for example, radar, or Wi-Fi, or cellular, as you click on these, a menu of datasets appears that tells you that this is what the available dataset is. And here are some of the use cases. And when you click on it further, it gives you access to a website which clearly lists that metadata representation and so on. So this is really a community resource and example of datasets organized that people can use.

Next slide please.

What software resources are available? So we believe that it's not just raw datasets, but also [it's the] ability to create your own dataset or even create standardized metadata representations. So, we have tools and APIs that allow you to collect or create SigMF standardized metadata for collected datasets. [Using] visualization tools, for example, you can create these new architectures like Open-RAN (Radio Access Network) architectures within the Colosseum environment and collect datasets just for that sort of environment. So this is called scope. There are a number of other APIs, and all of these are on the website.

Next slide, please.

We believe in community training and education because this is a fast emerging field, you know. I just put on my professor hat and whenever I look back in my wireless mobile networks courses, I see a gap between what we teach as part of regular communications and wireless versus things which are more hands-on and practical—the action of collecting datasets and the challenges involved in creating datasets that can lead to reproducible research. So we have a lot of tutorials all online and made available as part of this effort.

Next slide, please.

Here are some parts and just to seed some ideas as the panel discusses this forward. So the question is what can we do to facilitate data sharing? So one way in which we should think as a community is, What technical or transformations can we do at the input source itself? So for example, instead of IQ data that you see in the top part of the slide, in just low IQ pipelines could we create spectrograms and hand out the spectrograms a little bit more freely than we would IQ data? Could we share features and not raw data?

So here's the second piece out here in the slide. The second image shows your typical neural network. So if I take these multiple layers and if I slice them just before the last layer, which is a Softmax layer, what you get is an intermediate feature representation. It's not raw data anymore. So when should I slice that neural network to share features?

And can features then be shared more generally than raw IQ? So this is something that we should think about. What are the challenges in reverse-engineering these features and getting back perhaps more privacy, intrusive inputs? How generalizable is this method and can we really extract features and share them as a generic way to share input data without the raw data itself.

So then finally, just to talk to the community that we have rallied behind the SigMF metadata format. I know National Telecommunications and Information Administration (NTIA) is heavily invested in SigMF too, but is the standard sufficient to capture challenges of time bearing and adaptive signals? So once they create a schema, can the schema evolve or capture evolutions of the signal over time, especially for DoD use cases where a signal can have many different actions and interpretations. So that's all I have. I just wanted to seed some ideas and will look forward to more of the interesting discussion. Thank you.

Edward Oughton: Thank you very much, Kaushik. That was excellent. So now I would like to introduce Eli Cohen. Eli's coming from Palantir and he's a deployment strategist with a technical background in software and hardware. I'm very excited to see the [unintelligible] proposals that he's going to present in this session. Please take it away, Eli. Thank you.

Eli Cohen: All right, thank you everyone.

Go to the next slide, please.

So as Ed said, I work with Palantir. We work with a lot of different customers through USG [the U.S. government] and also commercial that are trying to get value out of their data. So I wanted to use the lens of this panel talking about data sharing and transparency to talk about why is that a problem, and then and then what are some ways that you can solve that? And I want this to be kind of platform agnostic. So these are Palantir branded slides, but for the purposes of the panel, this should all be quite generalizable.

So when I think about data sharing, and I'm often in the room with people that are trying to convince other people to share data with them, there are two major issues that come up. The first is privacy and security, and the second is the what's in it for me conversation.

We work with a lot of customers that privacy and security are paramount to their existence. If you look at some of the letters and acronyms down on the bottom right there, and so having support for being able to work in a SIPR [Secret Internet Protocol Router Network (SIPRNet)] or a NIPR [Non-classified Internet Protocol Router Network (NIPRNet)] environment to actually facilitate this data sharing, things like FEDRAMP accreditation, where the government says, yes, we trust that system to take this data and that security level and propagate those markings, is a really critical piece.

The other side of that is also from a data stewardship perspective. How do you make sure that data that has been shared is being used correctly and is being exposed to the right people? Can you audit who has access to that data? Has it ever left the system? Who's touched it? Those are really, really important questions that always come up when you're talking to somebody that says, I want to give you my data, but as soon as it leaves sort of the walls of my organization, what guarantees do I have that it's going to be treated with the same care and respect that it has within my walls?

On the other side of the coin is the "What's in it for me?" I think it's a really interesting conversation. I like to think about it in an ROI (return on investment) framework. There's an investment in data sharing that can be, Okay, I'll set up an API for you to call and that's really easy and it's all I have to do. I don't have to think about it. I don't increase my IT spend. Or I'm a particular RF shop and we do all of our data storage in this one format and you're requesting it in a different format. And now I have to go through this transformation process. There are clear differences in the level of effort that it takes to even participate in the data sharing in the first place.

And then the second part is the return part of that, which is, What do I get back from that? And so when we think about the tooling necessary for data sharing, you will not get data sharing to happen unless there's value that comes back from the data sharing. So the first part is how do you convince people to show up to the table by providing the right security protocols around it, auditability, things like that.

And then what are the layers of actual things that people want to do with it that make it valuable for them to put their data in in the first place? And so when we talk about platform capabilities, they're really four blocks is the data integration and security piece, which is that core of you have to treat data correctly and then everything that happens after that is value added.

Next slide, please.

So the framework that we've been thinking about, as informed by some work with a customer I'll talk about in a minute, is really about How do you create a framework that respects those permissions that ties in to the right organizations and that can that can provide value and security for everyone at the table, right? So it has to be able to work in the RF environment that we see in the world around us, which isn't just commercial systems. It can be DoD systems, right? And you leave those off the table and there's a lot that you're missing. This whole concept of How do I know that my model and the way that I see the world agrees with the way that you see the world, right? How can we actually have a conversation with data about modeling capabilities? And then, finally, when you want to look at something like, I've got an emitter and I've got a receiver, and they might come from different organizations with different information, How do I look at those holistically in the same place? So one of the experiences that we've been really fortunate to have over the past six months or so is supporting the FAA on the 5G rollout.

It's been pretty fascinating to see the mechanics of all of that going on in. And what that really looks like is telcos actually sharing to the FAA. These are the locations of our emitters. This is where the beams are pointed. This is the antenna pattern and feeling comfortable sharing that because they know that there's significant access control around that data that goes into a unified modeling environment.

And then the thing that they get back in a very, very quick term analysis is you said you wanted to turn on these 10 emitters, maybe think about turning that one down by two DB or rotating that one this direction or turning that one off completely and actually going and monitoring that that process. So speaking to some points that the previous panelists have raised about this iterative cycle, moving quickly, it's really, really critical to be able to create that value add for an organization like a telco to get something back from this data sharing to be able to do things faster and to create smarter investments.

I'm really looking forward to the rest of the panel at the discussion so far. Over.

Edward Oughton: Thanks, Eli. Before we progress, if the other speakers could just turn the microphones off, if they're not currently speaking, that would be fantastic. Thank you. So I'm very excited to introduce our next speaker, which is going to be Paul Tilghman from Microsoft, who is currently the senior director of Azure Spectrum Technologies. So Paul, over to you. Thank you.

Paul Tilghman: Good afternoon-slash-morning, depending on where in the U.S. you find yourself today. I'm really excited to be back at ISART or at least virtually back at ISART with so many familiar faces. So in these slides, what I want to do is, just in a few minutes here, open with, really, two different vantage points and some trends that I'm seeing in terms of what's happening in the cloud world that I think really starts to form the underpinnings of what next generation spectrum management looks like.

And so first, let me just start by saying, you know, in my role, one of the things that I think I really benefit from that I think may help open this conversation up a little bit, is that when we talk about the intersection of spectrum technologies and the cloud and a platform like Azure, I get the joy of looking at it both terrestrially and non-terrestrially.

And so I think often at ISART we find ourselves talking about spectrum management from a very terrestrial-centric perspective and I actually think some the most interesting challenges in spectrum management are coming out in the non-terrestrial world. Interactions, excuse me, between low earth orbit and geosynchronous-orbit satellites, for example, or in the interaction between terrestrial and non-terrestrial use of the spectrum—so, the C-band auction recently clearing spectrum in order to make more terrestrial use for 5G. And then, you know, challenges in the 12 GHz band over terrestrial versus non-terrestrial use. Do we do we deliver more satellite communication, or do we deliver more terrestrial (ground) 5G communication? And so I think if we zoom out from that, one of the things that we really need to look at is What are the key ingredients for a platform that enables next-generation spectrum management, whether it's terrestrial, non-terrestrial, or the interaction between the two? And my supposition is that cloud is central to all of these.

That could be Microsoft's cloud. That could be Amazon's cloud. That could be Google's cloud. That could be a private cloud. But the idea of distributed compute that is geographically global, I think is a key underpinning to how we approach spectrum management in the future. So three key areas that I want to focus on and just highlight a few industry trends that I think are useful as we move this conversation forward.

First is a platform for acquisition of data and metadata that tells us what the spectrum is being used for. So, I've got to get data about my world to know how I might want to even start to think about changing what I'm doing and affecting different outcomes. Two, is a series of standards for storage and distribution of that data as well as a platform for knowledge mining.

So whether that data is data in motion or data at rest, I need to be able to store and distribute that data in well understood standards. And then ultimately that data is only as useful as I can mine information out of it. A spectrogram isn't particularly useful. A, you know, a series of spectrograms that traverse an entire year for a geographic region with other exogenous data, datasets that let me know what's happening within that geography over that same period of time that's useful, and you can mine knowledge from that.

And the last key ingredient here is a platform to actually take action on your observations. So if you have data, if you can store, distribute, and warehouse that data and mine knowledge out of it, that's only useful if you can then do something about it. And so as I said, I think the cloud is really central to each one of these areas.

So let me focus on acquisition first. A major industry trend that's emerging is that data centers are now becoming antenna farms. Microsoft builds a new data center when it builds new cloud engine, we now do a full RF assessment, civil engineering assessment, etc., in order to actually build antennas on that data center. Now, we're doing it today to turn those into Earth observation ground stations to downlink data from space. But my point is that the civil engineering work and the RF work is going into turning the global footprint of where our data centers live into an apparatus for collecting RF data. Highly related is that we're now seeing Tier one telcos, 5G, 4G, etc. migrate to public cloud. And this is very much changing the definition of what the cloud is.

We would have traditionally said cloud is/are megawatt class data centers that live in a few limited geographies. Microsoft has about 60 of them globally. But now the cloud is a geographically dispersed concept. We have the far edge, the radio unit, the distributed unit are now really a part of the cloud. The near edge that contains the CU (centralized unit) and 5G is part of the cloud. Regional data centers that contain the core part of the cloud. So we've gone from just a single handful of hyperscale data centers to this geographically dispersed computing set of assets that cover a large geography and provide, again, an apparatus for collecting data about our environment. And the last thing I want to touch on here is the democratization of data.

Some of you that if you think way back into your brains here, might remember something that Microsoft ran called the Spectrum Observatory, a project I think was well before its time, and it amounted to basically a server and an old-school, I think it was a USRP1 [Universal Software Radio Peripheral 1 was an early software-defined radio]. You could go deploy on your property and collect information about the spectrum.

I think the time is right to think about recreating the Spectrum Observatory in a cloud-centric fashion where modern radios can be distributed, data streamed to the cloud, and automatically stored archived, warehoused and analyzed. That gets me to part two here: industry trends, and that's standards. I think we're starting to see the industry normalized around a handful of standards.

Let's focus on data in motion first. In order to bring data into the cloud, we need ways to standardize what that data is. It's very simple to say, like, "Oh, we'll collect IQ data." How will you collect IQ data? Is it interleaved? Is it 16-bit? What's the provenance of that data? Where did it come from? How is it collected?

What was the hardware? All of these are important questions when you're actually collecting the raw data in the first place. And so Microsoft and a number of others across industry have recently formed a consortium called DIFI—the Digital IF Interoperability Consortium—focused on adopting a standard that basically says, here's how cloud providers will ingest IQ data into the cloud in a raw streaming fashion. So we now have an industry standard says this is how the cloud will interact with RF sensors. It's great for data in motion.

What about data at rest? Kaushik already hit my favorite that we're seeing growing industry adoption across the community, and that's SigMF. I think SigMF is well-poised to be adaptable over time, extensible, and we're now even building native tools on Azure to go directly manipulate SigMF on top of the cloud without having to go in and out of intermediate file formats, as an example. The last thing I want to touch on here—so if I have standards to, ingress and egress data from the cloud, if I have standards to warehouse data on the cloud—I now need to be able to actually mine information out of the cloud. And that's another area where it's easy to think about creating relatively small machine learning models, things that fit within a single GPU and hope that we'll extract a lot of information about the spectrum from these.

What I want to challenge is that the scale of models, AI models, that are really doing important things in industry, has become so big that you really cannot train them unless you're training them at cloud scale. GPT-3 is 175 billion parameters. Last year we announced a model called Megatron Turing, which is 530 billion parameters. These models are capable of understanding over 100 languages natively and directly translating between them.

These models are capable of working in multiple modalities at once. So I can say something like I would like a photo of a cat wearing sunglasses on a beach at night and it can actually synthesize between human language and create that image, this kind of ability to take multimodal data and natural language and intermix it so that we cannot just have the data but ask questions of the data is key. Otherwise, we just have a lot of data and we have a hard data mining challenge.

The last thing I want to point towards as an industry trend here is the ability to take action on data. The reality is that all modern Tier One telco networks are being built Cloud-native. That is, rather than hardware, they're being built out of a series of containerized network functions that are geographically distributed across data centers. The space industry we're seeing is basically learning from the last decade of the terrestrial wireless community and is following suit. That means that whether it's terrestrial wireless or non-terrestrial wireless, that means communications is basically adopting the same CI/CD muscle [continuous integration (CI) and continuous delivery (CD)] that we see today in other software technologies.

So my telco network in the future will have the same daily, weekly rollout of new features that we see Office 365 do today. This CI/CD muscle becomes our action loop for how we do and manifest spectrum management. It means that the network will always be evolving and changing. And that becomes our entry point to take what we learn and put it into action.

So with that, I'm looking forward to the rest of the panel.

Edward Oughton: Fantastic. Thank you very much Paul. So without much further ado, I'd like to get into our final panelist, which is Ian Fogg who is VP of Analysis from Opensignal. Over to you, Ian.

Ian Fogg: Great. Thank you. So I have a few slides, so a few on who we are, what we do, and then I have some slides on actual real-world data looking at what's actually happening with mobile experience spectrum in a few different ways in the U.S.

So next slide please.

Opensignal is an analytics company. We do all the measurements, but we do a lot of scientific analysis to derive meaning from those measurements, which is critical. [audio lost] Those charters for our methodology are on our website.

Next slide, please. Thank you.

We do all the kind of technical measures. I think the panelists have talked a lot about signal measures. Signal is essential to understand spectrum and what it means for the experience of the users of that spectrum. But it's not sufficient. What we have been doing at Opensignal is taking those foundations of technical measures of signal speed latency and looking at what it means uses of that spectrum. So in the consumer space, that might be video streaming, multiplayer gaming, voice communications, or, most notably during the pandemic, group video calling, which is essentially what we're doing today. When we look forward, the cellular technologies, the 5G technologies that some of the panelists mentioned around some of the spectrum bands that are currently of the debate, 5G will power not just the consumer part of the economy but increasingly the economy as a whole, as the carriers and the telecom vendors move into smart agriculture, industrial automation, automotive connectivity. It's really a glue for all parts of the economy. So it's one of those things where to understand how spectrum has value is critical not just for consumers, but for the wider economy going forward.

So I have some examples here. All of these are published on our website, so you can look at them later and dive in. If you've got the slides, there's a link on each side to the source material, which has got additional data, additional analysis. If you want the first one of those.

Next slide, please.

One of the things we published recently, we looked at, was how C-band is actually affecting the user experience in the U.S. There are two charts here. On the left you can see the actual speed for upload and download through C-band on two of the U.S. carriers, and we've contrasted that with a 2.5 GHz spectrum. The other carrier has been using a similar kind of purpose.

On the right, you can see the jump in the overall 5G download speed around the time one of those carriers launched C-band.. So I think we're all very acutely aware that C-band has been quite a challenging rollout to the U.S. with a lot of debate between different sectors of the economy about how to clear the spectrum, when to do it, how to manage power levels and the rest. The good news is there is a benefit to the new uses of the C-band spectrum in the U.S.

Next slide, please.

We've also looked at one of the other spectrum models in the U.S., CBRS. This is data collected from smartphone users. This is all 4G data. On the left here, you can see how in a number of spectrum bands, the power level that the end-user device receives diminishes with distance from the tower. On the right, on the 3.5 GHz, you can see power levels are generally much lower. So what are the other kinds of key things that we see in the world as we talk a lot about spectrum? Spectrum is a very widely varying asset with very widely varying benefits. And understanding the characteristics of each type of spectrum and what it means for the use of that spectrum is really, really important.

On the right side here, you can see that those power levels correlate very closely with the end-user speed that users had at the same distance buckets from the tower. And you can see on the right side, there was a particularly large falloff in speeds on CBRS, partly because LTE 4G technology wasn't really designed to run on that high-frequency spectrum. This is one of the reasons why globally, 5G NR (New Radio) is being used at those frequency levels and is opening up many of these new spectrum debates on spectrum above 3 GHz.

Next slide, please.

We've also looked at unlicensed spectrum. On the main chart here. You can see multiplayer gaming. We've compared that with two types of 5G spectrum. Millimeter wave, this very high capacity, very high frequency, very localized spectrum with the overall 5G experience and with 4G. We've also split Wi-Fi out because one of the key things you can see with unlicensed spectrum is different kinds of Wi-Fi have different characteristics.

Public Wi-Fi is typically in a very noisy environment. It's typically a place where you have a lot of Wi-Fi hotspots in close proximity. Other Wi-Fi on this chart is typically residential. So it's Wi-Fi attached on top of home broadband. And it's typically a much better experience because you have less interference on that unlicensed spectrum because the residents tend to be further spread out.

On the bottom right chart you can see an even greater difference when you look at the speeds. And you can see public Wi-Fi is a fraction of the speeds of residential Wi-Fi in the U.S. But you can see also that 5G using licensed spectrum is considerably faster than public Wi-Fi. And in the case of millimeter wave, considerably faster than residential Wi-Fi as well.

So we can see with Opensignal data, different kinds of spectrum, different kinds of models whether it is unlicensed, licensed, or shared licensing. And we can see some of the real characteristics of how they're actually being used in the world. We are looking at not just the signal measures, but at some of the applications and services and experiences that people are using to move just beyond the technical measures, to the overall experience end-to-end of users.

Next slide, please.

We can also track just, you know, macro topics. This is a piece we published looking at just the overall 5G experience across the U.S., where there's wide varieties in how 5G is being deployed, and how extensively the quality experience is. You know, partly this is just the state of the rollout at a fairly early stage.

But partly this is related to the very complex spectrum picture in the U.S. You know, in some countries, like in the U.S. or in Brazil or India, spectrum is not a national asset or national license. In the U.S. it's very fragmented, those spectrum holdings. And that has a direct effect on the 5G and the cellular user experience. In some markets spectrum is. you know, licensed nationally and it's a much simpler picture.

But again, we can see those granularities, those variances in the experience, often determined because of different spectrum holdings when we look at the overall experience across the U.S. And again, there's more of this on our website. That's my opening remarks. I'll hand it back to Ed so we can jump into some discussion.

Edward Oughton: Thank you very much, Ian. And I really liked seeing the dense visualizations of real-world quality experiences, and they really kind of enhance the debate that we're having.

So I do have a couple of questions that I want to start us off on. And I just want to first go back to Greg, and I want to ask about what appetite there is for MOU's. And can you talk more about how that kind of data process kind of took place? And then I'd like to go to Kaushik please, because obviously, Kaushik you're on the kind of data generation side, and I guess my question is how you consolidate the synthetic datasets you are generating and whether you could use data on MOU arrangements to help improve your existing frameworks that you developed.

So, so Greg first and then please Kaushik. Thanks.

Gregory Wagner: Thanks, Ed. I didn't quite catch [what you said], you dropped out right there. You wanted to ask me about the appetite for... and then I lost the audio.

Edward Oughton: You mentioned in your initial statements that you've been involved in MOU's for data sharing. I think you said it was parametric data, essentially. So you [unintelligible] problems arise, your models, your analysis. Could you talk more about that process, please, and talk more about the appetite, whether there was appetite [for MOU's] or whether it's a quite hard process to actually go through.

Gregory Wagner: And so I'll answer those. The second part first, it was a kind of a lengthy process. And don't take this the wrong way, but there is a lot of legal review there. So that that takes time. And so, you know, at the action-officer level, the technologists might have had a general agreement, but it might take months and months and months to codify that agreement into something that both parties can sign. I don't know what you do about that. But at the technologist level, I think, or even under the 3450 MHz work that we're doing now, the department is very keen to get MOU's or non-disclosure agreements in place for the licensees there. So we can hear from the licensees and understand how they plan to use [the band]. The last gentleman, Ian, you know, kind of mentioned there's no national licenses, so, you know, we have to deal with these things locally, which increases the number of conversations we have to have. But how are you using this so that we can be in a better position to model the interference as early as we can? We don't want to assume everybody is using it [the band] the same way everywhere and then have to drive that conservatism out. If we can, we'd like to represent that as quickly as possible. We have to make sure that the carriers' data is protected. You know, this is a lot of secret sauce that's involved here. And it's important that we have the right protocols in place.

I would say there's a lot of appetite in that in the department to have those exchanges. But I do think it takes a little time to make sure that the proper protections are in place, not just for the initial exchange, but kind of understanding how the data can be distributed or what happens. So, you know, when we're done with the data, do we retain it?

What happens to the data as it gets baked into a decision that the department makes, which then forces the department to deal with a records management set of rules? And so now we have to hold on to that data for a certain amount of time to meet statutory and regulatory requirements in records management. So there's all kinds of interesting second- and third-order effects here that we have to be careful of.

And I think that's why it takes a little bit of time to nail those up. But once they're nailed up, they seem to work really, really well.

Edward Oughton: Fantastic. Thank you. And I think we have about eight minutes left before we're going to get to the final remarks. So, Kaushik, if you could just speak for a minute, please, about the validation your project and how more data or views might be useful for you?

Kaushik Chowdhury: Absolutely. So the mantra for machine learners is, The more data you have, grab it. Right? So that's the way we go with it.

I'll give an example of the RFML (Radio Frequency Machine Learning) dataset. And, so, we did a lot of interesting technical works that we used the RFML dataset for. This was the Data Frequency Machine Learning Systems program from DARPA. And Paul is here. He was the program manager. So we did a lot of interesting technical works that we wanted to tell the community that, Look, this is how we do it.

But Paul would scold me for sure if I would release his RFML dataset. So what we did was that we collected our own dataset, which was not at the scale of terabytes, but was somewhat smaller. But we did it in an RF anechoic chamber. We did it inside in a 2.4 GHz lab with proper precautions. So we validated results on both the government-submitted RFML dataset that we would not release and then on our own dataset that we would release.

And guess what? The industry started to pick it up. So if you look at the deep learning toolbox that MATLAB® brings out, it uses all our RFML dataset to showcase their algorithms. The cuSignal from NVIDIA [cuSignal is a GPU-accelerated signal processing library that is both based on and extends the SciPy Signal API, where GPU is a programable Graphics Processing Unit] uses our RFML dataset to validate their signal processing algorithms. Now, this is possible if you could establish a 1-to-1 relationship between the quality of data that we could share and what we could not share. And we made sure that everything from metadata representations to the diversity of data captures were all relevant.

So I think we need to invest a lot of time in creating good data and then validate against benchmark data which, you may or you may not be able to share.

Edward Oughton: Thank you very much. So I'd like to just go to this question that was in that public Q&A box, which is from Richard Bennett. And he's asked what can we learn from the fact that 5G radically out-performs Wi-Fi? And that's in your presentation, Ian. So I'd quite like to go to you, so you could take a minute and then I'm going to go to systems and models with Eli. So over to you, Ian.

Ian Fogg: I think it reflects a few things. I think it reflects the challenges of unlicensed spectrum. I mean, the many benefits of unlicensed spectrum, the flexibility, the versatility. But there are clear benefits to the licensed spectrum as well in terms of providing a great quality experience. I think the other piece to be aware of here is that that slide was in the U.S., right? And the U.S. has with the exception of millimeter wave, it's not been a leader in 5G. There are much better 5G experiences in other parts of the world where there is significantly more spectrum available for 5G. So I one of the other learnings here is, that's in a market where spectrum is in really short supply for 5G and where the carriers have had to manage uncertainty about how quickly they can deploy things like C-band.

Edward Oughton: Thanks for that. And I think when I saw your slides, what I kind of took away from it was that Wi-Fi seemed to be having these problems in public settings where maybe you have coordination issues and lots of interference. But then actually for the kind of home Wi-Fi setting where Wi-Fi is incredibly cheap to deploy, it seemed like it had much better performance. So maybe there's public cases.

Ian Fogg: Yeah, I think so. I think there's another piece here, which is, you know, if you want to get the benefit of one of these technologies, you need to make sure everything is in place. You need have the end-user devices capable of supporting that latest standard. You need the network supporting it. You need the backhaul supporting it.

And one of the challenges with Wi-Fi is that Wi-Fi devices tend to have much slower replacement cycles than do cellular devices. So even when you roll out the new standard, it maybe isn't deployed as quickly or as ubiquitously as maybe with a cellular experience.

Edward Oughton: Thank you. So now I'd like to turn in just the last four minutes while we're on the open session to Eli and Paul. And I'd like to get your thoughts, please, because you both presented ideas on how we could have system solutions to overcome, you know, maybe alternative evidence on spectrum across time and space frequency. Could you talk a little bit about the barriers to implementing the ideas that you put forward, please?

Paul Tilghman: I'll maybe just tackle one and then we can add others in. But one that I see is that we often end up with a position where the technical incentives and the technical "what's possible" do not align with business outcomes. And then a lot of times the gulf between business outcomes in fact would be possible actually betray an underlying gap from a policy perspective, right?

So if I pick on, you know, CBRS, right, I would say that if we wanted to go recreate CBRS in another band, what exactly are the business incentives to go create another type of spectrum access system, especially one that's maybe more complicated, more sophisticated, it costs more to run? Those really don't become clear until policy has cleared the way for the band or that spectrum access system to be in use.

So it took five years to kind of get the policies around CBRS right. So now we have CBRS. And I think because it took five years to get the policies right, we also have a lagged private 5G market where there probably isn't as much private 5G out there in the world as there could be or should be, because who is going to invest in building the substantial wave of private 5G technology, not knowing where the spectrum would come from?

And so I think the ability for regulators to sort of accelerate the regulatory frameworks so that business decision makers can say, yes, this is worth investing in because it will go create real opportunity revenue drivers. That's kind of a must, otherwise we'll always do regulatory first and we'll always be somewhere between a decade and a decade and a half behind where we could be just because of the speed of regulation.

Edward Oughton: Thank you very much. And Eli, over to you.

Eli Cohen: Yeah, I'll piggyback on everything Paul has said. There's the regulatory part. And then coming back to his first points about being cloud-native and thinking about platforms, I think one of the interesting trends that we've seen over the past decade or so is as it becomes easier and easier to get resources in the cloud and as more open-source projects exist to do small pieces of this overall spectrum analysis, spectrum management piece, the democratization sometimes leads to fractions as well. Right?

So we might see people on forked versions of models where there are slightly different variations on them. They're using data storage that maybe isn't compatible with other pieces. And so things that have made it very, very easy for players to stand up their own cloud interfaces and to put data in the cloud and to move their analysis to the cloud has led to a proliferation of cloud systems, which is in fact a pretty big challenge as well.

And so there's an argument that could be made around what's the right balance between everybody having the ability to go and spin up resources to train a gigantic model when they need it. But to also have that march, along with the rate of iteration that we see in this, is, as Paul said, a sort of CI/CD world of things do not stand still for very long. Right? How do you make sure that you're remaining performant over time? And so I think that coming back to some of the discussions that we've had about standards. About how do you share information with each other, how do you do that in a way that's responsible and actually passes value on down the value chain?

I think it's a really interesting discussion and I hope we'll see some interesting work in the next few years on how to action this.

Edward Oughton: Thank you. And I think, you know, some of what we just kind of discussed in the session, I'm very optimistic about the future. I'm glad we're talking about these cloud-native systems solutions because I can see how the evidence base could be generated. I think that's a good first step, even if it takes as a long time to kind of deliver on that vision.

So we've got nine minutes left. I'm going to ask each speaker, please, just to provide one or two minutes of quick kind of conclusionary comments. And I'm going to go through in the order in which we went through. So, Greg, if you want to just round up your thoughts, it'd be great to hear what you think.

Gregory Wagner: Thanks, Ed. I wanted first to maybe highlight the comment that Eli made earlier on the, you know, kind of the trust dimension and the return on investment question. I think that's essential. In the case of, you know, the 2025 MHz band that I spoke of earlier, you know, the DoD wanted access to that. So our motivation to share data was to gain access to the band. Whereas in AWS-3, it was kind of flipped a little bit.

You know, we got to say no. And so the carriers in some cases were motivated so they could get a Yes answer while maintaining the DoD's risk position. So I think that that's good food for thought going forward as we kind of contemplate this. And I guess if I had to wrap everything up, I would say that we've got some models, Ed, that we can work from going forward.

I think that it sounds like there's a lot of effort being put into standardizing some data platforms. We've had success in sharing the data. But as I indicated, we've got some time challenges here. You know, these things are working on scales of months, years in some cases, and they're resource intensive. But they do provide some pathfinders that we can use.

And in the end, you know, I come back to that same question. We do all this data sharing, we develop all these standards. But to what end? I mean, do we get a coordination zone that's set at 100 kilometers and after 36 months, we can revisit that and shrink it to 50 kilometers? Does that turn No's to Yeses?

And can we be articulate in how many dBs are we off from a No to a Yes, how much how much difference 1 dB will make. And those are business decisions as much as they are technical decisions. Thank you.

Edward Oughton: Thank you very much. So I think we're going to hear about one minute left per person. So, Kaushik, your final thoughts.

Kaushik Chowdhury: Yes. So one thought that came to mind is that we should think about RF data going beyond RF data. So to me, data would be multimodal. We have visual, lidar, cameras. All of this will augment if not, provide, context. But I think that came out in the panel. I strongly, strongly advocate for that. The second thing is training, data collection and utilization of data is as much an art as it is a science. And we must invest in that training pipeline, education, and workforce development to really bring out that next batch of engineers. So I'll pause in the interest of time. Thank you.

Edward Oughton: Thank you. Eli.

Eli Cohen: Okay, I'm going to auction the remaining three minutes between everyone. So, look, I think what's really interesting about this panel is that everybody's coming from a different perspective. But we're all talking about the same fundamental thing, right? The RF environment. And I think that until everybody that has a stake can look at the same picture and Ian can do his analysis and Kaushik can run his models and Paul can enable the cloud part and Greg can run the defense sector on this piece, it's going to be a scattered environment. And so I think that this panel is in some ways a microcosm of the world and hopefully more proactive communication like this can happen. Over.

Edward Oughton: Thank you. Paul.

Paul Tilghman: All right. If I were to wrap up here, I think something that I would love to see emerge over the next one to three years, maybe no more than that, max, is I'd love to see a moonshot program in spectrum management come out of—pick the appropriate part of the government. It's something that unites academic researchers, something that catalyzes practitioners, something that also provides clear, obvious business value. Because I fear that we will be arrested by a number of the challenges in trying to figure out what data do we need, when do we need it? How do we need it? Where do we need it? To what degree this needs to be multimodal? How do we distribute it? What problem are we solving? All of those challenges will continue to, I think, arrest the community. And if I go back to the one clear example and CBRS that we have, the problem there was easy to solve and straightforward because the incumbent was well known, well understood, and it was clear how to model them. If we want to move beyond CBRS, I think we need a sort of a uniting moonshot program that brings industry, academia, and government together to solve that problem.

Edward Oughton: Thank you, Paul. Let's move it to Ian with one minute left.

Ian Fogg: So I think what I heard from the panel today is, data alone is not sufficient, right? Whether it's Kaushik talking about machine learning models, Paul talking about the capabilities of Azure cloud, or Eli talking about Palantir's capabilities, that you need to have the data, that you need to have the measurements, but you need to apply meaning to them. How you do that requires data science expertise and all those kind of general purpose skills that could apply in any industry. But you also need to have a specialist knowledge about this industry and about these characteristics, as well, and tie those together. I think also to look at the different use of the spectrum, you need to understand different industries, the existing use of different types of spectrum and the potential use as well. And together we need to kind of allocate spectrum efficiently between those competing demands.

When I look at the U.S., and I compare it globally, it's a really complex picture in the U.S. And it's holding the U.S. back at the moment. And I think one of the things that we need to do in the U.S. on the spectrum is to be faster and more efficient at allocating spectrum well. And I think if we don't do it as an industry, there'll be external pressures from politicians, from consumer groups, from large industrial conglomerates to force us to do it better. That's my immediate observation, I think, here.

Edward Oughton: Fantastic. Thank you very much. Well, I guess this is our opportunity to kind of round everything to a close. And I know that I'm biased, but I actually found the discussion today very inspirational. And I think it really sets up a nice agenda for each of us in our respective areas to improve data sharing and transparency in the future in relation to spectrum management.

So without further ado, I guess we're going to end this session. So thank you very much for being here and we look forward, hopefully, to seeing more tomorrow at the next session for ISART 2023.

Thank you. Goodbye.

Mike Cotton: Well, thank you very much, Ed, and the panelists from the data sharing panel. I was pretty amazed at how we closed that out with all the summaries and all the way back to Evan and the economics panel too. I felt like this was a great day with some really bright ideas that came out of it. So I want to remind the moderators that we are to come back on the last day and try to recap towards a roadmap on policy, innovation, and spectrum around continuous evolving science in spectrum regulation. Tomorrow, Howard is going to kick things off at 1:00 PM Mountain Time. So please enjoy the rest of the day and we will see you tomorrow at ISART.

5. Day 3: Wednesday, June 15, 2022

5.1 Opening Remarks

Howard H. McDonald, Defense Spectrum Organization (DSO), Defense Information Systems Agency (DISA), Retired

Howard McDonald: All right. Good afternoon, everyone. Welcome to Day 3 of ISART 2022. I'm Howard McDonald, formerly with the Defense Spectrum Organization (DSO) and a member of this year's ISART Technical Planning Committee. Some quick comments before jumping into today's agenda. Recordings for Day 1 and Day 2 are being made available within the ISART virtual platform. It should be a "view recording" button next to each completed session within the schedule where those recordings are available. Also, Mr. Charles Cooper's keynote is being re-recorded and is expected to be available on the platform by Friday. We apologize for the technical difficulty during his keynote.

Now, back to the agenda. So far, we have heard an industry perspective on spectrum sharing. Also heard from a panel on the economics of spectrum sharing and a panel on data sharing and transparency. And we've heard keynotes from national-level leaders on their perspectives on spectrum management.

Today, we'll roll up our sleeves and pick a more technology-focused perspective on evolving spectrum sharing regulations. We have two panels lined up for this afternoon, one being risk-informed interference analysis, the second being focused on model standardization and using propagation as a study case.

But before we get to the panels, we have a keynote by Mr. Fred Moorefield, Deputy Chief Information Officer for Command & Control Communications, Office of the Secretary of Defense, Chief Information Officer.

But before bringing Mr. Moorefield to the stage, I have a quick anecdote to share. I participated in an Air Force–sponsored cognitive radio conference about a decade or so ago, and at that conference there was much frustration expressed by many participants regarding the lack of innovation in terms of spectrum access, new ways of doing spectrum management, technology, transition, etc. I opined at the time that the root challenge was lack of leadership, and I can tell you that over the past few years Mr. Moorefield has provided that leadership; and I look forward to hearing his keynote on the national security perspective of spectrum. So let's bring Mr. Moorefield to the stage.

5.2 Keynote: Cost-Benefit-Risk Related to National Security

Frederick D. Moorefield, Jr., Deputy Chief Information Officer for Command, Control, and Communications (C3), Office of the Secretary of Defense, Chief Information Officer

Fred Moorefield: Good afternoon, everyone. Thank you for the introduction, Howard. For those that do not know me, my name is Fred Moorefield and I serve as a Deputy CIO for Command, Control, and Communications (C3) within the Department of Defense. Prior to serving as deputy CIO for C3, I led spectrum for most of my career and have worked within the department to advance our military objectives around spectrum, while also supporting national initiatives to ensure global U.S. wireless leadership in the United States. I am pleased to be invited to this year's ISART conference. The theme "Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making" could not be more timely.

We are at a time where the growing demand for spectrum by our users are outstripping supply. We are at the limits of what current regulation and approaches to spectrum management can achieve. The status quo is unacceptable for the challenges that lie ahead. To continue meeting that insatiable demand for spectrum from all corners of our society, we need to rethink the entire framework for spectrum sharing as the foundation, from my perspective. Data, science, and technology will be the core parts of advancing spectrum sharing. The Department of Defense (DoD) has identified these areas for improving spectrum sharing and other needed innovations.

We released a data, cloud, digital modernization, command-control-and-communication, and spectrum superiority strategy, which combined are leading to widespread changes in how we operate and build systems within the Department of Defense. We know we cannot do this alone. Participating in forums like ISART is important to the department to hear what innovative technologies and research industry and academic leaders are pursuing so we can understand how they can help our mission. Your work can be key to improving our government capability and tools to increase the spectrum supply through spectrum sharing.

Back in 2010, there were many claims of impending doom around spectrum, some dubbing it a spectrum crunch or crisis. However, what we faced back then focused pretty much on the needs of one industry—the commercial wireless industry. Now, the importance of spectrum across multiple parts of government and the economy are unquestioned, and the crisis facing the U.S. leadership today and many spectrum dependent sectors is real.

We're in a new spectrum crisis, which will require a whole-of-government, whole-of-industry, whole-of-nation commitment to prepare for a future that must be built on more spectrum sharing. Without it, we will fail to meet our national spectrum priorities. We must start now and develop the vision, the strategy, the roadmap, and policies needed to revolutionize spectrum management.

If we are to be successful in developing greater spectrum sharing, our companies need to start making investments now, and the U.S. spectrum framework must be there to support these new uses. Our window for innovation and to lead in the next wave of spectrum technologies is rapidly closing because others are going to pick up on it and take advantage of it.

We need a strong plan to reform how we do business so we can kick off a new wave of innovation in the U.S. with spectrum sharing at its core. Data-, science-, and technology-driven approaches are key. You may ask why we at DoD are such strong proponents for more spectrum sharing. DoD is by far the largest federal user of spectrum, and the diversity and breadth of our spectrum use is unlike any other federal agency or commercial user.

We employ narrowband, wideband, broadband communications systems that are fixed, mobile, portable, satellite-, vehicle-, and ship-based. We have satellites for imaging, navigation, positioning, weather forecasting, and earth observation. We field radars of all types, different types of weapon systems like guided missiles, as well as systems to counter enemy attack. We have air-traffic-control, flight systems, drones, aeronautical mobile telemetry and other unmanned systems, and I could go on, and on, and on.

I'm just scratching the surface of some of our uses of spectrum to support our missions. For all these categories, we train both here in the United States and overseas with our allies. We must coordinate our use with other nations to ensure we do not interfere with their uses, government or commercial. During military joint exercises with allies we work to ensure that our systems coexist, so when called upon to fight a common enemy, we can achieve common objectives.

We work with our defense industry to make sure they understand what future capabilities we need to continue to be the best military in the world. In today's spectrum environment, DoD coexists with a diverse group of commercial, military, federal, and global systems. We are increasingly challenged to effectively prepare our forces to maintain the global order. We, too, are acutely aware of the high global demand for spectrum from across industry and other government missions.

No one doubts the potential economic benefits of spectrum. 5G and Next G promises a significant transformation in speed, capacity, and reliability. These technologies are also rapidly changing the character of modern warfare as more nations and non-state actors leverage cheap commercial technologies for military purposes. We're also seeing our adversaries invest heavily to counter our spectrum-based capabilities.

The current situation in Ukraine shows how important superior spectrum capabilities are to achieve our global security mission. This incursion will be studied for years to come and has long-range implications for spectrum management and investment. The operating environment has never been more challenging as the one we're operating in today. The spectrum environment is an increasingly congested, contested, and constrained.

DoD must continue to continually evolve to overcome new and sophisticated attempts to interfere with our spectrum-based systems. It will only get more complex, and we are approaching a turning point in how we exert spectrum dominance to continue to ensure our spectrum access serves as a strategic asset. Developing and promoting greater spectrum sharing is a way to ensure that we continue to serve our capacity.

We have been doing our part to advance spectrum sharing. DoD is not a regulator, nor do we want to be one. That role has been endowed upon by National Telecommunications and Information Administration (NTIA) and Federal Communications Commission (FCC) and they're resourced to do so. However, our mission requires us to plan for the future, and we work closely with FCC and NTIA to advance regulations and policies we require to continue to be successful in our missions.

In 2020, the Secretary of Defense signed Electromagnetic Spectrum Superiority Strategy, called the EMS 3 to focus our department-wide efforts in the face of this new operating paradigm. At the core, the strategy lays out what is required for maintaining freedom of action in the electromagnetic spectrum at the time, place, and parameters of our choosing. This involves making the DoD spectrum enterprise more fully integrated, operationally focused, dynamic, flexible, and resilient in the face of a complex operating environment. Our spectrum dependent capabilities and operations must be unpredictable, flexible, dynamic and resilient.

The 2020 National Defense Strategy, the Digital Modernization Strategy, the C3 strategy, and Electromagnetic Superiority Strategy and other strategic military planning documents all recognize that the nations that lead an innovative development and adoption of new technologies will reap dramatic strategic benefits. Leading a spectrum-based capability to achieve military superiority follows the core guiding principle.

Our adversaries understand this, too, and the threat is beyond theoretical. It is real, and already here. The status quo must change. The current spectrum regulatory construct, built on a 20th-century spectrum ecosystem, does not support DoD's needs today for the rest of the 21st century. Our mission does not allow us to be beholden to the current static processes.

We need policy and regulation processes and processes that are more dynamic, adaptable, and flexible to ensure we can continue to achieve operational superiority and unpredictability. So as we evolve our capabilities, we need the policies and regulatory framework to evolve too. This is why I was excited about the topic for this year's ISART. The type of work you are all presenting speaks to the need for increased sharing and modernized U.S. spectrum regulations.

Historically, the U.S. has successfully reconciled competing needs through our regulatory framework. To meet the diverse and growing demand for nearly all spectrum users, we must return to a balance. We must go back to the roots of policy principles that support U.S. technology innovation by reaffirming the longstanding view that spectrum policies must support diverse uses for both federal and non-federal users.

To do this, we must change business processes and invite the stakeholder community to contribute. We must improve how we cooperate and collaborate and evolve the regulatory framework to support a more adaptable and dynamic spectrum future. Ultimately, this leads to what must be front and center for U.S. Spectrum Policy: a commitment to unleash technology innovation, enabling more spectrum sharing and strengthening our national security.

The department has a long history of seeking out policy and technology innovation to improve spectrum sharing. We are on our second other transaction agreement with a National Spectrum Consortium. We have assembled diverse minds across industry and academia, focused on developing new and innovative spectrum sharing technologies. The consortium has 405 current members, 77 percent of those from nontraditional entities, not from the defense industry.

Of the 405 members, 225 are small business, 28 are academia, and 23 are nonprofit, along with 129 large companies. This forum has been an important source for DoD to bring in innovation, first to Advanced Wireless Services-3 (AWS-3; comprising the 1755 to 1780 MHz and 2155 to 2180 MHz bands) sharing challenges, and now for other bands. My colleague DoD CIO Vernita Harris is co-chairing a working group and a consortium called Partnering to Advance Trust in Holistic Spectrum Solutions or PATTHS.

This forum is working to build shared spectrum use cases, inform network architectures, and determine ways to share spectrum in the 3130 to 3450 MHz band. The transparency and partnership that are at the heart of the PATTHS effort is critical to a congressionally directed study on sharing options for the entire 3100 to 3450 MHz band.

This effort, which is already well underway with the participation of FCC and NTIA in the PATTHS and the Executive Steering group, support[s] plans for an FCC auction as required by the Infrastructure Investment and Jobs Act. We're also conducting a 5G pilot at Hill Air Force Base, where we are studying dynamic spectrum sharing solutions between radar and 5G systems operating in the band.

This follows our other major work in the mid-band 5G solutions spectrum space, including work to successfully share the 3450 to 3550 MHz band, which was auctioned earlier this year. And the Citizens Broadband Radio Service (CBRS) in 3.5 GHz. As I hope you are all taking away, more spectrum sharing is a major priority for the department. We recognize our responsibility as the largest federal user of spectrum to advance spectrum sharing for the nation.

This is key to not only the ability of our national regulators to meet Title 47 responsibilities to promote wireless broadband, but also to fulfill the Title 10 and Title 50 responsibilities to advance military mission needs. I should also emphasize that these spectrum challenges are not just between military and commercial wireless. There is a wide range of sectors that depend on access to the spectrum, including utilities, telemetry, new satellite mega-constellations, drones and autonomous vehicle makers, commercial space launches, and more.

There are many communities of interest that need spectrum beyond 5G wireless network operators. Dynamic spectrum sharing could support all of these users, from our perspective. I want to leave you with some additional thoughts on where DoD believes we need to focus our efforts to increase innovation and develop more flexible and adaptive forms of sharing.

Number one: infrastructure and tools. The entire spectrum management information infrastructure must be modernized. Our current systems cannot keep pace with the speed of technology changes. Our modeling and simulation tools are not able to effectively assess the impacts of new technology into an already complex environment. Dynamic spectrum sharing systems will not only support operations today, but also ultimately support autonomous spectrum operations that will be enabled by software defined capabilities, artificial intelligence, cloud computing, and sophisticated decision support systems. For these systems to work, we will need better spectrum management tools and data.

Number two: policies, regulations, and laws. Our laws, policies and regulations must be upgraded or changed to allow new spectrum sharing technologies to be unleashed and flourish. Companies and agencies need spectrum predictability, need to be able to invest now in spectrum sharing technologies as an industry. Sending a signal that more spectrum sharing is the new normal will allow all to flourish and plan for the future. Technology evolving faster than the law is not a reason for inaction. We must continually improve the Code of Federal Regulations, the NTIA Redbook, and other supporting documents to enable fully integrated operations and increased sharing. At the same time, we need to keep what works and retire the rest.

Number three: trust and transparency. Building trust and transparency into the U.S. spectrum framework is paramount. Lack of trust and transparency has stalled the spectrum community too long and must be repaired. Building trust and transparency requires a mindset and culture change. Culture change is hard, but we must recognize that in spectrum we all need to work together. Recent public policy fights have received big headlines. However, the quiet but steady work of the Consortium, PATTHS, and other spectrum decisions show how much we can do when we all collaborate and cooperate and work together.

Number four, next generation spectrum experts. And finally, the U.S. needs to continue developing greater spectrum expertise here in the United States. Both the commercial sector and the federal agencies rely on a highly educated, skilled, and experienced workforce to manage spectrum, build new and innovative spectrum technologies, and launch new spectrum-based services. The nation has fostered homegrown talent to compete both in a 21st-century economy and to ensure government excellence. This could include bolstering RF engineering in our universities or overhauling the spectrum management career field and associated training.

In conclusion, spectrum is deeply embedded in everything we do. Increasing spectrum sharing that serves all our society’s diverse and important needs represents a huge undertaking. However, the benefits to our national security, our economy, and the American quality of life make these investments a no-brainer. We must work together to propel our American strength throughout this world. Again, I appreciate you inviting me today and I look forward to working together and hearing more about your research.

Thank you very much.

5.3 Panel: Risk-informed Interference Analysis

This panel will first take a broad view of risk assessment in several regulated industries. We will explore what it is, how risk assessment is done, and what lessons have been learned about risk assessment in the last 40 years of use. We will then delve into the details of how risk assessment might be applied in spectrum coexistence studies. We will explore how risk assessment might make a difference in spectrum management, both in regulatory feasibility studies and/or to facilitate successful operation. Other questions include: What is unacceptable vs acceptable risk? What tools and skills are needed? Where has risk assessment made a difference to outcomes? What should we do differently, going forward?

Moderator: JP de Vries, Director Emeritus and Distinguished Advisor, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, Boulder, Colorado

Mohamad Omar Al-Kalaa, Staff Fellow/Electrical Engineer, Center for Devices and Radiological Health (CDRH), U.S. Food and Drug Administration (FDA)

Kumar Balachandran, Expert, Ericsson Research

Robert Henry, Principal Risk Manager, The MITRE Corporation

Kalle Kontson, Principal Professional Staff at Johns Hopkins University Applied Physics Laboratory

Nick LaSorte, Electrical Engineer, NTIA Office of Spectrum Management (OSM)

Howard McDonald: The moderator is JP de Vries. He's the Director Emeritus and Distinguished Advisor at the Silicon Flatirons. JP has done foundational work, great foundational work, in the area of risk relative to spectrum management, and I couldn't think of a better moderator for this topic. So, JP, I'll turn the stage over to you.

JP de Vries: Thank you very much and great to be with everybody. Our panel today is going to be talking about risk assessment. And we have five panelists who have experience, not only in government but also in industry and working for both. And we're going to have a very conversational session today, I hope, and we hope to actually have time for audience Q&A as well.

But let me just start briefly by giving you sort of my two cents about how I got involved in this and what I think the intersection is between risk assessment and spectrum coexistence. I got involved doing, you know, statistics when I was looking at the RF environment. And I got curious and thought, you know, where else can one use statistics?

And I came across this area of risk assessment, which, to my embarrassment was new to me, because it turns out that just about every regulated industry other than spectrum has been doing it for at least 40 years. And so I started learning about it and sadly, our panelist Prasad Kadambi can't make it today. He was with the Nuclear Regulatory Commission, [which] was a pioneer in this area.

And you know, as I learned about risk, and you'll have the experts talk about this, you know, the question I will have for all of them is What does risk mean to you? To me, it comes from a seminal paper back in the early 1980s that talked about the Risk Triplet. So, you know, it's (1) what are the things that can go wrong? (2) how likely are they? and, (3) what are the impacts when they do go wrong? And the fourth thing that one would add to that actually is, (4) What do you do about it, how do you how do you mitigate it?

And so I think the reason why this really appealed to me is it seemed to be a useful way of complementing how spectrum coexistence is often studied or done, which is in terms of worst case. And worst case is, you know, a particular point in this Risk Triplet. It's one of the things that can go wrong. It's the one with the worst severity you can possibly imagine and you ignore the probability. And very often the worst case is useful, because if you test for the worst case, then you don't have to worry. Then you are done. You don't you don't have to do any more.

But with that, what I'd like to do is to start with our panelists. So I'll ask each of them a question also just to introduce them to you, and then we'll start having the conversation. I'll start with Rob Henry, who leads MITRE's Risk Analysis and Management practice area. He's the Principal Risk Manager at MITRE.

And he's been doing this for a very long time in many, many industries for many agencies and departments. So, Rob, my question to you is, how do you go about introducing risk management into an organization that hasn't done it before?

Robert Henry: Thanks for having me on the panel, and great question, JP. And the first thing is really to understand what the objectives of the organization you're trying to work with are, because risk management is actually a measurement of your ability to fulfill on your objectives and your mission. If you actually don't understand that, risk analysis really doesn't play any role.

And so understanding and putting it in the proper context is the first step. It's amazing how many times the first thing I ask people is, what are your objectives? And often they can't even articulate that. So that's an important thing to even get to, is what are we doing? And then figuring out what are the things that are going to prevent us from getting there.

And so really connecting it—because risk management is all about achieving objectives. It's not about what's going to go wrong, it's about how do we achieve our objectives and remove those obstacles to it. So it's important to understand that, to place it in that context. And once you've done that, then they're more receptive because they understand why you're bringing this analysis to understand what you're actually trying to accomplish.

JP de Vries: Yeah. Thank you very much. And let's just go through the whole panel and then we'll get into the conversation. The second person I'd like to introduce is Omar Al-Kalaa. He's at the FDA (Federal Drug Administration). He is a staff fellow and electrical engineer at the Center for Devices and Radiological Health. And in a way, Omar is our bridge between risk assessment done for all sorts of reasons and applying it to wireless purposes.

So my question for you, Omar, is, you know, why is the FDA looking at spectrum coexistence?

Omar Al-Kalaa: Okay. First of all, thanks for having me here today. And I think I want to start my answer by concurring with Rob. It is all about the mission and what it is that you're trying to achieve. The mission for the Center for Devices and Radiological Health is to protect and promote the public health. And when it comes to wireless medical devices, that falls under the purview of the Center for Devices and Radiological Health and medical devices that have enabled wireless capabilities, might introduce risks to patients.

And when those wireless capabilities are in a scenario of wireless coexistence or when two systems are sharing the same channel resources, they might impact each other's ability to fulfill those functions. And that's when we start to think about, okay, what would be the consequences of the delay or disruption of wireless communication in a medical device? What is the medical device trying to do with that wireless function and what would be the consequences to the patient?

And the patient harm is at the center of this whole perspective.

JP de Vries: Great. Thank you very much, Omar. The next speaker or next panelist is Kalle Kontson, who is Principal Professional Staff at the Applied Physics Laboratory at Johns Hopkins. And Kalle actually led a very interesting project—it's in the references, if you want to follow up—which was incorporating risk assessment into how the Department of Defense does spectrum studies. So, Kalle, could you talk a little bit about why you did that and how you did that?

You're muted.

Kalle Kontson: Well, first and foremost, the why is because it was fun. But beyond that, what we realized when some of the legislation came through mandating some shared access to what was Department of Defense (DoD) spectrum, we had to step back and say, you know, when you have a shared access or shared resource, everybody has to assume some level of risk. It's like driving to work every day. Or, back in the good old days when we used to drive to work, there was always an assumption that everyone was willing to assume a certain amount of risk, some more than others. And you can't be too sensitive about what you consider a consequence of having assumed that risk. Being mad because someone cut you off is one extreme. You know, having a fatal accident is the other. There's a lot of space in between.

We realized that same kind of principle applied to the sharing environment that we were asked to consider during the most recent Advanced Wireless Services-3 (AWS-3; comprising the 1755 to 1780 MHz and 2155 to 2180 MHz bands) related activities, as well as other things that the DoD has to consider in both congested and contested environments. So what we did is we decided to try to address what turned out to be basically a many-on-one problem which was best tackled with statistics. And we had a wonderful working group that Howard McDonald and Greg Wagner talked about in supporting the Spectrum Sharing, Test and Demonstration (SST&D) program within the Defense Spectrum Organization (DSO) where we actually identified the parameters that exhibit the most variability, characterize them statistically, and used statistical math and convolution, deconvolution, and representing things as random variables to try to express what the realistic probability of a system impact—meaning system performance impact—would be. And the target was in the vernacular you're most familiar with, JP, and that is to try to fill and quantify the likelihood access of that classic matrix between likelihood and consequences.

JP de Vries: Mm hmm. That's great. And actually, you I think you've actually pressed a couple of Nick's buttons. So I'm going to I'm going to move to Nick to hear from him for the first time around. Nick is an engineer at the National Telecommunications and Information Administration (NTIA) Office of Spectrum Management (OSM). And, I think the first question is, you know, Kalle brought up statistics, so from your point of view Nick, why do we need probabilistic models at all?

Nick LaSorte: Yeah, thanks for having us. I did love, if we can just pull back to, what Fred said [Frederick D. Moorefield, Day 3, June 15 - Keynote: Cost-Benefit-Risk Related to National Security] about how the status quo needs to change. The future static spectrum management paradigm won't work for DoD going in the future. And so when we think about risk, right, we aren't worried about, well, the status quo, right?

But rather, we're worried about the risks in the plans that we're going to do to change the status quo. So as we're going forward, that's how we're incorporating risk, right? But, yeah, in terms of statistics, I think one of the powers of probabilistic models is, well, we don't need to have perfect information in it, right? So there is that uncertainty built into the probabilistic model, which makes it nice for us, right? Especially with spectrum. We'll never know.

JP de Vries: Yeah. I mean, one of the things that this reminds me of is one of the first things I read, which was a Nuclear Regulatory Commission paper, one of the early ones, and they had a chart and it wasn't quite the risk matrix which you can inveigh against later. It's not the 5 × 5, but what was really interesting was that they had probability, you know, the likelihood on one axis, but it was orders of magnitude, like 10^{-1}, 10^{-2}, 10^{-3}. And that was good enough for them. So you don't need precision, you know, and one of the things that that we'll come back to, Nick, you know, is actually this really interesting about your role is, you know, you do these studies for lots of different groups of stakeholders, lots of different proceedings and so on, and I want to turn to Kumar, who's a Principal Researcher at Ericsson Research and an expert in wireless communications networks.

And, Kumar, you work a lot with spectrum coexistence and the tussles around that. And so in your experience, when you have lots of stakeholders, what tends to be the sticking points between them?

Kumar Balachandran: To me, it's largely, you know, it's because of a lack of open information about building practices and the proprietary concerns between the industries. Typically, these interfaces between services or between industries are where you face the most difficulties. So there is a, you know, very little transparency about what sort of study assumptions you're going to make, what parameters are important, and so on.

And also, as it was pointed out, I mean, it's very difficult to agree on what the mission is, because if you have coexistence between more than one service, then typically the missions are different, right? So a typical example is between the satellite industry and the mobile industry or between radiolocation and the mobile industry as they have seen.

The other issue, of course, is that there could be a large deployment of uncontrollable equipment that already have an incumbent status.

JP de Vries: When you say uncontrollable, what do you mean?

Kumar Balachandran: In the sense that it's very difficult. So take the example of the GPS receiver case. You know, if you want to put mobile systems close to that band, then you have a large number of consumer devices that are out there in the market that cannot be replaced. And, you know, you can expect some sort of a natural end-of-life process, but it takes time to achieve that.

And then the other issue, of course, is ecosystem condition. So you could have situations where you have radios out in the environment that, you know, cannot be very complex because of their use cases. Say if it's Internet of Things (IoT), devices or, you know, other cases, you'll have problems with having enough complexity to actually handle, you know, very strict requirements on emissions, and on receiver performance, and so on. And lastly, I think a large part of this is also, you know, it gets dictated by dogma.

You know, there are there are conflicting mission parameters that are thrown into the mix. So, for instance, there could be a statement which is made that sharing is a necessity or that guard bands are bad. Or, you know, you might have other economic considerations such as, competition and technology neutrality coming into the picture, which will subtract from spectrum efficiency as a whole.

But you have to be very clear on what you want to achieve at the end. And when you have conflicting requirements being thrown into the mix, you could end up in situations where you're not able to account for all the risks.

JP de Vries: Mm hmm. Mm hmm. Yeah. Let's now go back to Rob. And actually, you know, I think, you know, this will be an invitation to all the panelists to respond to what you've just heard. But, you know, Rob, with your decades of experience and, you know, seeing this in many different industries, how do you respond to the kinds of things that you've been hearing from the other panelists?

Robert Henry: Well, I think there's a number of things that you have to keep in mind. What often gets lost in risk analysis is what decisions are being made. And so people are not focusing the risk analysis on the decision that actually needs to be. Are we making it what needs to be auction off? Are we doing a spectrum sharing decision?

What are we doing? Or, are we just trying to fit our known risk analysis to this one decision? So that is one thing that people need to keep in mind. As you know, it's focusing on the decision and the outcome that needs to be made and connecting back to that mission. The second thing is, there's many types of risk analysis that we have spoken about.

You know, Kalle was talking about some of the work that he was doing. As well as different types of risk analysis that aren't your traditional kind of 5 × 5 matrix risk analysis that really are appropriate to represent different kinds of risk. And so understanding that and being able to understand the complexity and the interdependencies between some of these complex systems that we're dealing with in the spectrum space.

So understanding that there may be multiple sources of risk too that could result in the degradation or complete displacement of a particular signal and understanding how those interact with each other. You can model those in a particular risk model and there's different ways to do that.

JP de Vries: So just for people who, for whom risk analysis is new, let's say this is the first time I've heard anybody talk about it. What is risk analysis? Can you give an example that might, you know, make it more concrete?

Robert Henry: Yeah. So risk analysis at its core is really the identification and characterization of something that's going to prevent a particular objective from being achieved. At its core, that's what it is. And there's a number of different types of things. We've talked about a little bit earlier where you're identifying specific risks that have a particular probability or an impact or you're looking at really kind of, I'll say, distributions of risk, that understanding that you could have all kinds of possible outcomes depending on the number of complex variables that are contributing to the things.

And so all of these have different kinds of [unintelligible]. So there's a [unintelligible] of enterprise risk analysis. You have, you know, probabilistic models, you have network analysis. There're numerous methodologies that can be applied in these spaces. But what's important is connecting it back to what we're trying to decide, and understanding whether the models you're choosing—you know, the old adage that models are always wrong but are often useful—it's understanding which ones actually apply to the decisions you're trying to make and do they have enough fidelity to inform that decision? And so, understanding the level of fidelity that you're incorporating into your analysis is also important and one of the requirements.

JP de Vries: So, one of the things that a number of people mentioned, and Kumar in particular, was when there is no agreement on what the mission is or what the objective is, when there are different perspectives on what decision is being made, how do you tackle that?

Robert Henry: Well, there's a number of different ways to tackle that. One is making sure there's transparency and making sure that there's justification of why they think their mission is the most important. I find that in conducting many a risk analysis with, I'll say, all the services in DoD, and let me say they did not agree on what was the most important, but they had to justify what they're doing.

So in making sure that it's transparent and saying, this is why we think it is, here's what it is. And there's a number of different methodologies that you can do to really elicit preference and all this kind of stuff. There's a bunch of different approaches that can be done to do that. Additionally, you know, like when you look at from the commercial sector, you can also look at it from pricing perspective, you know, how important is this?

And you can actually model this in a non-commercial sector. For example, "We give you so much money; how much are you willing to spend to have this not be interrupted?" You know, is it really that important to you, or not? And when you really get down to it and you get an honest conversation going with these mission owners, not all their missions are created equal.

Some, it's okay for them to occasionally be interrupted. Others are essential to never be interrupted. And all of them know that. But when, unfortunately, we have an environment and culture that it's, you know, you defend your turf to the last battle, and that's definitely prevalent in the spectrum space.

JP de Vries: Yeah. And you know that's something I want to use to go back to Omar. One of the things that I'm very aware of in spectrum is that the arguments usually seem to be between different services of different kinds of operators and the regulator—whether it's Interdepartment Radio Advisory Committee (IRAC) or the FCC or OSM—is the referee. And I used to think that, you know, for other agencies it's easier because, you know, there's the government and there's the industry and they have a debate.

So, you know, and I think Omar was trying to educate me that that's not the case. So, Omar, how do the dynamics work and how does risk assessment fit into the dynamics at the Food and Drug Administration?

Omar Al-Kalaa: All right. So I happen to meet very often with a corner-case of this risk assessment paradigm, where you actually can sit around a table with different people that are trying to compete for their objective. Because it is very common in medical devices to use wireless technologies that are off-the-shelf, often operating in unlicensed spectrum bands.

So you lose that access to those other services and other competitors to the channel resources. And just to put a flavor on this, if you're looking at a patient side monitor that is trying to communicate the patient's vital signs wirelessly, that patient's side monitor could be competing with someone in the hospital room streaming YouTube, and they [the patient side monitor maker] have absolutely no control over what that person [the YouTube streamer] is trying to do.

So when looking at this, we tried to factor in what built-in mitigations to the risk of delayed or disrupted communication at the medical device are already introduced. How effective the mitigations are. And then look at the totality of the picture of what is the overall medical device trying to achieve, what is the wireless function of the medical device that is part of the bigger system trying to do, and then consider the risks of those functionalities.

At the FDA, when we started to think about spectrum coexistence more specifically in unlicensed spectrum bands, which is again very commonly used in medical devices with technologies like Bluetooth and Wi-Fi, we tried to reference that thinking to the tools that are commonly used by our stakeholders, by the medical device industry. And these are standards and technical reports that are often cited in the regulatory submissions to the FDA.

So we went about developing two primarily cited documents in this space. The first is from the American Association for the Advancement of Medical Instrumentation (AAMI), Technical Information Report 69; I'm trying to avoid the use of acronyms. And that document really describes this whole conversation. It describes how wireless functions are part of medical devices, how the risk considerations should be taken into account, and then it provides examples for different functionalities in different medical devices.

And then it cites and other standards for the testing and evaluation of wireless coexistence. And that one is the IEE/ANSI C63.27-2017, "American National Standard for Evaluation of Wireless Coexistence," requirements. And I will conclude my thoughts here with these two documents, the Risk Analysis and Management and the Testing and Evaluation. They have a 1-to-1 mapping.

So when you're looking at the high-risk wireless function in a medical device, there is a direct link to a certain evaluation gear in the test standard. So the technical information report tells you, okay, go test this way. And that test severity, or how difficult the situation is during testing, decreases when you decrease the risk of the wireless function of the medical device.

JP de Vries: Mm hmm. Yeah. Turning to Kalle. You know, one of the things that Omar tees up, I think is, setting up your process in a way that is intelligible to your user base, or your stakeholders, in a way that makes sense to them. You know, if they are used to technical information reports, use that. I'm very interested in the work that you've done, Kalle, with DoD in how different stakeholders have responded to what you're trying to do. You know, human nature being what it is, some will be enthusiastic and some won't. What have been the kinds of ways in which people have responded to the introduction of risk into an area where it hasn't been before. Explicitly, at least.

Kalle Kontson: I think it certainly wasn't a step function of approval by any means. I think in the areas where I've had the privilege to work with the DSO, I think there was a very good starting point when the Commerce Spectrum Management Advisory Committee (CSMAC) first met and developed these curves that were based on statistics. And everybody said, yeah, well, we're not talking about a worst case where everybody's transmitting at the same maximum power anymore. That was, in my mind, an icebreaker. And it showed a level of cooperation in this shared environment that maybe set the stage.

And what I've seen—I'm hoping this answers the question—but what I've seen in the subsequent years, when this Spectrum Sharing Test and Demonstration program was being run, the stakeholders include the wireless operators, the individual services, the other agencies, NTIA, and labs from ITS (Institute for Telecommunication Sciences), and all of this, it took time, but all of us made some progress and made some serious, I think, inroads in accepting the fact that there is a quest for realism. That if you want to do a realistic—and these are my words, not the words of DSO or anybody else—but if you want to do a realistic, incredible job of spectrum sharing, you have to be able to have realism, for lack of a better description, on that likelihood access. You have to be able to calculate probabilities based on realistic parameters that result in realistic statistical distributions, so that you can at least have a high-fidelity, reliable answer that's been validated for how likely is it that you have some level of performance degradation. And you don't want to frontload the parameters you're using by conflating the consequences—as you pointed out earlier, JP—with the actual calculation of probabilities that's necessary for quantitative risk assessment. And that theme grew within the stakeholder community. It's not over. We haven't perfected, we haven't touched all the parameters, the most relevant parameters perhaps yet, but we've touched enough of them to see that there was more of an acceptance among all the stakeholders of pursuing that goal of realism in the quantitative assessment of what the probability of system degradation is. And then let's worry about the consequences later. Let's not [unintelligible].

JP de Vries: Yeah. And so you've teed up so many things that I'd love to follow up on. I'll go to Nick next. But you know, system degradation before I turn to Nick, because actually, I think the curves, the CSMAC power curves, I think came out of your group, Nick.

Nick LaSorte: That was before me, so yeah.

JP de Vries: Yes. But before we talk about those of the things, I will invite the audience, if you have questions, please submit them in the Q&A. And we hope that we'll have a chance to address at least some of them. So, Nick, the things that you've been doing. So Kalle's point about, that there was a breakthrough, you know, when you started being able to introduce these probabilities. And we'll talk about, you know, what realism means. You've got to do lots of studies and usually you've got to do them very quickly and you don't get do-overs, which actually goes against what this whole conference is about. So when you think about, am I going to do a risk assessment, say a quantitative risk assessment, you know, do the probability assessment versus doing a worst case, how do you balance the techniques that you use? How do you choose how to tackle the problem?

Nick LaSorte: Oh, yeah. Well, of course, you never have to start out with a full blown Monte Carlo analysis for any spectrum sharing. We can always start out simple. Like I think just recently in IRAC there was a great example of that in the higher gigahertz bands. It was just a basic, simple analysis done in Excel. But again, we're trying to drive towards the best answer, right? So, I like to think of models as maps. So we use them to explore possible scenarios.

JP de Vries: So I'm sorry. I'm sorry to interrupt, but you know, the word "model" is very overloaded. So when you say model, I think I have a picture of a map in my head. But what do you think of when you say model?

Nick LaSorte: Yeah, well, if we look at a spectrum sharing model, we have our link budget, right? We're looking at if there's harmful interference to the systems. So that could be, how do we model the incumbent systems, how do we model the other systems coming in, the propagation between those two? That's the spectrum sharing model that we're talking about.

But again, it's just the link budget, right? So it can be a very simple link budget. You know, whether it's free space or we have to do a terrain-based propagation model. I think when we put the title Final on a spectrum study, that's a no-no. Because it's iterative, right?

Everything is iterative because we're always improving things. We can always improve driving that uncertainty down, bringing us, like Kalle said, closer to reality, right? You know, we've been talking about stakeholders and again, pulling back to what Fred said, this is a whole-of-nation concept. For spectrum sharing, you know, no one agency can do a spectrum analysis, right?

No one small industry can do a spectrum analysis. We do need to bring all those subject matter experts to the table, right? Whether it's the wireless industry with Kumar, or Kallee from DoD and those radar experts. You know, Will from Cisco a day or two back asked—and he was talking about 6 GHz and those two spectrum studies brought to FCC, and again, there are these competing studies done by two different groups—and he, of course, asked, "Why couldn't the FCC or NTIA do that?" Yes, that's something we could look at. But again, we can't do that feasibility assessment in a silo, right? We do need to bring everybody towards that. So, yeah, the actual assessment really isn't that hard, right? The computer does all the work, right?

Modeling it, we have all the tools. So really, it's not it's not a time crunch on me. It's, How do we pull out that great data and the knowledge from our subject matter experts into the analysis? So then we can peer review it so we can have reproducibility in science. And this is not fancy new ideas. We don't need new ideas all the time. We just need to focus on the fundamentals of science—hopefully, that.

JP de Vries: Yeah, yeah. I mean, there's a lot more with everything that you're saying, and everything everybody else is saying. You know, I want to go back to a point that Kalle made in turn to Kumar. You know, Kalle was saying, focus on realism on the likelihood axis. And actually, you know, one of the things that Kumar was mentioning as we were preparing for this, asking the question, so I'll ask you, Kumar, the question that you asked, and I don't know if it's a rhetorical question, but is it possible to agree on the probability of risk in a coexistence discussion? Can we even agree? I think you're muted. You're muted, Kumar. Still muted. There you go. I think.

Kumar Balachandran: Yeah. Sorry. So, between services, I think it has to be based on some sort of a negotiated process, right? I think the regulator's job is really ultimately towards efficient use of spectrum. But if you look at what needs to happen before then, you have to allow this process of Coasian bargaining happening between the parties and the stakeholders involved.

And to a large extent, this is possible in certain scenarios. So for instance, in 3GPP, we do Monte Carlo analysis of performance of mobile systems quite regularly. But you'll also find that despite the fact that everybody agrees on the models, everybody comes up with different answers. And then there is another process of reconciliation that happens where you compare results from various companies and you try to figure out what makes sense.

And, you know, sometimes there is just a consensus view that has developed or there is an averaging of results or, you know, outliers are thrown away, and so on. But you need to establish the sorts of processes that allow for competing interests to do their own analysis based on agreed parameters for study, and then to take that and come up with rational outcomes.

And in some cases, it’s possible to do it, in in other cases, it’s a lot more difficult. So for instance, when we run up against negotiations with federal holders of spectrum, typically the DoD, there is a fair amount of information hiding that goes on. I mean, this happens on both sides, right? In our case, in the mobile industry, we are working at the edge of the state of the art.

So we are a little concerned about how much information we are willing to divulge to others. On the other hand, the DoD is dealing with sensitive systems, and they do not want knowledge about what is being actually done in constructing those radios, from getting out into the public sphere. So the bargain that worked pretty well during the AWS-3 evaluations and CSMAC was that the NTIA and ITS would conduct the studies based on parameters that we provided. And that worked out, I think from a process viewpoint, it worked out pretty well.

Then, on the base, if you go deeper into, you know, how effective was the modeling, were the right models used, was it realistic, maybe you can start picking at the assumptions that went into that entire study. But on the whole, I think the process is pretty established.

Another example is if you go over to Europe, because there are examples over there, and CEPT (European Conference of Postal and Telecommunications Administrations), for instance, does the regulatory work, but then you have all these other groups that are set up like SE7 for, you know, sharing and compatibility studies in mobile systems or C40 for space services and C21 for emissions and so on.

JP de Vries: Sorry. Just to clarify, Kumar, where are these groups? Which organization are they part of?

Kumar Balachandran: They are part of the European Union (EU) regulatory process. But the studies that they conduct involve all of the stakeholders. And they come up with quite detailed agreements on what kind of models need to be considered. And I wouldn’t say the outcome is always ideal in those cases as well because they have to deal with some of the same roadblocks that we end up at if we were to conduct similar studies over here.

But at least there is a process set up where real studies are conducted and regulatory decisions are made on the basis of evidence. Rather than the FCC putting out, say, a consultation and then trying to make some sense of all the opinions or the statements that are rendered in response to those consultations. Right?

I think there is room in this country to set up some sort of a forum by which stakeholders can get together and actually conduct reasonable studies of situations where spectrum use might get into conflict with one another.

JP de Vries: That's a very interesting idea. And let's get back to that. You know, I just want to circle back. One of the themes, you know, for the last 20 minutes actually was raised from something that you said, Rob. You know, when I asked, how do you tackle disagreements? You said "Transparency," was one of the things you said.

And, you know, several of the speakers have mentioned there are there are difficulties with transparency for commercial reasons, for national security reasons. How does that work out in other fields that you've looked at? I mean, you've done national security work. You've done homeland security work, you know. So, how does it play out there, you know, where clearly this is very sensitive information. How are you transparent in that situation?

Robert Henry: Yes, it's definitely always a challenge. And the transparency is both in the information provided and also the techniques that you're using. So there's two aspects of transparency in your analysis. So if it's a black box and they can't understand what happens. Yeah, and there's no logical understanding of what's being spit out of that analysis. It doesn't matter how sensitive the data that you have going into that process, that's not going to be used in decision-making because people don't trust the outcomes, they don't trust what's being produced, and they can't with confidence say, I'm going to do this.

Now, getting to the sensitivity of information. Yes, I've worked a lot of different things. I've worked in the intel community, the DoD, and other things. And it's really across both the industry and using and sharing information from industry and the government together in analysis. You know, the key thing is how do you compartmentalize parts of your analysis?

So the key thing is you have to structure it in a way that you're able to, you know, sensitize it and make sure that information is compartmentalized and it's not revealing things. And your overarching analysis, representing that in way that doesn't give away that sensitive information, you know. And so there are ways to do that.

It does take time to structure it in a way. But the key thing when you do that, you have to watch out from that black box thing going on. So you need to make sure that it's not just, "Oh, we told you it was okay, so therefore it's okay." Because no one's going to believe you. You know, it's like you need some evidence to support your claims on that.

So that's important. Having multiple parts on that, making sure it's structured in a way that people understand that, okay, this is some information here. There's some additional detail I'm able to represent maybe the level of risk, but not why it's at that level. Yeah, it's typically on that. And also there's some things, you know, that's always important to push back a little bit on the sensitivity, especially in the national security space, a lot of the stuff that they say is sensitive. The classified piece is this little piece and there's all this other information that is actually not classified that can be used in the analysis.

So it's understanding where that is and understanding that piece of it as you go forward.

JP de Vries: Thank you. So I will get back to sort of the fun I'm having as moderator asking people questions, but let's just tackle a few of the questions that are in the Q&A. I'll read the question and it's a jump ball. Let's just click. Anybody can respond to a question. So actually the first one . . . I'll read this.

"Risk can be quantified at different levels, e.g., as any signal or combination of signals service, application level, or even or at the broader socioeconomic level. In the context of spectrum sharing, how do you unify or balance these disparate notions of risk across different services or technologies or stakeholders? So if different people have different views of the world, how do you bring them together?"

Anybody?

Robert Henry: Well, I'll say there's always different levels of risk. And understand you could get different answers depending on which level you're looking at, because everyone has different priorities and different things. So often when you're looking at your scope of your thing, if you're making some tactical decisions, you know, there may be a different decision, then you're making a strategic decision. So it's recognizing that there's different perspectives and those perspectives are actually valid.

And it can often be in competition with each other. And so it's understanding that that's built-in and understanding that at this level, here's the optimal solution. But at this level, this is not the optimal solution. And it's up to the decision-maker to say, where do I want to optimize? Do I want to optimize up here, or do I want to optimize down here? And there could be different sets of answers to that question.

JP de Vries: Thank you. Actually, before we move on, I see Nick was nodding. I don't know if it was pained or delighted, but Nick, do you want to add anything to what Rob's been saying?

Nick LaSorte: I'm glad, Rob handled that question. He did a great job.

JP de Vries: They don't get any easier, though. So another question is . . .

Kumar Balachandran: If you want to give me an opportunity...

JP de Vries: Please, go ahead, Kumar.

Kumar Balachandran: So I think you have to look at the situation. So if you take something like the fixed services area, right? Typically long-range microwave links operate at, you know, say five nines (99.999 percent) of reliability in their dimension. But that availability is characterized on the basis of margins that are built into the system that account for precipitation, atmospheric effects, you know, other tail effects that may occur over the over the course of . . . And in certain situations, you know, some of those impairments that the wireless channel is going to be subject to might occur in concert. But most of the time, you know, there will always be excess margin available.

So, the question really is—I mean, in assessing risk, what you may want to find out, Oh what is the harm to the system if we assume that not more than a percentage of that margin will be required at a particular time? And these calculations are very rarely done in the design of the system or in the way the service itself is organized. So if you look at some of the requirements that come out of the International Telecommunication Union (ITU) on what sort of interference levels are, you know, acceptable for, say, satellite systems. You know, they say, "Oh, you have to have interference floors that are 12 dB below the noise floor."

Now, in the U.S., we have reinterpreted that as saying, okay, it's enough if we are only 6 Db below the noise floor and nobody has complained. On the other hand, you take the mobile industry and we thrive on being able to accept interference. But there are certain situations where tail effects actually can be pretty harmful to your system. So you could, for instance, take a 5G system that is deployed in a factory and there you can end up losing a production line for days if a single link is damaged. You really have to think about this in terms of what the impact is on your mission at the end.

JP de Vries: Right. So actually, you know, one of the things, Kumar, and maybe we will touch on this briefly and come back, you know, I'm wondering about what is changing that is bringing these risk conversations to the fore. Why are we talking about this in spectrum now? And I think the example you gave just a moment ago might be one of them. You know, the cellular industry is now selling products to people who do safety-of-life services, factory floors, etc. Do you think that affects the willingness to invest the resources to do risk assessment and management?

Kumar Balachandran: I think so. Or at least I hope so. But, really, I mean, a lot of what the cellular industry is trying to do is also based on aspiration. So, for instance, when cellular technologies are not being used for automation in the transportation sector or automation in industry, it's because of all the uncertainties that are created by the fact that people don't know what they can trust. So we haven't really gotten to the point where we are able to assess, or at least define, the level of risk in particular use cases and be able to differentiate between them properly.

JP de Vries: Hmm. Hmm. Hmm. Hmm. Yeah. You know, Omar, I want to sort of get your perspective from, you know, the view from the bridge. You know when you look at your community, how does this kind of multiple ways of understanding, risk and mission. . . . Now, you've created a framework where it's very straightforward, you know. FDA, there are four risk categories. Pick one. Does that solve the problems for you?

Omar Al-Kalaa: It helps. I don't think there is a perfect solution out there yet, but it certainly helps. And at the core of this framework and of this entire conversation, and I think this is a theme across all the other ideas that we've been discussing, is What is harm? And this goes back to the question that you asked me not too long ago about how do you define harm?

And I think I'm just lucky because I live in a world where harm is defined. And I know what harm means from the medical device perspective. It's the physical injury or damage to the health of people. So I have a reference point to go back to when thinking about, Okay, how do I deal with a certain device trying to access the channel when there are multiple systems trying to access that same channel at the same time?

So it always goes back to what will happen if that communication fails to go through. If the communication is intended to request a glass of water by a patient from a nurse station, then yeah, that risk is negligible, to be honest. If the consequence is the failure to deliver a high-priority alarm in an intensive care unit (ICU), then we should start thinking, okay, how do we mitigate that risk?

Or do we need to actually build into the device further mitigations, further communication capabilities other than wireless in many cases, just to mitigate that risk of the communication being lost.

JP de Vries: I mean, one of the questions, if I understand it correctly in the Q&A, is the observation that risk changes with point of view and with time. You know, four dimensions—where you are, what time it is. It's not static. How does your approach handle that or is it not relevant?

Omar Al-Kalaa: I don't think we look at risk being fluid with time. So at the moment of the analysis, when the medical device manufacturer performs their risk assessment and they determine all the hazards or the consequences, and they start to think about probability and severity, and they walk through the process to the point where they say, Okay, the risk for this certain wireless functionality in a medical device is minor.

That really concludes that risk analysis. And then they are offloaded to actual testing. They go to a lab, or they do the test in-house and they perform that evaluation over there.

JP de Vries: Okay. You know, one of the things—another question in the Q&A, which is, you know, "Can we federal and commercial users agree on key performance indicators that degrade as a measure of harm?" And so for all of you that have looked at this, you know, when you think about how do you quantify the impact—how do you do that?—and do you do you think that it works? Actually, Kalle, maybe we should start with you, since I know you've thought hard about impact.

Kalle Kontson: I think it's a contentious issue, certainly, about key performance indicators and the parameters that you would look at to derive those key performance indicators. I keep gravitating back to the technical parameters issue. If you really believe that quantifying risk is possible, then we ought to look at those key performance indicators as the kinds of, I guess, things like bit-error rates and technical parameters that that genuinely can affect system performance and try to identify all of them that are in play and represent them in some way.

And I harken back to the Institute of Electrical and Electronic Engineers (IEEE) 1900.2 (Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems) standard that divided the parametric space into logical domain parameters and physical domain parameters. But the point being, that—without going through the whole list there, there's lots of them—but you can select from that list a bunch of parameter combinations and that could be related to key performance parameters that I think we can all agree on.

In other words, a certain bit-error rate that occurs only so often would be acceptable for TV, for instance. We've done that. Those kinds of things have been done. And I think it takes a lot of work and we have to be willing to look at the full parameter set that's relevant, not just one figure, like interference-to-noise ratio at the front-end of a receiver or something.

And look at trying to agree among the stakeholders which ones are relevant to put into the process of quantifying risk. And that means find the ones that have lots of variability that affect your key performance parameter as a whole and quantify them statistically. And so beyond that, I think we've made some progress and to a certain extent we already have we still have lots to go, right?

JP de Vries: So you asked the question, and I wasn't sure whether it was a rhetorical question. It was an assumption. You said if quantifying risk is possible. So I'll ask you this question, Kalle, and then I'll ask the same question. Is it possible to quantify risk, and is it is it desirable to quantify risk?

Kalle Kontson: Yeah, I think it's desirable and it's possible. But my definition of risk goes like this: realism on the likelihood axis, then choose from the consequences part of the axis what number you're willing to live with. If you don't have realism to start with on that axis and you don't have confidence in your confidence intervals, if you'll excuse the pun, then you might as well not be dealing with risk. And let me illustrate by if I could just for one minute.

JP de Vries: Yeah. And actually, with your illustration, could you also address when you say "realism", what does realism mean?

Kalle Kontson: That means using realistic parameters that are representative of what might actually happen in both the physical and logical domain. Propagation loss, for instance, we don't use the worst case propagation loss. We look at the statistics of propagation through a forest, for instance, and we look at measurements to validate our models. And we're getting better and better at that. I have confidence that we are getting good enough to be able to do this already.

And then you pick a mean and the standard deviation around that and a shape and you've described that part of the math that's necessary to quantify that particular variable parameter. And you do that for all the parameters, including things like the dynamic power control in an LTE, or the probability of changing modulation and indices in LTE and a given resource block.

There's a lot of counter space to cover, but you can quantify that part of it. It takes a lot of work and a lot of data. My feeling is it's worth it, right? So, okay, could I just take one minute? But the one of the things that I hope for and I'm so confident that this is starting to show promise, is that in operational settings in military operations, we may be able to envision being able to quantify risk of RF interactions for the commander to use to make near real-time operational decisions.

And to illustrate that, if you're confronted with a situation that says, Do I send the squad in there to knock out a command post? Do I jam them, or do I listen to them to find out what they're doing, which might be even more effective? Two out of three of those, if we're really good at quantifying these technical parameters and the distributions and the shapes and the means and standard deviations, we can assign, hopefully, values to the chances of success for those electronic cyber type options.

And when you have, when you're making a decision like sending a squad in versus these other measures, there's huge consequences on deciding wrong. And that boils right back to what I started with, and that is if you don't have realism in the likelihood axis, you're going to make a lot of bad decisions one way or another.

JP de Vries: Nick, so, the same question I asked Kalle for you, which is, you know, is it possible, is it desirable to quantify risk, compare and contrast, quantitative versus qualitative?

Nick LaSorte: Yeah. I'd love to hear Rob's thoughts about a risk matrix, right?

JP de Vries: Yeah. I mean, yes. Let's go there. Let's go there.

Nick LaSorte: Rob. Yeah, lets.

Robert Henry: Happy to chime in. It's all about the level of fidelity needed. And so a risk matrix is very useful when you have a defined program that you're trying to manage in a project program. You know, context, it does not work when you're trying to do comparative things. It does not work when you're trying to do some of these probabilistic kind of modeling things.

And so it's understanding the kinds of things that you're trying to do. Now, can you quantify things? Yes. Is it desirable? Yes. It's all about how much fidelity do you need. How much confidence do you need in that to make that decision? Remember, people get stuck up and say, I need more video, more data, more data.

Well, do you really need more data to make that decision, or do you just want that more data? And really, the difference from qualitative to quantitative, it's really just you have more data to back up that qualitative assessment. We're talking about risk. Risk is something that may or may not happen in the future. So therefore, by its very nature, it's not certain. We're talking uncertainty here.

So data can give you more a predictive nature of that. It can help you get more confidence of that. But that's still a qualitative nature because you have to translate that data into a risk measure. People think, “Oh yeah, I look at tons of risk models over there,” and they say, “Oh, I have all these things.” It’s like, “Here’s the bit rate losses,” and who cares?

Robert Henry: What does that mean from a mission context? What does that mean to that spectrum device? What does that mean from what we’re trying to do? Yes, we should be able, as Kalle was saying, you know, properly characterize the probability of that being disrupted. Absolutely. And we want to have good models of that. But that’s not the end of the day.

We need to then take that to What does that mean if that gets disrupted or degraded? I need to understand that. And then I can have different risk tolerances. Getting back to the point of view question and the key performance indicator (KPI) questions that we were talking about a few minutes ago. Yeah, we can have different risk tolerances for a particular KPI.

You know, some people say, “I can only operate within this band of variability”; others can accept a much larger band. It depends on what kind of device it is. It depends on what kind of mission is being executed. And so all these point-of-view things actually do matter when you’re characterizing risk. And so you can structure these, you can create models.

You can create risk appetite tolerances. There’s all kinds of techniques and stuff that you can use to do this especially around KPIs. And so those are the kind of things that you can set and address and adjust over time, depending on what decisions are being made.

JP de Vries: So, Nick, how does that strike you? Does that resonate with what your experience has been?

Nick LaSorte: Yeah. And I do want to even pull back from what, I think it was one of the economists, I think it was Greg [Gregory L. Rosston, Day 2, June 14 - Panel: Economics of Spectrum Sharing], talked about risk appetite, risk tolerance. Now I’m glad Rob brought that up. But it does tie back to enforcement, right? And the economists told us this. So, could we increase the agency’s risk appetite if we had a mechanism that resolved interference within one minute?

Because traditionally, yes, it’s very hard in some bands, you know, it’s a manual process, right? So I’m glad you talked about that. And I love how Rob talked about, How much data do we need? Do we have more than we already have? And, you know, do we run the sensitivity analysis on the model, right?

Decreasing that uncertainty, if it doesn’t change the output, who cares, right? But if it is a sensitive input, well, yes, we do need to go out and measure to reduce our uncertainty in that. So yeah, I think it’s great. Rob talked about that and again, yeah, the transparency and things like that. So yes, I think it’s great.

And the other agencies are doing the risk assessment. But again, you can’t do it in a silo, right? Because one big uncertainty to them might be, “Oh, well, if we do share this band, what type of rules will the FCC make?" Now, the uncertainty is the FCC. So yeah, could DoD or the agencies share it in IRAC?

Right? So all the agencies are learning risk together. Because it's going to be hard. This is not going to be easy. We'd love to bring Rob into the IRAC and walk us through this as an agency. But then, of course, then we share that with the FCC and we have sharing mechanisms for classified material. So how could the FCC then reduce some of those uncertainties for the agencies?

Does it look at out-of-band emission (OOBE), you know, limiting those? To help the agencies take on more of a risk appetite. So yeah, I think it's great. We can't do this alone. Let's pull people in. Let's try and share it together.

JP de Vries: The thing that I just want to just throw in, and this is not a specific question, but anybody can pick up on it later or in their remarks. Rob, you were talking about, you know, what's the meaning of some risk? And one of the points that Prasad Kadambi [formerly of the U.S. Nuclear Regulatory Commission], the NRC person, was educating me about was the difference between uncertainty and ambiguity. And the reason I was reminded about that is when you talk about meaning, it's like STEM-educated [Science, Technology, Engineering and Math] folks are really not good with meaning.

You need some people who are trained in the humanities, you know, to puzzle over those issues because it's presumably not all quantifiable. Does anybody want briefly to respond to that? And then we'll go back to Q&A from the audience.

Nick LaSorte: And so you're talking about like non-stationary versus stationary processes? Is that what you are talking about?

JP de Vries: I don't think so. We don't have Prasad here to answer. But, you know, what I think about it's almost like an uncertainty. It's not something you can put a number on. And so in that sense, whether it's station or non-stationary, I don't know enough statistics to answer that.

Robert Henry: I mean there are ways to characterize things. Even if you look at the social sciences, you look at all kinds of things, you know, survey research and other kinds of stuff. They do it all the time. So there are ways to characterize it, quantify things on that. There's a whole body of research on how you go about doing that.

And, especially when you look at societal benefit, societal outlook, and anything like that. So not all of it is quantifiable and monetizable. It's like, how do you actually go about doing that? So there are ways to actually characterize them. We do these all the time and trade studies and AOAs (Analysis of Alternatives) and that kind of stuff where we're looking at not only the risk and the cost, but What is the benefit and how do we characterize that benefit?

Sometimes you have very specific performance parameters that you're measuring, and you can have that really, engineering differential on that. Other times it's no, what is the adoption rate of a particular kind of activity now that we have this in the place and what kind impact does that have on, you know, quality of life or other kinds of stuff?

If you look in the medical field, you know, you look at qualities, like lifetime qualities and other kinds of stuff that are measurable things, that are quantifying something that is more abstract and less concrete than what a lot of engineers like to do.

JP de Vries: So let me turn to turn back to the Q&A. We're not going to get to all of them. And some of them I'm having trouble parsing and some of them are more rhetorical than interrogatory. Let me combine a couple of questions. And again, these are jump balls. The first is What is an instance or an example of a success case for spectrum sharing?

And I presume the question meant doing a risk analysis for spectrum sharing. And then the second question is actually the forward-looking one, which is what spectrum sharing scenario or band would be a good choice for the NTIA, and I would add for the FCC or anybody else, to perform a risk-informed interference analysis? And how would that result in better use of the spectrum resource?

So does anybody want to talk about, you know, successes and opportunities? Yes, Nick.

Nick LaSorte: I do. Yeah. Okay. I was going to say harkening back to Fred again, he talked about bi-directional sharing. And I think it was even Carolyn [Carolyn A. Kahn, Day 2, June 14 - Panel: Economics of Spectrum Sharing] that talked earlier about, well, the spectrum pipeline is unsustainable as we know it because we typically have taken federal spectrum and transferred it to non-federal. So it would be a great risk assessment forward looking if we could see allowing the federal agents to operate between, for example, 2 to 20 GHz on a Non Interference Basis (NIB) in the non-federal bands.

We would love to see something like that on a non-interference basis. So for example, say, we have Kumar there, where it's a telco operating in the C-Band. But say they aren't using it in the desert at night. That might be a great opportunity for another agency to then use that spectrum from 3.7 to 4 GHz. And then when we think about the benefits that that would provide someone like DoD, because again, Fred talked about, oh, well we're going into these other theaters. Imagine the flexibility that gives. So again, I think that would be a great [unintelligible]..

JP de Vries: What I'm hearing is that's, you know, the value of sharing. How would risk assessment help do it better?

Nick LaSorte: So I think we could look at the statistics, again, of a single DoD system and how that would interfere with base stations. With a wireless terrestrial network. You know, we'd love to do that with the FCC. Again, we are looking at this aggregate interference. So it does simplify the analysis for us. Because, again, it could possibly be a radar that's rotating in the time dimension.

JP de Vries: So it's great the conversation is just beginning to warm up. So we've got Kumar next, and I'd like to ask you, then, Omar, whether there are any case studies that you felt were particularly successful in the work that you've done that we as a community, as a broader spectrum community, can learn from? And then Kalle had a point as well.

So. Kumar first.

Kumar Balachandran: Yeah. So I mean, I guess the question was about, you know, examples of, you know, where spectrum sharing has actually occurred. And I always have the story that I present to people. That even if you take the commercial mobile industry, we do share spectrum in the sense that when you go back to the old analogue telephone days, we used to distribute the spectrum that was awarded to an operator across 7 cell groups and, you know, 21 sectors.

And, you know, there wouldn't be any spectrum in an adjacent territory that's being used by the same system. But as you fast-forward over to, you know, 3G, 4G and 5G, and now we use spectrum across the entire system, the same spectrum re-used in every cell all along the way. And not only that, we have, you know, more advanced computing going into all our infrastructure.

So now we can share spectrum simultaneously even from within the same cell site between users and between, you know, between using advanced antenna systems and so on. But the way to look at this is what we have engineered is a highly spectrum efficient system. Right? We are able to do that. What we cannot guarantee is spectrum utility.

The only thing that guarantees spectrum utility from our industry's viewpoint is the market. And how many people are utilizing the spectrum that gets auctioned to an operator, you know, in a particular area. If you take the unlicensed bands, there are a variety of use cases that are already, you know, coexisting—Bluetooth and Wi-Fi and so many other systems.

They manage to coexist in the 5 GHz and 2.4 GHz bands. And now, of course, the 6 GHz band has been released. So there is a fair amount of spectrum sharing that goes on over there. Between services, there are many examples. The 6 GHz band shares with fixed services. And then the classic example, of course, in recent times is Citizens Broadband Radio Service (CBRS), where we share spectrum in a three-tier process. And, you know, I worked on CBRS for many years, so I can criticize it knowing about what was not done.

But what is also clear is that it has created a very innovative experiment on trying to examine what the realms of possibility are over there. And it's probably a good example to use, you know, because if there are problems with the system, that can be changed. I think one of the issues with the regulation...

JP de Vries: Kumar, could you just wrap that up? Yeah, no, just finish your thought.

Kumar Balachandran: Yeah. The thought is that one of the problems with regulation is that it gets enshrined in law and then it becomes immutable. So to some extent, we have to allow ourselves the latitude to make mistakes and then to fix them later on. And that is very essential. And that's perhaps something that we have not accounted for enough in our processes yet.

JP de Vries: And I think that that, you know, it goes the whole conference. And that's a very good point. So, Omar, just turning to you and I think we're about 15 minutes out from the end. So we're not going to get to all the excellent questions in the Q&A. Thank you, everybody, for those. Let's see how far we get.

So, Omar, when you look at what's worked in your field, what are the lessons that we should take from that going forward?

Omar Al-Kalaa: All right. A quick comment on what worked that I personally consider, regardless of how chaotic things are, and that's the 2.4 GHz industrial, scientific, and medical (ISM) band. I can see that it's a very successful example because it has allowed for so many innovations in the medical device space and those innovations are helping patients every single day. So that that in itself is a success.

I think one of the lessons learned that I want to share with my colleagues here on the panel and with the audience of the conference is that not all devices are created equal, even if they are using the same technology. So when you're talking Bluetooth, two devices could be using the same chipset in a completely different way.

And the outcome of evaluating how these devices coexist with Wi-Fi could lead to vastly, vastly different realizations. So what I'm trying to say is that there is value in looking at what the system, the overall system, the spectrum-dependent system that you're dealing with is trying to achieve not only from the bit-error rate perspective or from a certain specific KPI, but from across the seven OSI (Open Systems Interconnection) layers. And all of the software that is built on top of the RF hardware that is embedded in that system.

JP de Vries: So let me just make sure that I understand, Omar, because one way of interpreting what you said is that because devices vary so much from one device to another, and particularly when we're doing risk assessment, forward looking, we're thinking in terms of classes of devices of which may not even exist yet. It sounds like, you know, one way of interpreting what you say is, like, You're doomed. It ain't going to work because you can't look at specific devices.

But you're not saying that. I think you're saying, fix it higher in the stack.

Omar Al-Kalaa: Exactly. Or at least, broadening your scope to include additional layers in the stack.

JP de Vries: Yeah. Right. Thank you, Kalle. You've waited very patiently. Can you still remember what you wanted to say?

Kalle Kontson: Oh, I just wanted to pile on with what Nick said. And I thought the example of success of, certainly AWS-3 in my mind just because I think it did demonstrate sharing could work in two ways where the incumbent was the DoD, and in the case of sharing with broadcasters the incumbent was the broadcasters. Those are two instances where sharing worked. And Nick's use case of going all the way to 20 GHz and saying, look, you're welcome to come in on a non-interference basis.

That would be a wonderful challenging problem for these risk assessment [methodologies]. It'd be almost a given that we'd have to do a realistic quantification of the risk on a band-by-band basis for doing that. So I applaud the idea. I'd love to work on it.

JP de Vries: So let me just put a few of the things in the Q&A channel on the table and I, you know, invite you to respond to any of them, just looking at a few of them. One is, How do you handle an impact that the user feels is not acceptable, regardless of its low frequency? Do you continue to do risk analysis in some other form, or does it leave you no room to do that?

Another question is: Risk-based interference assessment usually would require data that doesn't exist or that would be hard to collect (the future). Actually, those of us who remember, Ed Thomas [former Chief of the Office of Engineering and Technology at the FCC] always used to love to say there are no facts in the future. You know, how do you quantify risk when partial or erroneous data itself could be a source of risk?

Another question, which is short and sweet, Does the FCC need a risk assessment and mitigation bureau?

And the last one I'll throw out here is "How much benefit comes from just doing the quantitative analysis versus the result itself? The attempt to do quantitative analysis could inform the qualitative analysis for the good."

Any thoughts about any of those? And actually, Rob, we'll start with you and go from there.

Robert Henry: Okay. So first off, on the first question on there, if the result is unacceptable, there's still risk analysis to be conducted. It's, how big of a margin do you need to prevent that? You know, how big of an exclusion zone or how big of whatever? There's a lot of different parameters you can look at that can minimize the use of spectrum to still preserve that and make sure that an unacceptable result doesn't happen.

And then another thing about it, so that's just one thing on that, on the data piece: It really depends on what you're trying to do. And I'm going to throw in, we're going to have some challenges coming down the pipe in the risk-based spectrum as you increase the number of, you know, dynamic spectrum devices in the field as well as, you know, things with frequency hopping and other kinds of spectrum things in combination with the spectrum sharing is like, how do you do those analyses? Those are more complex because it's a lot more data and it's a much more complex model. But I do think that, you know, having those models can inform some qualitative measures. So it's like having those detailed, you know, models that, you know, Kalle was talking about earlier, and other things, that high-fidelity kind of stuff can be used as a proxy and a value function on some other kinds of things that you're trying to do and that are more qualitative in nature. So, you can leverage some of your detailed analyses to the on-the-go thing.

But ultimately, you know, as we're looking at out across the things and understanding how things interact with each other, you know, I like to call it the coupling risk. How does this impact that? And a number of different things? It's like, what are those things? You know, you can leverage those to inform other assessments. So they have value outside of the isolated use that they were initially conducted for. But they can be used to inform other kinds of analyses that are maybe not in depth or have as much detail as that original one had.

JP de Vries: And anybody else want to chime in on any of those topics?

Kumar Balachandran: I think when you're doing an analysis of risk, you have to make sure that you're at least good enough where you're in the ballpark of where you want to be, and then try to improve. I mean, there's always a possibility that you're going to make some mistakes along the way. But those mistakes should not be to an extent where, you know, a lot of money has been invested in equipment or in systems being deployed and for policy to be backtracked along the way. That being said, if the level of risk is completely unacceptable to somebody, the question you have to ask is What is it worth to you? And really then it becomes a question of, you know, what is the economic benefit of giving you the facility to have a certain degree of use versus—you know, to society. It need not be only to the user of the spectrum. It could be to society as a whole or to the application under use in any case.

JP de Vries: What happens when the party you're negotiating with can't take money?

Kumar Balachandran: We do end up in situations like that. And that's why you have governments in charge of apportioning spectrum for use. And at some point in time the regulator is the last arbiter of record, right?

JP de Vries: Right. Kalle?

Kalle Kontson: I think you're starting to drift into the legal framework of whether or not exclusive rights should even exist. That's a big question. But whoever asked that question implies that you've still got exclusive rights. That's antithetical to sharing across different user groups and different types of equipment. But it's a key legal question about whether exclusive rights to spectrum in an unlimited sense can just exist. You can buy it, you can have it, you have a license. And even if you're not using it, you can tell everyone else not to use it.

JP de Vries: Yes, that that gets us into, as you say, legal areas about, you know, what rights do you have? You know, even in the spectrum sharing situation, parties have different rights. There are different tiers of rights that need to be negotiated. One of the things I just wanted to skip back to, and in a few moments I will ask all five of you if you have any parting thoughts, and you don't have to.

But one of the many things that was teed up that we didn't really have time to talk about, I want to skip back to. You know, there was that question of whether the FCC needs a risk assessment and mitigation bureau. But actually, Kumar, you were saying, you know, it's interesting you were mentioning some of the European processes and you wondered whether there was room for a stakeholder forum in the U.S. And I wondered if you, and it can be full spectrum coexistence, but let's narrow it down to the kind of technical analysis that we've been talking about here. Could you say a little bit more about what that might look like in brief? And then other folks can just respond to that?

Kumar Balachandran: I mean, ideally, I think it would be where there is free exchange of information between the stakeholders, agreements on the models to be used, some sort of an understanding of the risk to each entity. It doesn't have to be the same risk for every party, right. But they can put everything on the table, right? From economic risk out to, you know, what happens if the spectrum is not available?

And then it's a matter of creating the right kinds of dialogue between these parties. And the quantitative evaluation can definitely be part of this, but it will not end up being the sole reason for making regulatory decisions.

JP de Vries: And to channel my guru Dale [Dale Hatfield, Executive Fellow, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, Boulder, Colorado], so what are the incentives that people would have to participate in good faith?

Kumar Balachandran: Oh, I mean, in some sense, so, I'll tell you, one of the roadblocks that people face is that this is tedious work. And typically it's very difficult to find even companies who will assign enough resources to be able to serve this purpose, not to mention just the government. I know that, you know, for instance, when the NTIA does evaluations, they're severely understaffed and there's an incredible amount of, you know, effort that goes into the studies that they do. But at the same time, there's also a lot that does not get done.

In the same way, you know, you're going to end up in situations where you're going to end up in resource limitations on how effectively you can conduct these studies. The second issue, of course, would be in transparency, as we have talked about before. I won't dwell too much on it.

JP de Vries: Yeah.

Kumar Balachandran: Yeah. But you can set up agencies. Maybe ATIS [Alliance for Telecommunications Industry Solutions] is one route or maybe CSMAC is another route, if you are looking at interfaces with federal spectrum. So there are many other opportunities available. But you have to have a more open attitude toward sharing information and admitting, you know, inputs from everybody.

JP de Vries: Very good. Thank you. So in the last two minutes, let's just go down the line. Rob, Omar, Nick, and Kalle, the rest of the line. Do you have any parting sound bites for us on this topic? Rob?

Robert Henry: Yeah. So my parting thing is that it's not only risk analysis, it's risk management. It needs to inform policies, procedures, system designs, and other things that actually reduce risk. And so we can't just stop at the analysis step. We need to continue on and actually address the other pieces. Otherwise, we're not going to realize the benefit we're seeking to realize.

JP de Vries: Thank you. Omar?

Omar Al-Kalaa: Absolutely. I completely agree with what Rob said, and I want to highlight the value of engaging stakeholders to certain applications and engaging the opinion of subject matter experts (SMEs) for what a certain system is trying to achieve. And those SMEs might be different between different industries, and they're not necessarily related to spectrum at all.

JP de Vries: Thank you. Nick?

Nick LaSorte: Man, thanks again for having us. Yeah, thanks again, guys, for the spirited debate. Yeah, we support peer review, transparency, scientific reproducibility. We're hoping that, yes, the different stakeholders can at least share the data with the federal regulators. You know, does the wireless industry need to agree on what DoD is using for their radar interference margins? Right? Well, who's the SME in that case, who's the subject matter expert on the radar? And so, again, it's pulling radar and the subject matter experts to the table to let them characterize their systems. On the other hand, yeah, a large uncertainty, at least that we see now, for example, in the current 3.1 GHz study, right, it's this uncertainty of, what are the use cases of 5G in this band if it were allowed, right? So again, we rely heavily now on that SME experience from industry. So again, it's coming together. The hope is that we can share, uh, data, right? And it's the innovation theme that we hear over and over again, right? John Chapin from National Science Foundation (NSF) [Day 1, June 13 - Panel: Exploring the Theme of ISART 2022] talked about innovation, Canadian representative. And so it is encouraging innovation through using the risk assessment.

JP de Vries: So we are out of time. Kalle, do you have one sentence that you want to leave us with?

Kalle Kontson: Yeah, we had a good experience with the stakeholders cooperating in AWS-3 and the way forward to me is to have stakeholders have confidence in our confidence intervals. If you don't have that, you're going to have a long hill to climb.

JP de Vries: Well said. Thank you to the organizers for inviting us and enabling us to have this conversation. And thank you to everybody in the audience for paying attention. If you were paying attention and I can see you were, because we had a lot of questions, not all of which we were able to address. But in particular, thank you to the five panelists who not only gave us the time you've just seen, but they all did a lot of prep work, too. So thank you to all of them. And we're out. Thank you, gentlemen.

Robert Henry: Thank you. Have a great day.

Kalle Kontson: Thank you.

5.4 Technical Presentation: ITS Propagation Modeling Research and Development

William Kozma, Jr., Computer Engineer, Telecommunications Theory Division, NTIA Institute for Telecommunication Sciences and Head of U.S. Delegation to ITU-R Study Group 3 and U.S. Chair of Working Party 3K

Billy Kozma: Thank you, Howard. I'm Billy Kozma here at the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS), where I work in the Theory division, specifically on propagation. And we're going to do a real brief kind of overview on active areas of research that are going on within the field of propagation models here at ITS. So it's only about a 10-minute overview. So we're just going to kind of sample the buffet of things that are happening. We're not going to take questions, but if you do have them either reach out directly to my email address there. Or put them in the chat and either I'll try to respond maybe later, or we'll pick them up maybe in the panel that follows.

So with that, next slide.

So, you know, one place I want to start is really two of the key models at ITS that have been around for decades: the Irregular Terrain Model (ITM) and the IF-77 [(ITS-FAA-1977) propagation model developed for the Federal Aviation Administration (FAA) applicable to air/ground, air/air, ground/satellite, and air/satellite paths]. Many of you are familiar with these and have used them yourself. Others of you may not be as familiar.

But if you've used any sort of software to do, you know, interference analysis or any of the commercial packages, these are likely one of the models that is being used under the hood when you're working to do that sort of work. So you may have, even if you're not familiar with them, you probably have used these models unknowingly in the past. You know, they've been around [a long time]. They're general purpose models. Both are really founded on technical theory. They're based on electromagnetic theory and first principles. They build out from there. And then at the end, they kind of layer on statistical analysis based on a large set of measurement data to deal with things like time variability and location variability. You know, when we're talking about these things, having just median predictions isn't enough. Especially when we're doing interference analysis or trying to think about coexistence between systems. You need that layer of statistical distribution on top of that.

And so, these are well-established and [are still] used across the government and commercial industry for those types of work. You know, they were originally established back in the 1960s and 1970s. And there hasn't been a lot of work improving those to be up to date. Of course, today, now we're dealing with sharing scenarios and modeling scenarios that are quite different than what was originally looked at. It doesn't mean they're not applicable, but that does mean there is room for improvement.

And so we are looking right now at this. In the past couple of years, we've been throwing more resources at adding improvements and iterating specifically on these two models to push out some additional improvements to the community. So one of the areas is within ITM. ITM is a terrestrial model that does both point-to-point analysis and an area-mode analysis where you don't necessarily know exactly where it is. You know, it's more applicable for maybe a Monte Carlo distribution, or something like that.

We're aware that within a line-of-sight link, that there are some weaknesses in parts of the model depending on where it's applied, you know. And if you think about a sharing scenario, especially if you're sharing with the radar that's far away, those line-of-sight links can really be the long pole in the tent. Especially, you know, that interference from, say, a base station into a radar line-of-sight, having an accurate representation of what that loss is can be really important and can really dominate where those exclusion zone boundaries are or coordination zone boundaries.

And so over the past year, we've had some folks within ITS really looking at that more closely and trying to work out better ways to kind of improve that line-of-sight geometry within the ITM model. Within the past couple of months, they've arrived at some preliminary algorithms that show within specific sorts of geometries an up to 10 to 15 dB improvement, and that's really big. It's not general across all scenarios that are line-of-sight. And so right now they're looking at both generalizing that—how it applies to all different types of line-of-sight geometries. As well as proposing, you know, let's throw some resources at doing some measurement data as well.

Right now we've been using the historical measurement data, Phase 1 and Phase 2, that's hosted on the ITS website. So we're going to be taking some additional measurement data to really validate. And hopefully, in the upcoming years, push out some improvements to the model that are really going to be useful. Likewise in air-to-ground model (IF-77), you know, it's built on the same foundation, Tech Note 101, as ITM. But obviously it captures specifically the atmospherics that are involved in an air-to-ground link.

You know, much like ITM, it [IF-77] is limited to 20 GHz because as you go up, in particular for air-to-ground links, the atmospheric effects are really important. Especially when you're talking about the absorption of water vapor and oxygen. And so we're currently working on modernizing ITS MPM93, which is the Millimeter-wave Propagation Model [1993] that is able to capture that line-by-line summation of water vapor and oxygen within the atmosphere, how it affects both bending and the absorption of those molecules. And so we're looking at both modernizing MPM93 and pushing that into IF-77 so we can extend the upper limit of both ITM and IF-77 to cover at millimeter waves and support these new scenarios that we're looking at.

And lastly, something that I'll explain in a future slide here, we recently published a report on tropospheric forward scatter that re-derives the first principles of troposcatter that was used in the development of these models. So if you look at some of the citations, some of them are unpublished works. We had a mathematician re-derive that from first principles. And that's going to lay the foundation to some upcoming troposcatter measurements that we're going to be doing in modeling improvements.

Next slide.

Another area, obviously, that is quite large in the news nowadays is millimeter-wave propagation. March of last year we conducted some measurements at 37 GHz. We developed a new measurement system to do this. So these were mobile measurements. We drove through downtown Boulder. We captured those results. We did some initial validation with 3GPP models, on both non line-of-sight and line-of-sight types of scenarios. We compared that with environmental information, such as 3D Lidar data.

They didn't always agree. We had some hypotheses why they might [not always agree] and we did propose some additional measurements scenarios. We're looking at performing some additional measurement scenarios winter of next year because the measurements were originally taken without foliage, the leaves weren't out on the trees yet. We want to make sure that when we do a second set of measurements that the environment has the same characteristics as when we originally captured those. So we're hoping here in winter next year to do some additional measurements at 37 GHz and maybe rolling this into a publication and improving some modeling efforts within the millimeter-wave band.

Next slide.

So another real big program that's just kicking off this fiscal year [at ITS] is a mid-band propagation model initiative that's funded by the DoD. It ranges from 3.1 to 4.2 GHz and really everything is in play. We're looking at linked geometries, air/ground, clutter, but also long-distance diffraction and troposcatter links. And so really, this is a large multi-year program where we're going to be focusing on specifically that 3.5 GHz band, but really broadly, you know, 3.1 to 4.2 GHz. So we're going to be engaging with the community to do a community-driven modeling approach, which is something we're going to talk about in the panel coming up.

We've been rolling out a new measurement system. We developed a new clutter measurement system that not only has a lower noise floor than our previous one that we've used, but also incorporates a high-fidelity geolocation system so that you don't have GPS-drift when you go through dense urban areas or underneath tree canopies. So that's going to be rolled out. We're going to be doing diffraction measurements and we're actually setting up some long-distance troposcatter links to collect data to basically validate some of that troposcatter research model development I talked about previously, and possibly make some improvements there dealing with some atmospherics [with help from] experts in the atmospheric role from National Oceanic and Atmospheric Administration (NOAA) and other agencies. So, you know, it's really quite a big effort and it really covers a whole lot of propagation modeling here.

Next slide.

And lastly, of course, we're doing a lot of work in clutter modeling. Not just in the 3.5 GHz band, but also more broadly. We've been building on work that we've done with Advanced Wireless Services-3 (AWS-3; comprising the 1755 to 1780 MHz and 2155 to 2180 MHz bands) at 1.7 GHz. We're expanding this to mid frequencies, and really we're combining electromagnetic theory measurement data, both that we have and that we're going to be capturing, as well as environmental data when it comes to terrain, structural, or vegetative, that you can capture from Lidar.

How can we incorporate all this data that we have to really improve modeling as a whole both on a point-to-point and also statistically based? Getting those distributions of location variability and time variability are really important when we start to talk and think about how you manage interference as in some of the topics the previous panel talked about. And so these things are going to be rolling into clutter modeling updates to IF-77 and ITM. As you know, those don't have cluttered effects at the current time. And so we're really trying to feed this all through. And also there's going to be an open data component of this.

Last slide.

And then just, real quick, so we can get into the panel: You know, everything I talked about now, you know, you can imagine this is going into publications as we disseminate this information and things that work. But a lot of you, while you might say that's great and you're really interested in mathematics and the theory, there is a sizable chunk of you in the community working at a different level when you deal with these models, where you want to be able to do analysis or run simulations. And what you want is not necessarily the gory details of how the models work, but you want the confidence of, I need a model that I can plug into my simulation or my analysis, that I know is trusted and someone stands behind it, and then I can solve the problem that I'm really looking at.

And so we've rolled out PropLib, the ITS Propagation Library. We're open-sourcing propagation model codes on GitHub as a way to engage. We're issuing releases that are code signed so you know they're authoritative and came from and were validated and tested by ITS. You know, we're looking to engage community. If you find bugs, file an issue. You can start up a conversation, and we can iterate this in an open, transparent manner. And so we have a bunch of models in development that will soon be going public. Actually, later this summer we're going to be rolling out support for Linux and cross-platform Python packages.

So, if you're at that level, I encourage you to check out that GitHub link, engage us through that. And I think it's a really nice place where if you're interested in what's being done at the lower level, but maybe not the details, here's a way you can plug it into your larger simulations and work with confidence in the results that you're getting out of it. So with that, let's jump into the panel.

5.5 Panel: Model Standardization - Propagation Case Study

Model standardization at a scientific level is required to expedite and ultimately improve the higher-level spectrum-sharing analyses and decision process. Scientific consensus, in general, is difficult to achieve. In this panel, we focus on standardization of propagation models because of the unique challenges associated with its scientific complexity, diversity of use cases and conditions, and non-deterministic and highly variable outcomes. Are existing propagation model standardization processes adequate for the challenges of today? Is there adequate architecture with well-defined interfaces available to standardize the diverse set of existing and new propagation models? Is there incentive for the community to work together toward standardization of propagation models? What validation requirements are needed for community/stakeholder acceptance and trust of new models?

Moderator: William Kozma, Jr., Head of U.S. Delegation to ITU-R Study Group 3 and U.S. Chair of Working Party 3K

Reza Arefi, Head of Emerging Spectrum Strategies, Intel

Chrysanthos Chrysanthou, Technical Analysis Branch Chief, FCC

Andy Clegg, Spectrum Engineering Lead, Google

Tony Rennier, Founder and CEO, Foundry Inc.

Sana Salous, Professor, Chair of Communications Engineering, Department of Engineering, Durham University (UK)

Billy Kozma: Excellent. Okay, so I see us all up here. So I'm going to just give a quick introduction to everyone here. And then much like the other panels, they're going to get a little five-minute introduction background as to where they came from and then we're going to really dive in. I have a lot that we'd like to talk about. I think there's a lot here, and I do want to make sure we end on time.

So joining the panel here, we have five panelists. We have Reza Arefi from Intel. I'll let them speak specifically, but I'll do a quick introduction. Chrys Chrysanthou from the Federal Communications Commission (FCC), Andy Clegg from Google, Tony Rennier from Foundry, and Sana Salous, from the University of Durham in the UK.

And I'll give a special thanks to Reza and Sana because I know they're joining us quite late in the evening, so I appreciate them being part of this panel. Real quick, before we jump to the slides for everyone listening, what we're going to talk about here is model development and standardization, but in the idea of how do we do this in a way that supports the theme of this whole ISART in the sense of iterating, right?

Normally in traditional spectrum sharing scenarios, it's this large effort you arrive at, one model or models, but one approach is to do the modeling and it all goes out the door and you see how it does. And maybe you gather data on your assumptions and on how that was performing. But we never really go back and say, well, how can we refine the model, how can we iterate and improve on it? And so if we want to get into this iterative process, right, just like you would any engineer or scientist who's working on a problem, how does that supported in the traditional way model development is done both in a time scale–wise and, frankly, dealing with personalities in organizations, because that's also a challenge as we work on this.

And we're going to touch on a bunch of different topics really through the life cycle of model development here, but with that, I'll jump in and let Reza go first to introduce himself and then we'll jump to the panel discussion. So go ahead, Reza.

And could we put the slides up for him?

Reza Arefi: Thank you very much, Billy. I'm very much glad to be here among friends talking about this very important topic.

If you would go to the next slide. Yes.

Just in place of introduction, I work for Intel Corporation as Billy said. I lead what we call Emerging Spectrum Strategies and Planning. And that's another way of saying that we try to stay ahead of the generations and try to intercept regulatory and product development in a way that the timelines match. By trying to predict what's going to be needed in both regulatory and especially spectrum, as well as technology development. I've been involved in the standards for longer than I've wanted.

And also since 2001, I've been involved with international regulations, specifically with the International Telecommunication Union (ITU). In ITU I've done various things, but in terms of modeling, the most recent one was development of ITU-R M.2101, which is a recommendation on modeling of 4G/5G systems for sharing and compatibility studies. And that's a model that since this was developed, every sharing study in the ITU uses this or they're supposed to. And currently I chair a group that's in charge of the development and updating of that recommendation, ITU-R P.2108 Recommendation on Clutter Loss. And we are trying to update and improve that as we go.

In terms of other activities, I'm active in Next G Alliance. In North America I'm the Vice Chair of the Spectrum Working Group. And again, we're trying to have a forward looking angle to spectrum for next generation and needs.

In terms of industry, I'm vice-president of Global mobile Suppliers Association (GSA) and an executive board member representing Intel. I'm also a member of the FCC Technological Advisory Council (TAC), the Communications Security, Reliability, and Interoperability Council (CSRIC), and the Commerce Spectrum Management Advisory Committee (CSMAC). And my focus is the work I do at Intel is basically identifying optimal spectral resources that's for next generation [communications] and application-centric approach.

That’s all. Thank you.

Billy Kozma: Thanks, Reza. So next we have Chrys from FCC. Please put up his slides.

Chrysanthos Chrysanthou: Good afternoon, everybody. I’m Chrys Chrysanthou and thanks first to Billy, the National Telecommunications and Information Administration (NTIA), and Institute for Telecommunication Sciences (ITS) for the invitation to participate in this panel and provide my personal perspective on the standardization of propagation models. I’ve only been at the FCC two years under the [unintelligible] and I engage in different areas including propagation. But my engagement with propagation started back in the mid-1980s at Polytechnic University with Dr. [Henry] Bertoni [Polytechnic Institute of Brooklyn, now the NYU Tandon School of Engineering]. Then I was focusing my analysis on urban propagation.

Let’s go to the next slide please.

At that time the focus was primarily on urban propagation and [unintelligible] we shifted at that time to a focus on propagation modeling. We went from more microwave lengths that were in rural areas into much more analysis of propagation modeling in much more complex urban environments in cities. And that also changed the mechanism of propagation that in an urban environment you have the multiple diffraction paths over the rooftops that was well explained back then by [Lewis E.] Vogler, Dr. Bertoni, and others. In the early 1990s we saw a lot of other analytical and simplified models in urban propagation to consider and account for the canyon effects.

However, going from this model that was presented in a lot of papers into building a standardized software tool that will represent that kind of environment. It was a big challenge and is still a challenge. One of the reasons was the lack of full data that will allow us to characterize these environments and specifically, the 2D and 3D vector data that provide information on buildings and streets. The other big problem was very limited to measurements. That is what allows you to validate the models.

And so, lots of issues I think and you kind of mentioned it a little bit. To build a propagation tool is a complex effort that requires a lot of different expertise. And we also sometimes had difficulty finding people with a good knowledge of geospatial engines. I think these are the main reasons that led us back in the 1990s to kind of depend still on terrain-based models for rural areas and empirical and semi-empirical formulas for urban environments.

Let’s go to the next slide.

So, however, I think in the last few years and thus and even from 2000, we see some of these obstacles to start to be overcome. We see more geodata available to us.

And also there are much more measurements. Well, thanks to the efforts of NTIA, ITS and other agencies. So that helps us to take some steps forward. I think there is still an issue of getting geodata and if you try to procure it, it is very expensive. So I think that right now we are at a crossroads, and I do believe right now that a lot of things are starting to fall in the right place.

And the question we have to really answer is, How can we evolve our processes. All right. To standardize the software tools and software propagation tools along with data and measurements where the concept is really to have better and more efficient spectrum sharing. I'm not speaking about modeling ITU standards that are very careful or in other standards. I'm speaking about building a platform, all right, a platform that can allow us to do click-and-play to validate our models, and also give some kind of acceptance based on analysis of these tools. It's going from modeling to software tools. It is a different ball game, right.

Now, when you're talking about tools, we're speaking about the product, and I think we need to treat it like that and put the framework around that in order to be able to develop it and validate these tools. I do not think this is a new idea, but I think right now maybe we need to discuss it.

And one idea, and I think it may help, is to have an independent testing lab that can facilitate this access of flow of plug-and-play and validate. And you have there the data that you need like terrain or building data in order to do your analysis.

It's certainly an expensive proposition. And certainly when we have that discussion with the government and industry, we need to consider how we are going to share the cost. To give an illustration of the complexities that we, at least in my perspective, have for building a propagation model, I have something that we are doing in-house in the FCC right now.

That is a capability that we really started back in U.S. Army [unintelligible; CSRIC?] that was working there and [unintelligible; CSRIC?] provided the rights for the code. And you can see on the left the very complex urban environment. And I think that picture is from 2008 that I have shaped to size of Baltimore—only a few cities I had access [to].

We are using ArcGIS to go and extract key parameters from that environment to kind of fit the simplified models on the right. As you can see, after you've finished this modeling, then it is a question of where I'm going to get the geodata and, on top of that, where I'm going to have measurements in the same city?

It was very interesting. A lot of times you have geodata in one city, but the measurements in another, but not in the same place. And that was a big problem 10 years ago. But I think now this data becomes more available to have geodata for different cities and measurements in maybe a lot of different cities and topologies.

Next, [slide] please.

Here is what I think of as a roadmap that we all we went through as an industry. We started somehow with very empirical models. But as the features became available to us like, clutter class today, which we have been building for a long time. Then we can really actually build much more complex and accurate models. In my opinion, still, even if we consider several features to characterize an environment, we may need some empirical formulation due to the complexity of an environment. Environments, and especially urban environments, are changing and there's a lot of parameters that cannot all be captured in shape files. So that the empirical formulation can maybe be determined using the collected data, crowdsourced data, by sensing. And you apply some new techniques from artificial intelligence (AI) and machine learning (ML) to determine that kind of empirical contribution.

Next [slide] please.

So here I leave you with some of my last thoughts on propagation modeling and standardization of that, along with data and measurements is just one of a lot of other capabilities that will be required to do efficient spectrum sharing. And I don't think working by ourselves in silos will help us.

It's about propagation tools and all other kinds of capabilities. It requires a lot of resources, and it requires consensus between industry and the government. I do believe creating some environment that will allow us to do, as I said, plug-and-play [analysis], will help a lot. And I know that NTIA/ITS is trying [to provide] something like that based on your description, Billy. I think that's where I will leave it and thanks for the opportunity to provide my perspective.

Billy Kozma: Thanks, Chrys. Next, we'll go to Andy, if you want to give just a quick overview and then we can dive into the discussion.

Andy Clegg: Yep. Really quick. So I'm Andy Clegg, spectrum engineering lead at Google. I'm involved in the development of the standards and involved in the proceeding for Citizens Broadband Radio Service (CBRS) since before CBRS existed. I'm now working on the Automated Frequency Coordination (AFC) system. So a lot of experience with spectrum sharing frameworks and also the use of propagation models in them. I made a lot of noise during the creation of CBRS Standards with regard to the fact that we were using overly conservative propagation models. And I'll explain why I think that in four pictures.

So if you go to the next slide, this is the first picture.

So when we embarked upon CBRS, one of the first things I did was to create a measurement campaign for propagation loss in the 3.5 GHz band. And so I did the area outside of Washington, D.C., where I live and set up a system to measure propagation loss in the 3.5 GHz band.

And what we what we found is sort of represented on this plot: The blue dots are the actual propagation loss that we measured; the green dots are the prediction from the Irregular Terrain Model (ITM); and the red dots are the difference between the two, on a point-by-point basis. And if you note, the distance that we're looking at here is only a kilometer.

And if you look at this, we have cases where the ITM-predicted loss is well over 50 dB less than what the actual loss is. And so if we use a model like this for spectrum sharing, we're going to be leaving a lot of spectrum on the table because ITM is going to tell us the loss is something, but in fact the real loss is a lot more and we could have packed more people into the spectrum.

So this was a very big eye-opener for me. And the first introduction to how unsuited ITM is to actually doing propagation loss measurements for spectrum sharing.

So, next slide is Why is this?

Well, it's actually when you look at it, it's very easy to understand why ITM under-predicts loss or in urban environments and suburban environments.

So this is a picture from Google Earth 3-D representation from Google Earth of Manhattan. And Manhattan is very challenging propagation environment because you have all of these big buildings sticking up and everything. And so to Chrys's preceding presentation, all of these buildings actually add a lot of attenuation to the signal traveling from one part of Manhattan to the other.

But if you go to the next slide,

this is what ITM thinks Manhattan looks like. It doesn't know anything about the third dimension of the clutter of the buildings. It thinks everything is flat and only the thing it takes into account is terrain. But obviously the propagation environment in a place like Manhattan is a lot more complicated than just the terrain. The buildings add many, many dB of additional loss that is not considered in ITM. Yet, we are using the ITM model for interference protection in CBRS, so it's entirely unsuitable for that, in my opinion. I was really happy to hear about all the work that Billy described that they're working on. So I'll leave you with the last example of why ITM is unsuitable.

If you go to the next slide.

So for those of you familiar with CBRS, the red areas are the dynamic protection areas where ships operate radar out in the ocean out to a couple hundred kilometers or so. And the green areas are what have been defined by NTIA and the industry as the dynamic protection area (DPA) neighborhoods. These are the areas in which CBRS devices that are limited to 50 watts effective, or equivalent, isotropically radiated power (EIRP) must be considered for their potential interference to ships that are as much as 200 kilometers offshore. And it's really amazing when you look at this plot that, you know, are we really saying that a 50 watt device in a valley in West Virginia could really cause interference to a ship 200 kilometers off the coast of North Carolina? And the answer that ITM tells you is, Yes, that's possible, because the prediction shows that it could have a significant contribution or a not insignificant contribution to interference 200 kilometers off the coast. Of course, to most engineers, that seems like a nonsensical conclusion, but that's what comes out of ITM. The reason it comes out of ITM is the troposcatter mode.

It's a persistent mode of propagation off of weather and an index of refraction variabilities in the troposphere. And the troposcatter predictions in ITM are what cause the prediction of potential interference over very large distances because it propagates up into high parts of the troposphere and back down again. But the fact is the troposcatter model in ITM has never really been fully validated. And certainly not in a range of environments, in a range of frequencies, in a range of time has it ever been validated. It's basically based upon a few points of data that were acquired closer to the time of Marconi than the present day. And yet we're building modern spectrum management and spectrum sharing frameworks upon the troposcatter model. It was really cool to hear Billy say that they're actually building troposcatter lengths and testing it.

The reason why this is difficult to test and validate is the troposcatter mode predicts typically well into the 200s of dB of propagation loss—230, 240, 250 dB loss, even. And that's a really large amount of loss that's very difficult to measure. And so you need specialized equipment, high-gain antennas, all sorts of other things, high-power transmitters to test it. And it's not an easy task to do so.

So kudos to ITS to getting involved in testing and validating the troposcatter model in ITM. So we'll be very interested to see the results. We hope that what they determine is that the troposcatter loss is actually much higher than ITM predicts. If you find that it's much lower, I want to talk to you before you publish those results, but otherwise we're very excited to see that ITS is embarking upon that. So anyway, that's it. Thank you all very much.

Billy Kozma: Thanks, Andy. Very good. We'll jump over Tony Rennier, of Foundry. Go ahead, Tony.

If you can bring up his slides.

Tony Rennier: All right, guys and everybody. I'll try to go quickly. I sometimes tend to talk longer, but we'll try to make up some time here. So, first of all, thank you for inviting me to this panel. I really appreciate the opportunity to talk about particularly all the work we've done in Spectrum Sharing Test and Demonstration (SSTD). I've been hearing through the whole conference issues that I believe, in at least in some small way, we've been trying to or have addressed in SSTD. So I'm anxious to talk about that.

Before I get in, Just this as a disclaimer: I'm going to try not to say anything too terribly controversial, but if I do, it's just me. I don't represent Defense Spectrum Organization (DSO), SSTD or any other organization I'm affiliated with.

So next slide, please.

But in the interest of time, I'm just going to keep this short.

I've been working with Spectrum, but I'm a newbie really, and most of the people I work with, they say, Oh, you've only been here since 2007, you don't know anything. But I've been here since 2007. I work with a lot of the Department of Defense (DoD) tools. A lot of that includes propagation analysis. But the most important piece here, at least for this discussion today and for the panel, is the work that I took on in 2005.

And in that work, I've been the chief engineer of the of the SSTD program. We've heard a lot about SSTD from various folks and I'm grateful to hear that. But just as a note, we're going to talk now today and have a discussion about propagation. But SSTD is a lot more than the propagation. And this model standardization techniques capabilities that I'm going to talk about today we've been applying them to the LTE, 4G/5G characterization, DoD receiver characterization, as well as aggregate interference assessment.

So we have four different buckets of models that we work on to try to do standardization.

So next slide. Whoops. Okay.

Before we get into some of the key perspectives gleaned from the propagation model, just a couple of notes on SSTD and we've already talked a lot about it in the conference, but if you haven't had a chance or you haven't been tracking it, I've got sort of a timeline there on the left, it's a very high level.

And really the big takeaway there is, you know, that one of the themes of the conference is we have a linear regulatory process and what are the ways in which we can turn that into an iterative process? And at least in our way and at least with Advanced Wireless Services (AWS-3) though, it does absolutely adhere to the linear model, we have taken, sort of the initial look, the first thing that came out when the analysis started. We've been iterating really for six years, working to improve the models and improve on the predictions that are made in terms of the coexistence and spectrum sharing. And so it's not the full deal. It is not, obviously, the idea that we could go back to the FCC and have an updated Radio Network Optimization (RNO) or something like that. Based on the findings that we've had in the last six years, that's not in place, obviously. But at least in terms of the way that matters to AWS-3 licensees, we have been iterating and I think we've had some good success there.

And in terms of the right side [of the slide], just a couple of notes. SSTD because it has been around for six years, we've had an opportunity to do a lot of really great work. But just a few things to highlight here for people that are really interested in propagation, and I think most people here are: We've gotten and we had an opportunity to do a lot of data collection. We worked with ITS for most of the entire six years. Chriss Hammerschmidt, who's now retired, and her team members were tireless in their efforts to go out and measure the 14 different areas across the U.S. and really high-quality good measurements were made. So we've got a lot of drive-test history that we've been able to collect.

The second big item in terms of data, it's something that's new for us and one that we haven't yet had a chance to explore. But we partnered with the FAA. And the FAA has this program called the Automatic Dependent Surveillance–Broadcast (ADS-B) program, where all aircraft that fly in the U.S. are required to transmit every few seconds flight data about where they are, where they're going, things like that.

And there are 700 ground stations spread across the U.S. that receive these signals. In some cases, a given transmission might be received by 40 different ground stations. Each of those ground stations records the received power, the signal levels of those messages. And you combine that signal level with where the aircraft is when they made the transmission, and you're talking about a ton of a propagation data that can be gleaned from that. So we're really excited about that database and the opportunity to explore it.

A second key item coming out of the SSTD program is the development of two, what I call differential, propagation measurement techniques. Both of these techniques use ubiquitous transmitters. In one case, we're using GPS satellites, and the other, again, we're using these ADS-B transmissions, and we have an embedded receiver somewhere in clutter or in a building, for instance. And then we have a clear line-of-sight receiver. And by comparing those two measurements, we get good estimates of what the clutter of building exit-loss data is for that. This ability to get a 360 degree azimuth, 0 to 90 elevation angle view of a building penetration or clutter is something that's extremely useful in our AWS-3 assessment. So we're really excited about that.

Third, and one, again, that's somewhat new for us, we just started about a year ago. We finally got enough data in house where we started thinking about using machine learning techniques. And I know it's sort of a hot item and a bit of a buzzword these days, but I'm really excited about the fact that we've actually been able to use some of these techniques to generate a much improved category model, which I'll talk more about probably during the discussion, and even a predictive model for clutter, which was something I just I never believed that we'd be able to get to, but we have that and in fact, we're presenting to the FCC TAC later this summer if you're interested in that work. Also, I'll just note that there's several papers that we provided as part of the ISART conference. If you go to the website, the I forget what the link is [https://its.ntia.gov/isart/past-programs/2022-isart/], but if you go to the title page and you can go in, you can get all of that. So there's a lot of papers talking about all the SSTD work that are available. Oh, it's the bibliography and resources tab, I see that now. So, all right.

And next slide.

So in the planning meeting for this panel I sort of was asked to provide perspectives on standardization [of] propagation models. To answer that question, I think back to some of the key things that were the most important things that we discussed over the last six years as we worked our way through the beginning, the initial state, what we got generally out of CSMAC and was sort of the starting condition, and then where we are today. And the first one I'm sorry, that I'm like the eighth person in the conference to bring this up. But you know, you can't overstate it, you know, George Box said, "All models are wrong. Some are useful." It can be sometimes hard to resist the urge to dive into the weeds of an enticingly complex problem. But I'm going to give credit to Howard McDonald, who until very recently was the DSO lead for this work, helping us to remember that "Fussing over a 0.1 dB mouse only stole time from the resources when there were 10 dB tigers in the room." So this is really important to keep in mind when you're working on modeling.

The second idea is, "Propagation is already a variable phenomenon." [Paul McKenna, ITS] I guess that probably will not come as a surprise to anyone who's studied it for more than five minutes.

But when you get into the modeling part, it's sometimes easy and even convenient to ignore the randomness inherent in the phenomenon. When you consider that two identical propagation measurements day-to-day are often ± 7 dB different, it really starts to change the way you think about your models and how you want to try to model something. I'll credit Paul McKenna from ITS. He worked with us tirelessly throughout the program for ensuring that we didn't forget this fundamental truth and that if we do have to decide that we can't use the random variable, the proper distribution to represent something, that we need to be very careful about how we choose the equivalent value. Just as an example, a 5 dB clutter loss is not equivalent to a 0 to 10 dB uniform clutter loss distribution—if you care about aggregate interference, that is. So, thank you, Paul, for that.

The last item here on this one is, "There is not one model to rule them all." [Chris Anderson, U.S. Naval Academy] This is not one that I've heard in the conference, although I think there have been folks that have alluded to it. Going back to the idea that all models are wrong, if you try to use the same model everywhere, you're going to be even more wrong.

A simple example of this comes in the form of whether reflections have an effect on signal levels from an interferer. The answer is, of course, Yes and No, and using the right model that addressed the most important aspects of the environment is key.

Also, it's important to understand that almost always a propagation model is created to answer some other question. For example, will my radio work or will I see interference from a radar? Depending on the question that the model was supposed to answer, you might find differences in the way people went at it and some of the assumptions that they might have.

I credit Chris Anderson, of the U.S. Naval Academy, for reminding us to check the label on all of our models and resist the urge to try to find that one-size-fits-all approach. It doesn't.

All right, next slide.

Now I'll talk about the perspectives on standardization, which is really what we're here to talk about today. You can't measure the world, but a model that's untethered from measurements is hard to trust. And so what's a modeler to do? It is important to do your best to bridge the gap.

On SSTD we used the data we had to validate propagation techniques that predicted the propagation loss for a given path. Then we took those techniques out for a walk around the country, giving them the geospatial data they needed, and then using software to generate distributions for an LTE sector, which was a decision point for the business process for AWS-3. Finally, we used category models to combine like sectors to generate distributions.

The next point is that there is safety in numbers. If you're assessing inaccurate interference from a large field of emitters, getting propagation loss right for each one isn't as important as getting it right on average. It's okay if I'm a little low on one as long as I'm a little high on the next, that idea. The approach works well for site-general models where you have categories. It, however, can be quite tricky if you're trying to increase fidelity on your way to site-specific models. So, you do it at the beginning, but remember, as you try to get better, some of that safety goes away because your numbers get smaller.

By far, the most important perspective is the one that we've been talking about all week. It's the last one here. Trying to do model standardization is a "Big Bang" event where the research team toils away for a week or even months to generate a propagation model that is then presented as fait accompli [a thing accomplished and presumably irreversible] is problematic, to say the least. An iterative approach that tackles one issue at a time and includes stakeholder collaboration, solidifies agreements as you go, and allows for the technical work to incorporate lessons learned in one iteration into the results for the next is a much better approach.

Howard McDonald refers to this as "Peeling the onion," and it yielded very good results for SSTD. Thanks.

Billy Kozma: And last is Dr. Sana Salous. You want to go ahead and give a quick overview? Thank you.

Sana Salous: Yes, thank you. I've got some slides. Okay. So I'm coming from the academic point of view, and I'll give some overview about the work that we have been involved with, in particular, of course, in the ITU.

So the topic that I've chosen for this evening is the 5G models, because these were quite challenging in the sense that you would see that the frequency bands that were identified were fairly diverse and also the environments are fairly diverse.

So if you go to the next slide.

So my background is that I have been working in radio propagation for about 40 years, and I first started in long-range propagation studies in the HF band and then moved up gradually now to the millimeter wave [band]. And in order to do these various propagation measurements and modeling, I tend to design my own radio measurement capabilities, So we have custom designed radio channel sounders. I also work a little bit on radar, but this is not the topic for this evening. And the results that we have done recently were contributed to the ITU-R Study Group 3. The ITU has several study groups and the one that I'm working with is the one that works on propagation. In Study Group 3, and you mentioned Paul McKenna, because he is also involved in the same group, it works in both the ionized and non-ionized media. So basically from my point of view, it covers all the areas that I have been involved in in terms of propagation from atmospheric up to now, the millimeter wave.

So next slide, please.

So, the challenges for the 5G models are that . . . It was at the World Wide Communications Conference in 2015 that they presented us with a fairly long list of potential frequency bands. And you can see this, these were ranging from 24 GHz up to 86 GHz. And that's a very big challenge if you are trying build custom-designed equipment in order to do these measurements.

They were also different bandwidths, so they were covering from 1.6 GHz to 6.5 or even 10 GHz. And the ones that are highlighted in red in this table are the ones for which we have built some equipment in order to do measurements that we contributed to the models that were developed for 5G.

Let's go to the next slide, please.

So the other challenge is not just that we had to have a very wide range of frequencies. We also had to cover numerous different scenarios. And I've put here the ITU recommendations that we have contributed to. So for the outdoor environments it is ITU-R P.1411, and for the indoor environment it is ITU-R P.1238, and they deal with different types of scenarios.

So when you look on ITU-R P.1411, it tells you it has specifications. And we've heard from the previous presenters talking about urban dense, urban / suburban, residential, and so on. So you would have to look at all of these different environments, try to do measurements across different parts of the world, because the idea that these models are general, so they should be applicable not just in Durham, but they should also be applicable in Japan and the U.S. and different parts of the world.

And again, for the indoor environments also we had to look at different potential environments and different and classifications. Currently there is a great deal of interest in industrial environments. So we needed to find some typical factory-type of environments in order to do measurements. And these are quite challenging and completely different from a shopping mall or a conference room type of environment.

If you go to the next slide, please.

Another issue that came up, a question that came to the ITU, is if you are now going up in frequency, would you be able to use the same frequency band, indoors and outdoors? And so there was a necessity to identify the propagation, or the penetration loss, between outdoor to indoor. And in order to do this, there was a new recommendation that was developed for 5G and that was ITU-R P.2109.

And in order to do this, we had to go to a specific site in the UK, which is the building research establishment, because, again, in order to come up with a model that is applicable universally, you also had to have typical types of buildings. So in the UK they have what they classify as traditional and modern buildings. And the traditional buildings, like a Victorian house or a 1980s build, and the modern buildings would have a higher type of glass and other glass and so on, so they would have higher penetration loss. So again, we had to go to that specific site and do these measurements which were collaborative with Ofcom, the UK regulator.

Go to the next slide, please.

And, finally, what we have also looked at is fixed lengths. So, for example, we wanted to look at backhaul. And, generally, all of these various fixed lengths previously were done over a fairly long range. So the fact that 28 GHz was studied for many years, the impact of precipitation on 28 GHz have been studied for a long time—for example, in the Rutherford and Appleton labs they have looked at it for long distances—but then if you want to look at it in the building environment, you do need to have shorter lengths. And we looked at an existing ITU recommendation, which is ITU-R P.530 and it had some models that were applicable for distances greater than 500 meters and above and the length that we have set up was typical for a building-to-building type of environment, potentially across a few meters.

So we set up these lengths at about 36 meters. And there is also a general perception that a millimeter wave is primarily line-of-sight. And therefore, you can actually have more than one length between buildings, you direct one toward the other building, and you should be okay if there is another link. So we put one at an angle, 45 degrees, totally non–line-of-sight. And we found that we could actually get the signal from the non-line of sight. So there is interference in that situation, even though people have traditionally thought that it shouldn't be an issue.

And we studied the impact of precipitation using the picture you would see on the left hand side to my side anyway, is that this drosometer which measures the rain parameters, the drop-size distribution, the rainfall rate and so on, and we studied it on two frequencies on the 28 GHz and also the 70 GHz.

Of course, now that we are moving to 6G bands, we are going to update all of our equipment to the next two frequencies, which extend up to 300 GHz. So that's the next phase. But so far, these are the different recommendations that our research at Durham University contributed to in terms of the propagation models. So I will leave it at that point and thank you for [unintelligible].

Billy Kozma: Thank you, Sana. And so with that, I want to start to jump in here with a discussion. Like I said, we're going to kind of cover the arc of model development and standardization and how that can be applied to this iterative approach. And I think the best place to start is really not a technical question, but it's one of these soft ones—but I really think it sets the foundation for everything we want to go to when we have these sorts of conversations, whether it's the Spectrum Access System (SAS) work that Andy talked about or the AWS-3 that Tony talked about. And I know you've all had different experiences dealing with various organizations.

What ends up happening is we bring people together, we bring engineers together, ideally. Sometimes that's not always true. They come with their own organizational biases, and that's not a negative necessarily to everyone, right? If you're a government agency with some incumbent system that's a safety-of-life, and that's your mission, you know. It's in your interest to maximize protection of that asset versus if you are a commercial entity, you have a financial stake as to what's coming on and it does color your opinion as to what types of approaches you come to it [with]. And, you know, we're going to protect the guilty and the innocent and not name names—although if you have positives, you know, feel free to offer those up. But we start off on this foundation and we bring people together from varied backgrounds and we have to start establishing trust. If we want to be able to have these conversations in a collaborative and productive manner, we want to revisit—so talking about what Andy showed in his slide—the idea that maybe we can iterate this and make these models better, ignoring the impacts to like auctions and [unintelligible] there. We need to have this foundation of trust so we can really have an open conversation before we even get to the technical aspects of that and critiquing each other's work, you know, we need to establish that foundation.

And I'll throw this question to you first, Reza, because I know you've dealt with this some in the Clutter Group within the ITU; and then Tony, I'll go to you. Because you've had some positive experiences you alluded to with AWS-3 work. How do we manage and establish that framework right from the start, where we can develop that trust so that when we have those hard and technical questions it's not taken personally, and we can revisit those decisions later on?

Reza Arefi: Yeah, thank you, Billy. And I apologize. I was under the impression we were doing intros first and then so I didn't present actually my content slide, which actually goes very directly into what you're asking. So if I could ask that that slide that I didn't present be put back on screen, I think especially with the Clutter Group that you mentioned, that's quite important.

Is it possible that we get that slide?

Yes, this. Thank you. So especially in the context of clutter and the pictures that Andy showed that actually quite directly presented the importance of taking clutter into account. So we had various types of inputs in terms of measurements, simulations, both ray tracing and Monte Carlo simulations. And, we looked at a variety of those. There were some issues with harmonizing methods.

And then in standardization, not necessarily in the sense of, you know, a standards development organization (SDO) publishing a standard, but mostly harmonizing guidelines that people use. We've seen that actually harmonizing the verification process, the collation of data to increase variability, to enhance the model. All these are these are very, very important.

We have seen, for instance, the measurements that you get in urban, as an example, urban areas in different parts of the world look very different. In order to be able to have a larger pool of data to draw empirical models out of, you would want to make sure that the kind of environments that you take measurements in are comparable or complementary, right? So, it's important to record exactly what kind of environment. Some people are very detailed in what they present, like Professor Salou's. But some others are not. They opt for brevity. And that makes it a little difficult to just, you know, to just right away go into the processing of the data.

One of the things that would be very important, and we've have seen this the clutter development, is what I call calibration, calibration of data and also a calibration of the equipment and the measurement methods. We have seen that simulation assumptions have been very important. In all the ray tracing that we have seen presented to us, whether you put the antenna right next to the building or whether you randomly drop it somewhere in the middle of the street, sometimes it makes a big difference in the outcome.

You might not think that, you know, harmonizing the antenna placement is such an important element but it is. In ITU Study Group 3 we have tried to create these forms for people to fill out but they're not really descriptive enough. There are still a lot of things that people can introduce.

We have tried to make these forms not just for measurements, but also for ray tracing. But we've noticed that, for instance, different versions of digital maps have differences in a way that create very different results in terms of one building being there or not being there, depending on the time of the production of the map.

One thing that, in my view, is going to help us quite a bit is creating what I call interim results. For instance, just an example: Let's say two people are doing measurements in the same frequency range in two different urban areas. One, let's say in Australia, another one in Denver, right? What's urban in these two different places might look different. So having an idea of how these two urban areas compare through creating some of these, um, interim results, for instance, statistics on multipath, accompanying the measurement data with the power delay profile to also let us have an idea of how these two environments compare to each other. Or if you're doing simulations, providing also the probability of line of sight, distance to the first building or second building, these kinds of things that accompany the measurement or the simulation data give us more means to be able to compare and verify the proposals.

So these are some of the things that might at least go a long way in trying to enhance the models that we have and also arrive at new models and extending various aspects of the existing models, the frequency, the environment, etcetera.

Billy Kozma: Thank you, Reza. As I said, panel, as we as we go, if you guys want to jump in and respond or disagree with anything people say, feel free to as we go from there. I know, Tony, you've had, as has been alluded to, some success in this area of developing a good relationship between, you know, AWS-3 the DoD side and the commercial side where, as you alluded to in your talk and other people in this panel, working through and breaking down the problem into smaller and smaller chunks and taking them off the table. And you don't always have that sort of relationship between the agencies that you can do that. Can you comment on that? I think it's worthwhile.

Tony Rennier: I think it's a really important point, Billy. We're really lucky, you know, in that we had a little bit of time. Because then if you think about how CSMAC works, you know where they get two weeks, and they got to come up with a model. It is just sort of a, you know, a big free for all in some cases.

But we were able to initially, you know, it just took time. In the beginning, there was very little trust it. There was very little what's yours is mine and mine is yours. There was none of that. But because we were sort of focusing on a fact-based or a physics-based problem and we were able to all get together and collaborate with each other, what we found in almost every single time is if we actually, you know, sit down with someone across the table from someone else who also is sort of signed up to this fact-based, physics-based analysis and you walk them through why you think, and then they walk you through why they think, you can almost always figure out where the disconnect is and figure out, you know, how to come together. We never had a single experience where we could not solve a problem. When we had a problem, we sat down with the other side, whether it was folks in the commercial wireless industry or folks, you know, on the military side.

We sat down to talk with them. We were always able to get there. And I think that's a testimony to the you know, the good faith part of it. You know, "My mind's made up, don't confuse me with the facts" kind of thing. We didn't really experience any of that. We had a lot of obstacles initially, but by patience and going through things in a very detailed way and inviting everybody into the actual process of generating the models, we were able to overcome all that.

So it was, you're right, it was a very positive experience on our end.

Billy Kozma: Yeah, I think that's great and I'm going to transition from there and throw it over to Andy. When we start to talk about model development, Paul Tilghman of Microsoft made a comment yesterday in the data panel [Day 2, June 14 - Panel: Data Sharing and Transparency] that the 3.5 GHz SAS, you know, if we did it today, it would be different. There were things we learned.

And of course, that lends itself to one of the overarching topics here, which is how can we incorporate and maybe iterate faster. And it was clear from your presentation, you've had some views and you've talked about this before in modeling development, but you know, as Tony said, sometimes it's not necessarily our choice, but we don't have enough time to get that initial effort right.

We have Congress saying something or it comes down from regulators and we have to hit the ground running and you start somewhere, and we may know it's conservative, but that's usually where you want to start. And as you showed there, you know, there's room for improvement. Give me your take on some of that modeling and incorporating that in as to how you can work that problem iteratively and objectively, right—with the opinions.

Andy Clegg: So, you know, a couple of thoughts on the CBRS regime and it's related to propagation and it's also related to the lessons learned. One of the lessons learned in CBRS is that by nature of how we did the standards and then the certification testing, everything's baked in now. We were tested against a particular propagation model, and that propagation model is now baked into a SAS and effectively unable to change.

Because if we change it, if we change the model we're using, we sort of void our certification. So we sort of baked into the process the inability to evolve with better knowledge of better propagation models. And I think that was a pretty big, I don't want to say mistake, but pretty big something we gave up that we probably shouldn't have given up.

We should have allowed ourselves to evolve as knowledge progressed. So one statistic I like to throw out is that we've been operating CBRS now for two plus years and there has not been one reported case of interference to a protected incumbent in the band, not one reported case of interference to a protected incumbent in two plus years and over 200,000 base stations deployed, not any reported interference.

That tells me one thing. That tells me that we were vastly over-protecting the incumbents because, you know, that's a basically a 100 percent reliability. And that means something's wrong in your formulas. And a lot of that I attribute to propagation models that are overly conservative. I think there needs to be built into spectrum sharing frameworks some closed-loop mode where we actually determine what the received interference is and feed that back into our systems to be able to account for that. If we're never interfering, obviously we could turn our power up a little bit, reduce or increase the loss predicted by the models. If interference is predicted, maybe we need to dial it back down a little bit. But none of that's baked into CBRS. We're sort of working on baking that a little bit into the AFC thing.

But those standards aren't done, so it's not clear we're going to be able to do that. But we definitely need some kind of closed-loop way of confirming that the propagation models we're using in spectrum sharing are not overly conservative or not under-conservative.

But I also recognize, as several of the speakers have said, propagation models are very dynamic. I mean, propagation is dynamic. It varies, you know, sitting in one place you can see 23 dB of difference in propagation over the course of an hour or so, you know. So it is very dynamic and it's hard to get a handle on. But I think the way we're doing it in CBRS is not the way we want to do it going forward and we need a much more dynamic kind of closed-loop way of validating our propagation models.

Billy Kozma: Yeah, I think something you touched there is, you know, to be able to have that feedback loop really requires the trust to share the data, right? Including the fact that the data may at first glance, shall we say, not appear to benefit your own situation on what's going on. But that doesn't necessarily mean that's true, right?

Because that could just be a first impression of it. And you kind of have to take a holistic part of the view of the whole scenario and what's trying to be done. Reza talked about this when he was talking about when you're incorporating datasets, you have the problem of both different people taking measurements with different systems and incomplete data.

Sana, you've taken a lot of measurements. I'd be curious to hear your comments on this, because it's both measurements of people objectively deploying systems, whether they're spectrum monitoring systems, but it's also data we're talking about from the 3.5 GHz SASs themselves and the operators. What are they seeing and what are they doing? You know, the more incomplete the environment we're looking at, the harder it is to really improve things.

And so, Sana, let me throw over to you on that topic of taking measurement data that you can aggregate together. Because if it's vastly different, that becomes real problematic.

Sana Salous: That's what we've done in the models that we have developed. So the model that we developed for ITU-R P.1411, the outdoor scenario model, there were mainly three administrations. It was the UK, Japan and actually from Korea. And we also had some input from Intel. So these were conducted in different environments and we did try to measure as much as possible different variations in the classification as given in the recommendations for suburban/urban, dense urban, and so on.

And in the end, the model is representative of those datasets. The measurements needed to be done to a certain standard. So I remember that when we first brought in our data, because of the high losses in the millimeter wave band, we didn't take lots of measurement points. And basically Nippon Telegraph and Telephone (NTT) said, Well, we've got this high-gain amplifier and we're going to take continuous measurements. So we had to come back and rebuild our equipment in order to be able to take more data points.

So what I'm saying is that there is a need for some agreement for those who are developing the models in terms of the methodology for collecting the data. And we are now going to hold a meeting next month specifically for that purpose because we are looking at now even higher frequencies, up to 140 GHz and 235 GHz.

And it's even more challenging to collect data. So we are going to have a meeting to agree on the number of data points, the spatial separation, the environment, and so on. So a great deal of effort goes into these models and a great deal of data are collected. But, of course, the equipment that's used for these collections needs to be verified.

And so we sometimes are provided with measurement data that we do not take into the development of the model either because the setup was not done in the right way, as we have all agreed, or that the equipment is not appropriate. So it's a big challenge and I appreciate that when you say it might not work in all environments, but I thought that that was something that people have considered in terms of cognitive radio.

So you try and monitor the spectrum and then say, well, nobody's using it. Maybe I can open and use it. But then you encounter, you know, you're facing the hidden node problem where might be actually a primary user, but you're not seeing it because you are hidden behind the building or something. So it's a big challenge and I think agreement. We try to do as much as we can in terms of developing these models and we try to take as much data as possible in different environments to make it as site-general as possible.

But yes, I mean, for example, the model we developed for ITU-R P.1411 we published it in version 10. Then people went to it and did Monte Carlo simulations and came back with a question: Why does it do this at these points? So we had to do a little bit more work and refine it in order to answer that question. So the model in ITU-R P.1411-10 is different from ITU-R P.1411-11, the next version, because we did a little bit of refinement on it when people used the model and came up with a question.

Billy Kozma: And I think something there that's important is, you have to be—again, this builds on the idea of trust, when you get together and someone takes measurements, that's great—but you have to be willing to be critical of those. And if it's decided they aren't representative or there is something wrong, throw them out. Just because someone went and took measurements, doesn't it mean they're all the same. And you have to be willing to essentially reject datasets, if need be, if you're doing some sort of empirical [unintelligible], or you're taking statistics. And that can be difficult when people spend a lot of time. Measurements are difficult.

Chris, you mentioned, too, about the data, the environmental data, you know. We've had this wealth of that and that's really valuable. It does, however, sometimes lead to, when we start talking about modeling, [unintelligible] how do we set bounds on models, right? Andy alluded to this a little bit as well. But we have these models and perhaps they were there for specific types of scenarios or for specific types of data, and we say we have all this other data now; we want to kind of apply them to it. And that can lead to some very different sorts of results, I would say, coming out, that might not be self-explanatory. So do you want to comment on that? I know, you guys, you've been looking at using those datasets. You're on mute, Chris.

Chrysanthos Chrysanthou: Thanks for reminding me. Billy, when you say datasets, you mean measurement datasets?

Billy Kozma: Measurement and environmental, right? Because you've been working a bunch with vector data, but that's not necessarily, you know, applicable to all propagation models out there. They may not be able to handle that sort of, kind of, information in their assumptions.

Chrysanthos Chrysanthou: Yes. And you're right. I mean, usually speaking about environmental datasets actually that translate and have available a lot of features. It can be built-in, strict widths, everything in there. And the accuracy of the models, in my opinion, it depends on how you address these environment datasets. And in my opinion, that's a trusted data. When you build your model, you need to consider that everything is very relative. Is everything relative between the antenna to the rooftop line? You may have to consider when you are on the rooftop of buildings and other things. But in the end, in my opinion, when more features are available, then they allow you address and have better predictions.

The other thing about measurements is that certainly the measurements need to be continuous. And that's why, in my opinion, down to the road, we may need to have much more ground sourcing data, if I understand your question correctly. For me, ground source data, it needs to be accumulated on a daily basis and maybe if have sufficient ground source data in one city, we may start to look beyond traditional propagation modeling.

We can start to look to techniques like clicking that may allow us to validate our measurement data and check that all data is collected and also allow us to validate propagation models. So I think the way that we can trust them, in the end, is allow the people to share this kind of data and allow different people to, as I said, have access. And use that data to improve their models.

Hopefully I answered your question, Billy.

Billy Kozma: So yeah. And I think that's an important point is that, you know, when we as a community, work on modeling and modeling improvements, I think it's important to really be transparent about what we're doing. So that if you're working on a standard and you're trying to improve things by publishing both the work on the model, which usually does get published, but the data that goes back up in the assumptions, that would allow Sana who has come from a university background here, or allow someone who's an objective third party to basically perform analysis and try to validate some of that. Someone who's been separate from the process. If we think things are closed up and then at the end of the process, as Andy talked about, bake it in, you don't really have that sort of outside feedback. There's no mechanism to bring that in and work on the problem.

And I'll throw this in, I know we have like five minutes left, as one of our last things—how do we facilitate that iteration? You know, Andy brought up a point, not baking it into the results, and that was clearly different than how it was done within AWS-3, where you had flexibility, Tony, to do some of that iteration to work on the problem that way. And sometimes there are time constraints. But I'm curious, really, anyone here, you know, in a minute, what would your thoughts be to kind of promote more of that, both iterate in realistic timescales, understanding we're probably going to start conservative, but as we get data and we can reevaluate those assumptions and we can kind of move the whole problem closer to a more complete solution.

[Crosstalk]

Andy Clegg: Sorry. I was just going to say I think we have to iterate on iterating. So I would say the, the first thing you do is, for example in CBRS, let us turn up the dial a little bit and see if we get any interference complaints after, you know, three months or something like that. And then when I say iterate on iterating, we do need to iterate to a manner where in spectrum sharing frameworks you can adjust those dials much more dynamically.

But let's not try to boil the ocean from the start. Let's make it so we can adjust that dial every month or two or three at first and get experience for how that feedback loop works.

Tony Rennier: Yeah, I'll just double down on that. I think Andy is absolutely right. I mean, I think, and we heard this in Fred's [Frederick D. Moorefield, Day 3, June 15 - Keynote: Cost-Benefit-Risk Related to National Security] comments earlier today, if you don't get to a dynamic spectrum sharing scenario of some sort, you know, we're doomed. I mean, if you have to sort of understand up front what the propagation environment's going to be like before you can do anything productive, we're always going to be limited by, you know, all of this that's going on right now—the variability, the uncertainty, the lack of data—all of these things are going to contribute. And so, you know, yes, you know, in a perfect world, you know, something which Andy describes and something that's automated and it's like, well, I don't really care what the propagation model is, I'm just going to start working. And then when I create interference, I'm going to stop or I'm going to pull back. And whatever the propagation is, it is.

But, you know, I think we're a long way away from having any sort of a regime where we can do anything like that. And Andy's comment on boiling the ocean, I think, is a good one. But, you know, we need a lot more data. I think we could still make a lot more progress on propagation models if we have a lot more data, talked about that, you know, using GPS satellites and using

Automatic Dependent Surveillance-Broadcast (ADS-B) signals. It's just two ideas for generating terabytes of data. The Federal Aviation Administration (FAA) data we got, it's 36 terabytes of propagation data. Imagine: 36 terabytes of propagation data. So I think we have room to improve. And Andy is right, if we don't get that image sharing, there's only going to be so much that we can do.

Reza Arefi: One thing I'd add here is I think at least part of this is on the people and engineers who do the measurements and do the reporting, taking enough care to present more information on how the measurement has been done in what kind of environment and all the conditions, the type of antennas, etcetera. I think it's very important to make the data useful for others also to have these larger sets.

And again, Sana sets a very good example on how this is done. And, Billy, we have seen all kinds of things, right? Things come in a way that's very hard to verify. Right. And that wastes everybody's time, including those who have actually done the measurements. And so especially now that we are moving towards some uncharted territories, you know, there's quite a lot of stress on, for example, what about 100 GHz where a lot of the existing models stop working or stop being valid. What about those, right? And so expanding into that territory, it behooves all of us to try to do this right again, to do this right from the very first step, in order to get something meaningful in time. It might take longer if you do it the right way but at least we'll get there with less trouble.

Billy Kozma: Thanks, Reza. And thanks, everyone. Yeah, this has been a good discussion and I think we could probably talk about this and go ideas for another couple of hours really. Because I think we've all seen positives and negatives in the existing process, and we need to learn from that. We need to take away the things that worked and apply them to the bands.

Because as everyone here said, spectrum sharing is not going away. And the more rigid we make both the way the sharing is done and the way the whole process and modeling is done, it just hinders the overall results at the end. And perhaps in some cases, leaves no one satisfied as to where you ended up, with no mechanism to go back and kind of improve that.

So, we'll end on that. I thank you, Reza, Chrys, Andy, Sana, and Tony for being part of this. I appreciate that. And Rebecca, I'll turn it over to you to close it out, or whoever it's going to be.

Reza Arefi: Thank you.

6. Day 4: Thursday, June 16, 2022

6.1 Opening Remarks

John Chapin, Special Advisor for Spectrum, National Science Foundation and ISART Technical Committee member

John Chapin: Good morning, everyone. Welcome to the last day of ISART 2022. I am John Chapin of the National Science Foundation, a member of the ISART technical program committee, and your host for today's show.

First a couple of announcements:

- If you missed any sessions, you can see the video on the platform. Go to the schedule and you'll see a button "view recording" next to the completed sessions.
- The videos will stay available for 3 weeks on this platform and will be available long-term on the ISART website once they have been closed captioned.
- There will also be a written report after a few months.

Today's agenda starts with a talk on Fast Interference Management. Then we have a panel on technical enablers for continuous regulatory improvement. That is followed by a panel where moderators of each of the panels you've heard this week come together, share their key takeaways, and pull together the key themes of ISART. Eric Nelson, acting director of ITS, will provide final remarks to close the symposium.

For our first agenda item, the talk on Fast Interference Management, I'm in the awkward position of introducing myself. The ISART chairs asked me many months ago to give this talk, then the way things worked out, it happens to be on the day that I am the host. So I will let you read my biographical information on the symposium website, and I will jump straight into the talk.

6.2 Technical Presentation: Fast Interference Management

John Chapin: Great. So this is the talk on Fast Interference Management, and it is my personal opinion.

Next slide, please.

So bottom line up front, I'm going to talk today about the concept of interference management speed. And this is a useful perspective to help think about some aspects of the future growth directions of spectrum management.

Now, I'm drawing on an underlying definition of interference management, which comes from the Defense Spectrum Organization (DSO): "the activities and processes executed to enhance electromagnetic compatibility and prevent, prepare for, respond to and recover from electromagnetic interference." That is a beautiful, clear, and comprehensive definition. It's much better than anything I could find on the International Telecommunication Union (ITU) website for what we're talking about here. So thank you to the DSO for that.

So why is it important to focus on the speed of these interference management activities? Why is that fundamental?

Let's go to the next slide, please.

This whole investigation grows out of a thought experiment I did about a year ago. I was looking at some recent shared bands preceding since about 2000, which we as a community sort of have an intuitive feel somehow form a set there. They have commonality with each other, but they're somehow different from everything that came before. So I asked myself, How could we most crisply identify the fundamental common characteristic of these rulings that differentiates them from previous regulations?

Next slide, please.

What I ended up with is the statement that in these rulings, the rights granted to new entrants depend on time-varying external information. "External" in this context means information that comes from outside the device or system that the rights apply to. So, for example, in TV White Space, if you're a new entrant and you want to transmit, your transmission rights depend on the operational status of wireless microphones nearby. That's time-varying information. It is not available to you in the ruling itself. You have to collect it and process it to determine what your rights are.

Similarly, in the context of Citizens Broadband Radio Service (CBRS), your transmission rights depend on the location of Navy ships with their active radars. So when we look at this hopefully crisp and useful description of this class of spectrum sharing, we notice this word time-varying here.

That's really fundamental. And when we're thinking about time, we have to ask ourselves, How fast does that external information change? That turns out to be a really useful categorization of different bands and different spectrum sharing mechanisms.

So let's go to the next slide, please.

So that's where we define the speed of interference prevention. We're going to define classes of interference prevention speed based on the rate of change of the external information that determines the rights of the new entrants.

What I'm calling Class 1 is more legacy traditional spectrum management approaches. That's where the information that determines your rights is stable over long enough time, like, say, years, that decisions about what your rights are can be made entirely by the regulators in the rulings. In some cases, it might only be stable for weeks or months, but in that case, the regulators can't act on it. But it's still possible for human beings to manually collect the information, analyze it, and determine the rights. So the regulators might delegate those decisions to user organizations.

So when you look at these rulings, you'll see things like exclusion zones for fixed incumbents that don't move over the course of years, or statistical models for propagation and deployment. Now, these recent bands that are of high interest to us, the spectrum sharing bands, this is cases where the rights for the new entrants depend on information that's only stable for minutes or days. That's what I'm calling Class 2. So this would be, for example, the location and radar activity of ships. We see pretty substantial enhancements in spectrum access efficiency that we gain by going from Class 1 to Class 2, as witness that famous change in the exclusion chart in CBRS where all of the coasts were excluded at first, and then they managed to shrink that quite substantially by building rules that depended on Class 2 information.

We can see that efficiency growth continuing in the future as we start moving from Class 2 to what I call Class 3, drawing on information that is stable only for milliseconds or maybe a few seconds. In this case, it becomes pretty hard to use a centralized system like a Spectrum Access System (SAS), and we have to delegate the decision all the way down to the edge device. We can already see some emerging bands that require Class 3 for efficiency.

Just look at the experiments going on in the 3.1 GHz band out at Hill Air Force Base. You're trying to share spectrum between a radar on a fast moving jet and a terrestrial cellular system. And, you know, if you try to make those decisions in a centralized nationwide SAS, you'd have to exclude a couple of states' worth of cellular activity on the ground because that plane moves so fast and the radar behavior changes.

But if we delegate the decision to the edge devices and we can respond in milliseconds to seconds, we can open up a lot of new spectrum access. I anticipate that we're going to see Class 3 in other bands in the future as well. So this is a useful perspective. When we're looking at a band, we're looking at a spectrum sharing case. Let's ask what class the information stability time is in, and that gives us a lot of guidance for what we might be able to do in that band. But we can also look more broadly at what happens ex-post.

Next slide, please.

So this is the speed of interference response. Now, in this context, it doesn't make sense to define this based on a time constant like seconds or milliseconds or minutes or days. We'll get there eventually. But the real fundamental thing that determines the different classes of interference response is the desired outcome for the potential victim of that interference. So this chart should be read from the bottom up. Start on the row that's labeled Class 6. That's where we are today. That's where the time expected to respond to an interference event once it begins is so long that you really do expect the victim's mission to be significantly impacted. So if you have spectrum sharing, say, between a cellular system and a non-cellular actor, generally, if you get interference that's reducing data rates in one of the sectors, it can take days to weeks at minimum today to get that identified and mitigated. And that's a very significant concern for the mission of the cellular operators.

Going forward, what we're really looking at doing is trying to move out of Class 6 and accelerate into Class 5. That would be a spectrum sharing system that's capable of responding to interference fast enough that it actually protects the success of the victim system's mission. An example for that would be a radio telescope. You know, if you have an observation that you're going to try to do and there's an interference at that frequency, the radio telescope could switch to a different observation that's in its queue. And when it comes back half an hour or an hour later, if there's a high probability that that interference has been mitigated and gotten out of the band, well, then the radio telescope can still accomplish all of the observations it was planning to do that day. And we're now in Class 5 where the victim's mission success is being protected.

That difference from Class 6 to Class 5 is significant because it dramatically enhances the willingness of incumbent spectrum users to share spectrum. And that directly translates into accelerated proceedings and faster growth of spectrum sharing, faster growth of overall efficiency. So that's really important. I would note, though, that there's been little attention in recent regulations on using the spectrum sharing mechanisms to accelerate that enforcement. That's sort of an after-the-fact consideration.

But as Mark Gibson told us on Monday [Day 1, June 13 - Panel: Industry Lessons Learned from Spectrum Sharing], there's currently a bit of an impasse in the 6 GHz multi-stakeholder group about how those mechanisms should be used to accelerate enforcement. And, you know, an acceleration, you know, from, say, two weeks to one week probably won't make much difference. But if we can accelerate from Class 6 to Class 5 where we're really protecting the victim's mission success, that's when we get a qualitative rated jump in the success of spectrum sharing.

Looking forward a bit, it's a bit of science fiction, but the acceleration from Class 5 to Class 4 is where we go from an interference event that impacts the victim's mission, but we can still get to mission success. In Class 4, the spectrum sharing system reacts quickly enough that you protect the victim's current activity. So an example of that, where you have a victim that is, say, a communication system, can we mitigate interference before the accused overflow?

Next slide, please.

So that brings us to this overview icon, the six classes of interference management speed. This puts together all of the information I've talked about, the three classes of interference prevention and the three of interference response. And it shows the pairing of these into the three different time scales, one and six, or the manual time scale, that's traditional spectrum management. And where we're really trying to get to is to the mission time-scale and eventually to machine speed.

Next slide, please.

So this is what we call Fast Interference Management. And that's really the goal of recent, and we hope, future spectrum sharing procedures.

Next slide, please.

This view, I said was useful for thinking about where we're going in spectrum management. So let me just point out some of the recommendations that come out of looking at things through this lens.

First one here is that we shouldn't just focus on interference prevention speed; we should also consider interference response speed when specifying the requirements on sharing mechanisms. I will point out that if we're going to get into Class 5 or Class 4, we need automatic mechanisms. And those automatic mechanisms then are going to depend on setting quantitative protection thresholds they can take action against. And that's been an ongoing debate. But I think we really are going to have to go in that direction.

Second, if we're looking at continuous regulatory improvement, the theme of ISART, we shouldn't just look at, you know, potentially changing the propagation model over time or improving a power threshold. We should consider specifying that we may potentially accelerate interference management in a band through continuous improvement processes and try to incrementally get those efficiency gains that come from faster speeds.

Finally, I don't have really the time to fully explain the argument for this. The regulations in a band end up specifying the speed of interference prevention and the speed of interference response in that band. And once that's been specified and you develop those systems, it gets really, really hard to change that speed. But that speed ends up determining what missions can use the band and what types of systems you have to build to operate there. So, given that we want to support a range of different missions in a range of different systems, we really should aim for a portfolio of bands which in regulation are specified to have different interference management speed.

Next slide, please.

This viewpoint of speed is not just about interference management. It actually turns out to be quite relevant when you look at the future of rights assignment, rights definition, rights trading, and so on. Again, not really the time to get into detail of this, but what I found in my analysis is that if we're going to get to interference control down there at mission speed or machine speed, then as we start doing things like trading interference rights—you know, one of those things that [Day 2, June 14, Economics of Spectrum Sharing panel participant] Martin Weiss did some really wonderful work on a decade ago, we need to think about doing rights, trading at machine speed and mission speed as well, to have, really, a balanced system.

That's going to be somewhat in the future. But as we are defining the rules and the mechanisms for upcoming bands, we really should be looking at accelerating the rights trading into these speed classes, not just, um, the interference management.

Next slide, please.

So, bottom line, I've tried to bring forward this concept that Interference Management Speed is a fundamental attribute of spectrum sharing. And that makes it a useful perspective for thinking about our future directions in spectrum management.

Next slide, please.

So with my last minute or two, I'm going to talk here about something completely different. I'm going to really use the time to make a shameless plug to the ISART community.

The program at Nation Science Foundation (NSF) that I am the champion of, National Radio Dynamic Zones, or NRDZ, we are anticipating soliciting proposals in 2023 for research that many of you—the types of areas that you have expertise in—research on the adoption of dynamic spectrum sharing from perspectives like social, behavioral, and economic research; how that interacts with technical regulatory changes; how spectrum user business models might need to change; how these new forms of spectrum sharing impact auctions and [in?] federal agency incentives.

So I really want to solicit your attention to and potential proposals to this opportunity. We are anticipating these to be solicited as supplemental proposals to the study awards that we're issuing this fiscal year. So if you're interested in this, I encourage you, sometime this summer perhaps, to take a look at the slides in the video that are on the website [https://nsf.gov/mps/spectrum_innovation_initiative.jsp] after the awards this year are announced. After the awards this year are announced, please take a look at the award search to identify and contact potential teammates. Participate in the first community open meeting; it'll be a virtual online meeting this December. And email us with any questions. We'd love to engage with you on questions, whether that's faster interference management or anything else that's related to the adoption of dynamic spectrum sharing. And with that, I will finish.

Next slide, please.

I do think we have a couple of minutes here for any questions. And I see one question. Whoops, it was there. Yes. "How would you recommend handling interference response activities to cause an unnecessary disruption to the suspected source of interference when the actual cause of Electromagnetic interference (EMI) is something else? In other words, what is the recourse for a shared user being disrupted or degraded because the incumbent user incorrectly attributes fault to the shared user when it was actually caused by something else?"

I mean, this is a super interesting question, one that I think is well deserving of research about how you set up the incentives and the mechanisms to deal with that. I would point out that this kind of an issue occurs any time you have a shared resource, and it's difficult to identify who's consuming the resource in different ways. And we still have a lot of past history in other resource management activities that might be relevant to addressing that

6.3 Panel: Technical Enablers for Evolving Regulatory Processes

Evolving regulatory processes result in changing the regulatory requirements in a band after equipment has been deployed. Post-deployment regulatory changes have traditionally been constrained by the high cost of doing new compatibility studies, agreeing on the costs and benefits of the new rules, implementing and deploying new equipment, and designing new sharing or spectrum access mechanisms, as well as the associated high risk to existing revenue streams or mission capabilities. What technical solutions, components, designs, and approaches are being developed that will reduce these costs and mitigate these risks? How can translation of spectrum science R&D results to practice be improved to accelerate use of these new approaches?

Moderator: Douglas Sicker, Senior Associate Dean for Computing and Professor of Computer Science, University of Colorado-Denver

Charles Baylis, Professor of Electrical and Computer Engineering, Baylor University

Shannon Blunt, Roy A. Roberts Distinguished Professor of Electrical Engineering and Computer Science, University of Kansas

David R. Jackson, Professor, Director of Graduate Studies, Department of Electrical and Computer Engineering, University of Houston

John Kuzin, Vice-president of Spectrum Policy and Regulatory Counsel, Qualcomm Inc.

Tommaso Melodia, William Lincoln Smith Chair Professor, Department of Electrical and Computer Engineering, Northeastern University

Douglas Sicker: Thank you, John [John Chapin, Day 4, June 16 - Technical Presentation: Fast Interference Management]. That was a really fascinating presentation. And the whole framework that you laid out just speaks to all of the technology innovations as a number of the dimensions that we are looking at. So I think it's a really useful framing, and I hope that maybe we can touch on it later in the closing comments.

So I have the unique pleasure of being the last main panel and dealing with things that I think are kind of seminal to this whole discussion of how do we make regulation more dynamic and more iterative, which is, What's the underlying technology?

With that said, we cannot in this in this panel or even in a workshop, articulate all of the different technology opportunities that one might have. Whether it's at the device level or at the service level, at the data level, or what it might be that could be a part of a faster, more iterative regulatory spectrum management framework.

But what we did do is we asked the five panelists who are experts in different domains that are very relevant to this space. And that's going to be today's discussion. We're going to start with our five guests going through some of the thoughts that they have in terms of what's the emerging technology that could have some of the biggest bang for the buck, kind of an iterative spectrum management process. And then we're going to have a set of questions as well as questions from the audience. So I'm really excited. I want to go through quickly who's going to speak in what order. And then I'm going to turn it over.

So we have Charlie Baylis, who is a Professor of Electrical Engineering at Baylor. We then have Shannon Blunt, who is a Professor of Electrical Engineering at the University of Kansas. David Jackson, who is a Professor of Electrical Engineering at University of Houston. John Kuzin... Well, actually the order is Tommaso Melodia who is a Professor of Electrical Engineering at Northeastern. And then wrapping it up is John Kuzin, who's the vice-president of Spectrum Policy at Qualcomm.

And I did that very purposely because I think as we talk about all these different technologies, John can end with some of the things that are happening in industry and some of the things that are being thought of at that level. So I think it's going to be a very interesting set of discussions. And I look forward to hearing questions from the audience.

So with that, I'm going to turn it over. Charlie, you've got the stage.

Charles Baylis: Thank you, Doug, for this good opportunity to serve as part this panel. I'm Charlie Baylis. As Doug mentioned I am at Baylor University as a faculty member there. The technology enabler, as John Chapin was speaking about a moment ago, he was talking about iterative policy and being able to write policy more quickly. And one of the things that is going to enable iterative policy is reconfigurable circuitry—being able to, at the bottom level, have the capability of making an edge device adapt its actual physical performance in real time to enable flexible use of spectrum and spatial parameters to share.

If we could go to the next slide, please.

So I just want to acknowledge that the funding for the brief comments I am about to make. Some of the research has been funded by the Army Research Laboratory (ARL), the Office of Naval Research (ONR), and also the National Science Foundation (NSF).

We could go to the next slide.

So enabling iterative spectrum policy to reconfigure circuits: How do we want to do that? Well, rigid circuitry could limit iterative spectrum policy, moving from rigid to real-time adaptive. The problem is that a lot of the legacy systems out there right now have either rigid, inflexible front ends for their transmitters and receivers, or perhaps even broadband front ends, which … that's an improvement sometimes, but it can also be a degradation of what could be if we could reconfigure.

Here's a couple examples due to the lack of circuit reconfigurability where systems could be limited in being able to shift frequency-use in real time. In the S-band military radar loses range when changing in frequency to avoid wireless communication. This is a pertinent topic with the sharing of the 3.45- to 3.7 GHz band. And soon to be the 3.1- to 3.45 GHz band.

A radar system frequency needs to be able to optimize its range and still be able to transmit and detect at the same range, however, it's well-known fact in microwave circuitry that the impedance termination of a power amplifier that is optimal for output power is actually frequency dependent. So if I'm operating at 3.3 GHz and I move to 3.1 GHz, I'm no longer going to be getting maximum range if I'm terminated in the 3.1 GHz optimal impedance. I would like to be able to reconfigure and re-optimize my range. Another example that we're dealing with right now in our NSF-funded work is a 24 GHz 5G network right now must turn off to avoid passive sensors during operation. If there's, for example, a weather radiometer, which needs to detect water at 23.6 GHz, the only thing we can do is turn off the 5G network. Could we do some things to perhaps re-orient the 5G network and make it reconfigurable to the circuit-level in real-time to avoid the passive sensors so it can continue to operate? That's a question we're asking. So the potential impact, obviously, is if we can reconfigure in S-band now, we can maintain the detection range.

Now we need to be able to reconfigure probably within a millisecond if we're operating a radar in concert with its pulse repetition rate and also its pulse length. And then also, can we spatially distribute a 24 GHz 5G network? And briefly, I just want to run through a couple of examples.

If you go to the next slide.

So let's zoom in on these examples just a little bit.

There's a video on the top, right. That picture on the top is actually a video. If you would click on that, you'll be able to see it playing. If not, that's okay. We'll do without, but I think that video at the top right should play, actually. So anyway, what you will see is that video is able to play is there is a spectrum plot on the top left.

We have a reconfigurable impedance that we've developed in collaboration with Purdue University. They develop this tuner and we put it in. And we've demonstrated the change in calculated radar range that's available as the frequency shifts, if we reconfigure this impedance tuner to rematch our power amplifier. And the goal that we're really meeting is shown in the bottom left of the slide where we can increase our detection range by putting this tunable matching network in between the power amplifier and the antenna.

Now through the Navy funding, we've actually been able to do this down to the level of 600 microseconds reconfigurability using a tuner that's based on plasma switches. And because the tuner is electrically actuated, we can actually now reconfigure on a pulse-to-pulse basis with the radar. We're going to be presenting that next week at the International Microwave Symposium (IMS) in Denver, actually.

Next slide, if you would.

So this is the second example. I mentioned the 24 GHz system where we're operating 5G at 24 GHz, but at 23.6 GHz, we need to be able to maintain the ability to detect water vapor in the atmosphere. We don't want to interfere. So what we can do is put impedance tuners between the amplifiers and the antennas in each element of the phased array.

And we can do directional transmission where we can transmit in multiple directions at the same time under the same aperture. Now, one of the problems with this is you can actually have nonlinearities in your power amplifier that cause unwanted transmission beams if you don't tune as we've shown in some of our work that you can see on the left and the bottom. But we can actually do impedance tuning to linearize our transmissions to avoid these unwanted beams and make sure that our interference is kept out of the non-intended directions.

Next slide, if you would.

Finally, I'd like to go to the third example, which is a spatial spectral broker. This has the ability to do iterative spectrum management and be a middleman between the system and the circuit level. And this is something we're working on for funding from the NSF Communication and Information Foundations (CIF) program. You see on the left, we're working with a bunch of radiometers, and we have this broker that takes in manifold requests, which you can see on the top right. A manifold request is essentially what resources are needed by each spectrum user. And then a broker compares the request between different systems and decides which system can use what resources. And we actually output out of this broker a spectral spatial mask that allows us to limit the spectral spatial transmissions.

If you go to the last slide.

So in conclusion, iterative spectrum usage must progress from completely rigid spectrum to as close to real-time assignment as possible and this is governed by the scenario. But circuits right now are limiting the ability to do that. So we need to be able to develop circuit reconfiguration both at the circuit-level and the array-level. And this is something we're working on to enable this iterative spectrum management.

Thank you. Appreciate it.

Douglas Sicker: Thank you, Charlie. Very interesting set of research topics. And we'll come back to a couple of the topics that you covered as we speak with the others. I'd like to ask Shannon out to go.

Shannon Blunt: All right. Thank you, Doug. Thank you for letting me be here and have the chance to wax philosophical, which, as Doug knows, I like to do a lot. So I'm very much a radar guy. So I'm going to talk about some things really from a radar-centric perspective as it relates to spectrum sharing.

Next slide, please.

So, radar is generally viewed somewhat as old technology. It's been around for a bit. It had a big impact on World War II. Obviously, we all know of it from air traffic control and weather tracking. But nowadays, we're actually seeing an explosion in the number of applications for radar. Automotive is a big one. Hand-gesture recognition, tracking of space debris, and there are a lot of others.

And on top of that, one of the things that is occurring in the radar space, really dovetails with what has occurred in the last few decades. You know, for the reason why we all have these wonders of technology [shows his cell phone] in our pockets that are basically pocket supercomputers. Is that digital revolution? Well, it's likewise having an impact in the radar space.

So this notion of a radar as some static entity that we can look at as it's going to behave a certain way, we're going to see that change, too, over time because you're seeing things like large-scaled active electronically scanned arrays (AESAs), agile waveforms, radar is becoming itself more dynamic, driven by a cognitive paradigm. More sophisticated interference cancellation, which is really good for everybody, as well as a multistatic/MIMO (multiple input, multiple output) operation.

All of these are contributing in various ways to enable new types of radar modes. And so really where I'm going with that is we do need to be careful not to necessarily just paint radar in a box of, okay, it's going to be there doing its thing because we're going to see that change over time.

Next slide, please.

So putting this now in a spectrum context. So, I mentioned the cognitive aspect. A significant driver of what we're going to see in terms of emerging radar technology is the same thing we're seeing for a lot of these other technologies that use spectrum. And that is a software-driven platform or software-driven capabilities, which really allows now sensing to occur, or the dynamic operation of sensing to occur, at machine speeds.

Now, that obviously creates other difficulties, which I'm going to touch on in a second. But, you know, just bear in mind that what this means is, again, we're not going to be talking about some static system anymore. It's likewise going to be trying to dynamically operate. Now, one of the radars [unintelligible], and I should say radars have been dynamic for a long time. They've just been dynamic at lower speeds of given operating environments, [unintelligible]. One of the limits for them is not really a technical limit. It's more to do with the research community, [unintelligible] and I'll touch on this later [unintelligible] based on [unintelligible] but one of the limiting factors that has to do with the research community, [unintelligible], is that we do not really fully appreciate [unintelligible] the intricacies of the problem. So, really it has to do with this notion of over-abstraction.

So consider a few aspects of radar. Radar requires high-dynamic range—several 10s of dB. [unintelligible] Radar needs high fidelity and coherency for any kind of interference cancellation. [unintelligible] and then, related to that, radar needs high dimensionality for coherent integration gain. And yet we have to deal with inherent distortion due to the radar itself, both from clutter scattering from the environment as well as just the fidelity, a limiting aspect of the transmitter distortion

If you're trying to transmit at high power, which is obviously one of the reasons we're here talking about this, is the growing of ubiquitous interference as well as a dynamic interference aspect. And then, of course, flipping that around, there is a push within the radar community to essentially become a better spectral neighbor. How do we from a radar standpoint, try to mitigate interference to other users that are sharing the band, as opposed to just saying, "Hey, leave us alone"?

Okay, next slide, please.

So to kind of tie some of those things together, I've highlighted three—and one of them is probably a bit controversial, at least to radar folks, kind of hurdles-slash-opportunities. One I've touched on, the one at the top, already. And that's this notion that as radar systems themselves become more dynamic, really this notion of cognitive radar, then you end up with this sort of cognitive versus cognitive paradigm, which in a sense is not really a new thing. We've all known as things become more dynamic, this is going to start to occur.

But consider it from a radar-centric perspective. So radars, as I mentioned a minute ago, require coherency, require fidelity. Well, what this is going to do is introduce more non-stationarity, which is actually going to impact one of these facets that radar really needs. And this is both from the standpoint of dynamic interference, as well as a radar tries to itself become dynamic to reduce the mutual interference. It's kind of interesting that as it tries to solve that problem, it actually introduces more problems upon itself through this non-stationarity.

There's also a trend toward, and this is part of the 6G paradigm in particular, more airborne- and space-based communication nodes. Well, a lot of the work that is looked at from the standpoint of interference, from a radar perspective, is sort of under the assumption that a lot of the commercial communication is going to be terrestrial based. Well, now, adding this elevation dimension really complicates that problem. A way, sort of, a way forward, I won't say it's a solution, but is really the consideration of more sophisticated interference cancellation. For any of you who might be familiar with the notion of STAP, it's Space-Time Adaptive Processing, used in airborne- and space-based radar. What they do is they couple the domains of really Doppler and spatial angle. And that coupling introduces a multiplicative increase in degrees of freedom. Well, that's great, because more degrees of freedom mean more ability to suppress interference. Assuming your front end is not saturated. But that also comes with the curse of dimensionality that you now have to process at a much higher level. Now I mention that because philosophically you can now start thinking about coupling other different dimensions as a way to get to higher dimensionality to then combat increasing amounts of interference.

And then finally, and this is the one that's probably more controversial, particularly to the radar, folks: So, the other day, John Chapin asked me this question about, well, what's the impact of solid state power amplifiers—which means we can now have longer pulses or essentially higher duty cycle radar operation—what's that going to do? I will tell you that there's an interesting report that the National Telecommunications and Information Administration (NTIA) put out a few years ago that really assessed the trade space of duty cycle. Well, now consider going to higher and higher duty cycles potentially— here's the controversial part—potentially even pushing to 100 percent. So, now, all of a sudden, we have a radar that's operating essentially in a Carrier Wave, or Continuous Wave (CW) mode. Now, there are radars that do that now, but they tend to be low power, short range, partly because they have repeating structure. If you introduce a non-repeating structure in that, you now have, potentially, the ability to start trading off what a pulse rate could do possibly in a CW mode. And it introduces an interesting trade space because you can reduce peak power, but—and I will say, from the radar standpoint, there some potentially very interesting prospects there, from the standpoint of a coherent integration benefits—but now, too, from the standpoint of the interference to other users, well, a lot of communication systems think of pulsed radars acting like shot noise, but it's not shot noise anymore. So it puts it into a different part of that interference trade space.

So with that, I'll leave some more for discussion for later. Thank you, Doug.

Douglas Sicker: Thanks, Shannon. Very interesting talk. And again, we're seeing both Charlie and Shannon's discussions sort of taking the system-of-devices perspective and thinking about the services and pointing out some of the challenges that we're going to have as we go into this more dynamic use, whether it be the issues of stationarity or other such things. But I also think it's interesting to know that, you know, some of our assumptions about what the service was and how it operated and how it should operate could very much change. And I think that's going to be a really interesting dynamic and maybe a part of John's past interference litigation structures as he goes forward.

So without further ado, let me ask Professor Jackson to go.

David R. Jackson: Okay. Hello. Say, am I able to share my screen? Can I do that?

Douglas Sicker: We have your slides on our end, David.

David R. Jackson: Yeah. If I share it, it'd be nicer, 'cause I could then use my pointer a little bit.

Douglas Sicker: Okay. There you go.

David R. Jackson: Can everybody see that? Is that okay?

Douglas Sicker: Can you make it bigger?

David R. Jackson: Let's say it's as big as I can make it on my end.

Douglas Sicker: I can read it.

David R. Jackson: Okay. All right. So welcome, everybody. So my brief presentation here is going to be active electromagnetic interference, or EMI cancellation approach. I'd like to recognize my coauthors involved in the research as well.

So what is active EMI or electromagnetic interference cancellation? I'll talk a little about that. And Can it really work? That's the fundamental question I want to pose here. I want to give some preliminary results in two categories. One would be reducing the scattered fields from an object because scattered fields can cause electromagnetic interference. And I also want to give an example where we might be able to reduce what I might call a quiet, protected region or zone—in other words, an electromagnetically quiet region where there may be some sensitive installation like a radio telescope or something that you want to really protect and not have any interference in that region. We have very preliminary results here in this paper from a couple of years ago, but this is really just a project that we're getting started on.

[Slide]

Okay, what is active cancellation? Now, I think we all know about noise canceling headphones. So that's kind of a very simple example of active cancellation. You might have an interfering signal coming in from outside and the electronics in the headphones generate its own countering signal to cancel that interference so that the user hears only the music that they want to hear or whatever, and not this interference coming from outside. It is almost a perfect cancellation. So that works good with audio frequencies, like headphones. But here's the fundamental question: Can the same kind of principle work for radio frequency signals, electromagnetic signals, like, for example, microwave bands? Can we actually reduce electromagnetic interference at those kinds of bands?

[Slide]

Now, here's a simple experiment that we did to investigate the feasibility of this, where I'm going to try to reduce the electromagnetic scattering from an object. Now, in this simple demonstration, the object is a very simple metal plate, roughly about one-foot-by-one-foot. But visualize, if you would, that the metal plate is just a simple model for something more elaborate, which could be a building or a tower, something that's scattering the signal, and that signal is causing interference. So we have an incident wave coming from a distant transmitter hitting the metal plate of the object that is producing a scattered signal, which is going off and causing interference in some direction. And we want to see if we can reduce that scattered signal that's going off in a direction maybe toward a sensitive installation.

Now we put our own radiating antenna on the substrate here with a sensor and an electronic system. The electronic system takes the signal picked up by the sensor, and it amplifies it and phase shifts it and feeds it back into the antenna. And that antenna then radiates a countering signal that tries to eliminate the scatter signal that's going off in this direction toward the sensitive location. And the idea is that if we calibrate electronic system properly by changing the phase shift and the amplification, we can greatly eliminate the scatter signal at least at one frequency, the center frequency, of the signal.

Now, here's a simple numerical illustration. Here is the incident wave coming in. It just looks like a blob because it's a microwave signal and it's oscillating so fast and that you can't see anything. But notice that in this normalized scale, the level is 1. Now, here's the scattered signal from this metal plate. The red dashed line indicates a level that would be present if the system is not activated, but with this electronic system activated this shows the scattered signal. You can see the level is greatly reduced from what it would have been without the electronic system.

Now you see sharp spikes at the leading and trailing edges of the pulse. That's because it takes some time for the information being processed by the system to go from the sensor through the electronics and re-radiate from the patch. During that time the system cannot radiate an effective countering signal. In other words, we're processing with electronics at the speed of light, so that's the best we can do, and the signal's coming in at the speed of light. So it's always going to be from causality those spikes at the trailing and leading edges. But the good news is that overall energy has been greatly reduced compared to what you would have without the system.

[Slide]

Here's a second application where I'm using just one frequency now, not a time- [unintelligible] signal, to keep it simple. And I have an incident plane wave coming in here along the ground and it's going to cause interference in this region here. I want to protect this region, a rectangular region of interest. We put our own phased array there, in this case, a phased array of 201 elements, and it's going to radiate its own pseudo–plane wave propagating in this direction to cancel the incident plane wave coming in. So, again, we get an interference effect to create a null or a greatly reduced overall signal in this quiet protected region. We're doing it at 3 GHz and the width of the phased array is 60 feet.

[Slide]

Now for numerical simulations, here's what we get. So you can see from the color map here that we have greatly reduced the overall field level in this quiet region. Here's the width of the phased array. And in that region, that's roughly the width of the phased array, we get a fairly quiet protected zone. If you take a slice, horizontal slice through this rectangular region—you can see the plot here—we've got a nice, protected region, but outside the boundaries of the phased array the field increases very, very rapidly. So it's not successful at reducing everywhere, but a certain protected region can be created, which is roughly the width of the phased array.

[Slide]

So my conclusions are: Active cancellation *may* possibly be a tool that we can use to augment existing strategies, for EMI reduction in the future. There's different ways we can use this. We can do scattering from an object if that's causing interference, or we can actually try and directly cancel incoming waves creating some kind of a quiet zone.

Now, the method is not perfect, especially for time varying signals because we're canceling the signal using electronics, which processes at the speed of light and the signal's coming in at the speed of light. But still, the preliminary results seem to indicate it's a promising technique and we can greatly reduce the overall energy that is scattered or that's available to cause interference in this quiet zone.

All right. Thank you very much.

Douglas Sicker: Thank you, David. And as you can see, I very purposely had David come after Charlie and Shannon because I wanted to get down into kind of like the active methods for cancellation. And you can see also that what David's described, you know, really fits in again, with, John Chapin's kind of fast interference mitigation kind of concepts. This gets down into the quick-response opportunities. And while not perfect, it is, kind of, the bleeding edge research.

And of course, as I said at the beginning, this is just one of many, many, many, many areas that we could talk about in terms of dynamic spectrum management. There are at least five other areas of cancellation that I've been following in the space that take very different approaches from what David's doing. So I think, again, what's neat here is that we're moving from this very fixed mentality of how we use the spectrum, from decades ago, to a whole different way of thinking about it. And what that means in terms of how we build the devices and how the service operates, and as Shannon said, even what the service does, how we conceive it. It really gets to be very interesting.

Up next is Professor Melodia. And Tommaso is going to tell us how he's going to conquer spectrum, which I love that term. So with that, I want to turn it over. Tommaso.

Tommaso Melodia: Thanks, Doug. So I come from the world of wireless networks, wireless systems, and obviously spectrum for 6G is part of ongoing discussions. And 6G will require new spectrum bands and it will also operate concurrently with 5G bands to support transition between 5G and 6G. Spectrum will simply be heterogeneous. It will include licensed, unlicensed, and shared spectrum bands in the low bands, in the mid-bands, upper mid-bands, in addition to millimeter wave, and possibly some THz bands.

So next slide please.

We need to develop the intellectual foundations, practical technologies, and policy recommendations, as well, I think, as an agile spectrum–educated workforce to enable a more flexible, full spectrum future. What does a more flexible spectrum future look like? We certainly want more spectrum for all, what we call conquering the spectrum. Unveiling untapped spectrum in the upper frontier [?] in the sub THz band, and also in the upper mid-bands.

We need dynamic and predictable use of spectrum—what we like to call programing the spectrum through virtualization, softwarization and algorithmic innovation in this space.

We want security and protection for spectrum use, what we refer to as protecting the spectrum.

And I think we need to develop really new clean-slate approaches to leverage these new spectrum bands that are not available today, including the millimeter wave and sub THz spectrum bands and new Artificial Intelligence (AI) methods to softwarize spectrum access and to learn to share portions of the spectrum among different systems and applications.

There are certainly core differences between the mid-bands and the high-frequency bands with different challenges and different technologies. In the mid-bands, especially in several bands, the spectrum is crowded, and the main challenge is to deal with incumbents, co-channel interference, out-of-band interference and in a sense it's an old problem. But I think we have new tools today to deal with it.

On the hardware side, new frequency-agile front ends that will enable spatial diversity to [unintelligible] the need of the hour and also understanding from a systems level of how to leverage these capabilities to create more diversity. And at the same time, I think that the key enablers for spectrum sharing. I also believe that softwarization, virtualization and artificial intelligence will play a key role here.

Next, please.

When we talk, for example, about the work that has been done by the Open Radio Access Network (RAN) or O-RAN Alliance, there is a lot of work focusing on interoperability and availability of open interfaces and the effects that that can have on markets. But, besides this disaggregation, I think the real disruptive innovation with the Open RAN architecture lies in exposing network control knobs and spectrum control knobs, if you will, and analytics for a centralized programing platform that is referred to as the O-RAN intelligent controller.

Now this enables access to sophisticated spectrum sensing information that was completely unavailable in the past, which can be processed and combined with database-driven approaches to obtain a fine-grained control of the network and functionalities and of the physical resources at all layers of the protocol stack to guarantee sharing and coexistence between, you know, for example, Wi-Fi and cellular in unlicensed bands, but also sharing between commercial systems and government-focused systems, like radar or others, and sharing between different commercial systems in the same channels. And, you know, the latter can also happen through other techniques, etc.

And next, please.

At Northeastern we are investigating a number of these techniques. This is an example of recent work that we presented at InfoComm 2022, which were in an open RAN context that we really investigated the nexus between softwarization, spectrum sharing, and algorithmic innovation based on AI.

We developed a framework based on Open RAN for spectrum sensing and channel selection to leverage this information and control knobs exposed through O-RAN interfaces. An agent running in the near real-time running touch-and-control can collect information to train deep reinforcement learning agents that can control the radio units to reactively switch cell frequencies, as well as various other parameters of the communication process in real-time to avoid Wi-Fi activity.

Right? The decision-making happens through these deep neural networks that run on the near-real-time RAN Intelligent Controller (RIC) and it's being tested at scale in the consumer wireless network emulator to collect specific large-scale, well-formed datasets that we use to train the neural networks. It's a first step. I think the results are encouraging. With a pool of shared-frequency channels, Wi-Fi and cellular can coexist seamlessly through Open RAN control. So there's no reason to believe we couldn't do the same, for example, in the upper mid-bands, which are covered with a number of incumbent users.

And that's what I wanted to cover today.

Douglas Sicker: Thank you, Tommaso. And you can see now we've gone up to the kind of the system-of-systems of view of how you can approach this problem. And again, thinking back to John's [Chapin] dimensions, it might also be changing how quickly we can respond. And in consequence, in that interference mitigation. But this now gets to a point where we actually have a means of throwing portals and other capabilities that integrating the solving the problem, which I think is a very interesting and powerful kind of approach to the problem. So, thank you.

And now we're going to turn to John Kuzin, from Qualcomm. And John's really going to kind of take it up another level, which is, really think about how might we apply some of this technology to certain bands and to certain services and what it might look like. So, John, please.

John Kuzin: Thanks a lot, Doug. So first off, I just wanted to thank the organizers for inviting me to participate in the symposium. And I also thought that John Chapin's presentation that set up this panel was particularly helpful regarding interference protection, because it is critically important to look at both the detection and the response feeds with regard to the services that we're looking to share with.

So, Qualcomm has been very actively studying new approaches to spectrum regulation in order to enable more intensive spectrum sharing among diverse and unaffiliated users for a number of years. And you've just heard a lot of great material on the technical side of improving spectrum access. On the regulatory side, there are ways to improve spectrum access and reliability in spectrum that's regulated as unlicensed and or shared using, in our view, very simple technology-neutral rules that enable such tools.

So, we at Qualcomm have encouraged regulators to adopt enabling rules to implement these concepts. But it's taking some time. We're going to keep at it both in standards bodies and with regulatory authorities, because we know it's going to improve spectrum efficiencies and support the growth that we're going to continue to experience and have to enable.

So looking at the Federal Communications Commission (FCC) in particular, and it also applies generally to other regulators, rules governing spectrum access have relied on two regulatory paradigms: licensed access and unlicensed access. And both paradigms generally have the regulator define in-band power levels and out-of-band divisions. Power levels for licensed services are generally higher than the power levels for unlicensed services to enable broad coverage areas, and interference is handled differently, however. So licensed services have legal protection from interference, and the regulator will take action against entities that cause interference to licensed services. And because licensed services permit higher power to basically cover areas that are several miles in radius, in many cases—in the case of mobile services, for example—exclusively-licensed spectrum allows a single entity like a mobile operator to manage spectrum access by multiple users on an interference-free basis. So the tools that a mobile operator uses today include many different techniques, but a lot of them are based on synchronized access, advanced antenna systems, and other tools that work very well when one entity controls access.

So we look at this and we believe that many of these tools can be used to improve spectrum access. The tools that are used to improve spectrum access in licensed bands can actually enable increased utilization in shared and unlicensed bands. And that's one area where we look for inspiration. So as most of you know, unlicensed services have no interference protection, and they're required to accept interference from licensed and other spectrum users. And unlicensed services work well, in general, in smaller areas where the communications range is tens of meters and interference remediation, in general, is under the control of and managed by the end user.

But there are regulatory approaches that can be used even in unlicensed bands that enable much more intensive spectrum use in bands that are unlicensed, that are shared, that actually can enable multiple licensees to operate on the same spectrum at the same time and place. So for more reliable unlicensed communications, it would be possible to implement a rule that requires time synchronization, that would allow these advanced techniques to allow multiple unaffiliated users to use spatial sharing to provide much more predictable access and, therefore, support very low latency, improved throughput, and essentially, much more efficient spectrum access.

So one of the things that Qualcomm proposed several years ago, when the FCC was first implementing the rules in a 6 GHz band, was we offered a rule that set limits on channel occupancy times that actually we showed wouldn't favor asynchronous nodes over synchronous nodes and vice versa but would effectively lead to much more efficient spectrum access by forcing the asynchronous nodes to communicate in a synchronous manner.

This is something that wasn't adopted, but it's definitely something that should be considered. We know that standards bodies are considering a rule such as this. But as we look to open up new bands, implementing a simple technology-neutral rule that would implement this is something that's definitely worth considering in our view.

And then another approach: looking at what has been defined as a license-shared band in July of 2016, when the FCC opened up a bunch of millimeter wave bands, effectively for 5G, there was a piece of spectrum that's referred to as the lower 37 GHz band, which is a 600 MHz wide band that was allocated for shared license use. But it still hasn't been opened. So we have proposed an approach that would allow multiple licensees to operate on the same spectrum at the same time and place without causing harmful interference to one another.

So unlike unlicensed approaches where heavy use can swamp the medium, the licensed-sharing proposal that we've put forth for this band would allow a limited set of operators to share spectrum on an interference-free basis by effectively mandating synchronized listening intervals that would allow licensees to identify potentially vulnerable receivers.

So in our proposal, in this 600 MHz band, there could be six licensees each that had a 100 MHz priority license where each is able to operate across the entire band in the same place in time, so long as they listen before operating on another spectrum on which they have secondary access. And we've done extensive work. We've had demos at Mobile World Congress that essentially show that this approach provides much greater spectral utilization, improved throughput with a quality of service that's akin to what can be provided today in exclusively licensed spectrum.

So these techniques are focused on increasing the likelihood that communications are successfully received when they're transmitted and use the least amount of transmit power to ensure successful transmissions. And this provides obviously, power efficiencies. Green communications is a big focus as we start to ramp up connecting the Internet of Things (IoT). It is critically important that these devices operate with the least amount of power.

So this has been a focus of the FCC, in particular, Commissioner Geoffrey Starks. And, you know, energy efficient communications were a key part of 5G and green communications are only going to grow in importance as we move to 6G and beyond. So thanks for the time today and I look forward to the questions from you, Doug, the audience, as well as the remarks from the other panelists.

Douglas Sicker: Thank you, John. And I think I really liked having John wrap it up at the end, because what you can see here is there's technologies that are being implemented and it's like smarter versions of listen before talk. We all know the approach; we know the goodness of it. We know what you can do but applied in new ways it just shows the low hanging fruit and the opportunities that we can do to be more efficient. And, you know, as we start opening up that aperture and start adding more and more technology solutions to this problem of rapid, dynamic, and iterative spectrum management, I think it's going to be an endless amount of opportunity for research.

I did want to ask one question to the group and then we'll then we'll start jumping in into the questions from the from the audience. Let me ask you this. And I don't know. You can just answer. Anyone who has an idea, just throw it out.

What should we not be doing? What technical approach should we avoid at this point? What's too expensive, too hard, too inefficient? Whatever dimension of the well, probably not that way.

And I know it's a little bit of a curve ball, but I thought it'd be interesting to start there and then kind of walk all the way back to listen before talk. So, any ideas, gang?

David R. Jackson: Maybe what we should [unintelligible; not be doing is?] doing nothing. We know it's an important issue and we have to come up with innovative strategies.

Shannon Blunt: I'll chime in. I'll use this as a chance to get back on my soapbox, Doug. One thing we should not do is, and I'm going to point out a little bit of a finger here broadly, but it is keep doing very theoretical studies that are not physically meaningful. Because I'm a radar guy, but really, I come from the signal processing community and that community really looks at a lot of these kinds of problems.

Shannon Blunt: But I see so many papers that my eyes hurt from rolling them so much because it's just it's very, very theoretical without considering the physical aspects of the problem. I'll go again to what I mentioned earlier in radar. Many, many tens of dB have dynamic range and there will be assumptions. As I like to tell my students the most dangerous assumption is that when you don't know you're making. Things like, oh, well, we'll assume it's band-limited; not unless it's infinite in time.

So you know, dealing with spectrum roll-off, things like this. The fact that aliasing is always there because nothing is truly band-limited. It's all these little theoretical assumptions that, yeah, you can go crank out papers all day long, but things just don't make that connection to the real world. You can't even do benchtop testing with them sometimes. So that's I will step back off my soapbox now. But I had to say that.

Douglas Sicker: I like these both. I love the well, let's not do nothing and let's, let's not be theoretical anyway. Any other comments from the gang?

Tommaso Melodia: I agree 100 percent with the two so far. Yeah, I would just add we really need to go beyond silos in various different disciplines. Any communication problem or interference problem is also a computational problem with physics and limitations of devices. And, you know, we really need to go beyond silos. And it's hard to do in academia because the incentives are not well aligned to do that. But I think we can do better.

Charles Baylis: Tommaso, so I think... Go ahead, John.

John Kuzin: One thing I would add is and I think we're moving in this direction, it's not as fast as we would like, but we're moving in this direction, which is away from absolute interference protection and really looking at what level of noise in your band can you handle and still operate effectively. And I think, you know, just as an example, the FCC's decision in the 6 GHz band that, you know, allows unlicensed communications in a manner that does not provide absolute protection to the incumbent users, but instead, in the FCC's estimation, and I believe they're right, makes interference highly unlikely, but not impossible, because there's a lot, as you all know, there's a lot of this gray space. There's so much of this gray space where two services can operate pretty darn well. And as soon as you say, you know, NIMBY, right, Not In My Back

Yard, get the hell away from me, you closed that off. And at least now regulators and hopefully the federal users are recognizing that there's benefits to actually having picnics in your backyard and saying, you know, Come on in, let's talk about what we can do together. And I think we're moving there because we have to. And that's a good thing.

Douglas Sicker: Yeah. Charlie?

Charles Baylis: You know, John, I think your comments piggybacked on Tommaso's well, and I was going to make the comment that, really, we've got to not only move beyond silos, but I think we have to move beyond our level. And I think those comments are actually one and the same. You know, I think this is great, this panel today because I think John's [Chapin] in setting this up and Doug's intent was really to say, Look, we want to enable iterative policy, but technology has to be there to enable it.

And obviously on this panel, we're looking at technology at multiple levels. But I as a circuit person can't do my work effectively unless I know what the system person, i.e., Shannon or Tommaso, is doing. And they need to be informed by the policy person. And I think the more that we can build situations where we can work together instead of in our isolated levels, you know, we've got these multiple levels from policy to circuit, if we can avoid working in our own level, but work with others in different levels, we're going to make more and quicker progress on this.

So this is a great start. I appreciate the fact that we're having an eye on iterative policy and how do we enable that? That's great start. And that's the framework I think we have to have. So don't work in silos don't work on your own level exclusively I guess would be my comment.

Douglas Sicker: Yeah, I agree completely. And you know, getting started, I guess is what David really was saying. Let's do something. To John's point, I mean, I can tell you years back when I was in government, how frustrating it would be, the absolutes of spectrum interference issues. And that's been talked about for years, how we open that and get a little more flexible and a little more tolerant.

And I think we really need to accept that model. But at the same time, I think we can probably do things in the technology space that could really just fundamentally change the way that we think about interference impacting our services. So there's so many levels to this problem, even from just a technology perspective that to iterate through all of that would be, you know, again, a number of different workshops.

So I do want to, I did want to, pull some of the questions. I'm going to grab the one which said—and I'm not going to ask David, but it's a David question—which is active cancellation. I'm going to ask the others. Where are good bands or where are good services for active cancellation? And I could pick on Shannon, because you know that stuff, because, you know, David and Shannon and I and Charlie are working together. You know what David's proposing. How does this play in the radar space? Could it play in the continuous wave space; could you have a CW that would sit in the middle part of that zone that he [David] had and then still have interesting operational radars.

Shannon Blunt: To tell you the truth, going to something that is like more CW would probably be more amenable. And I'm going to I'm going to claim a bit of naïveté. I know what David's doing, but not to the level of being an expert in it. But when you're talking about high-power and pulsed systems, the transient effects at the beginning of the pulse, I mean, they make things harder to deal with and you get spectral spreading from those regions. Going to something that is at a minimum higher duty cycle or, at the extreme, more of a CW, you basically just have more of a stationarity to the problem that I suspect would work better in that context to actually allow you to cancel regions without getting the transient effects where you're going to have any type of interference spikes. That's at least a kind of off-the-cuff answer.

Douglas Sicker: Charlie, Tommaso, John?

We can move on. So there's a bunch of questions that are popping in. And by the way, if the panelists see a question they want to grab, please let me know. I'm happy for us to jump in as a group and just kind of parse them. But I did want to take this next one that I saw, which was how quantifiably better is this compared to active noise cancellation systems?

And this obviously is pointed toward you, David. I don't know if you see the question.

David R. Jackson: Okay. Thank you. Yeah, well, first, thank you for the question. A very good question. We haven't really pursued passive cancellation in the same aspect. Here's my gut feeling though. At least active cancellation gives you more flexibility because with active cancellation you have control over the phase shift and the amplification, so you can generate a countering signal no matter what the level of scattered signal is or interfering signal. With passive cancellation, I think. it could work, but it's a lot more limited probably. And, as I think you pointed out also in your question, there's bandwidth issues. Maybe a passive scatterer could do a good of canceling at one particular frequency only. But [what ?] is the bandwidth going to be with that? With active cancellation, you have more control. I mean, there is still going to be a band limitation, of course, but you can design it based on the bandwidth of the amplifier and the electronics, and your antenna, and so on. So you have more control over it. So I think that's the big advantage. So, I think passive scattering could be suitable in some applications, but I think it's not as general as active cancellation. That'd be my answer for right now.

Douglas Sicker: Thank you, David. Did somebody else want to say something on that? Okay, just noise in the background. Nick [Nickolas LaSorte, Day 3, June 15 - Panel: Risk-informed Interference Analysis] asked, What's the right strategy for creating testbeds to bring these radar technologies together with the latest telecom systems? And I know that Shannon, you've thought about this; Charlie, you definitely thought about this. So I'd like to … I'll call on Charlie.

Charles Baylis: Okay, good. Thanks for the question, Nick. It's a good one. I one thing I want to comment on as John Chapin mentioned earlier, is the Hill Air Force Base effort that's going on right now to look at radar and communications. Now, I'm not sure how this effort has progressed completely. When it was first launching, I actually posed the question to them, Are you looking at radar technologies and how they can be innovated to collaborate with wireless communication? Or are you looking at communication technologies and how they can be innovated to collaborate with radar?

And it turns out that the effort, at least from its initial onset, was constructed to look at improving communication technologies. But the radar technologies weren't being examined, which I thought was, you know, that's a very needed thing. So whether we augment Platforms for Advanced Wireless Research (PAWR) with radars or build new PAWR and NERDs (Network Enhanced Realtime Drone) testbeds around readers, I mean, I think all these are viable things. I do think that the Department of Defense's (DoD) effort at Hill is an excellent one. But I think it's got to be augmented to look at new radar technologies. If we leave radar in the dark ages and only innovate wireless communications, we're only solving half the problem. I think those two need to be looked at in concert. So that's the opinionated soapbox I would make. Shannon, I'll let you take a stab at it.

Shannon Blunt: I'm going to answer it in a what's going to sound like a really weird way. And that is, I think, a good way that we can explore more writ large [clear and obvious] RF Testbeds is to do it at ultrasonics. Here's why I say that cost. Cost in scale, actually both. Because obviously you aren't going to have polarization, but you can get a very sophisticated setup that has multiple different modalities on the order of hundreds of dollars. Which means that all these universities that are playing with these things can now have very simple testbeds that are actually very capable.

We've got one right now we've been slowly building up that operates at a whopping 40 KHz, but you can do some really cool stuff with it. You can try out things that the cost to set this sort of thing up at RF would be prohibitive. And you can try, and you can fail. That's kind of the benefit.

You can try things and see what doesn't work, which kind of helps you narrow down what might work.

Douglas Sicker: Yeah. And I think that's an important point. And Nick, again, thanks for asking that question. I mean, we're at a point where we can start doing stuff that we couldn't do before. So these testbeds could take off and it could be cheap. I mean, even compared to 10 years ago, let alone 20, it's a whole different world.

The other one I wanted to ask.

Tommaso Melodia: Maybe Doug just wanted to add something related to Nick's question, which is just a great question. And I think one of the challenges that the platforms have had has been the availability of spectrum for open experimentation and access to broad spectrum bands. And so I think enhancing powered platforms with, for example, radar or other spectrum-dependent systems would be great.

You certainly need to bring the right expertise, which the power platform teams don't necessarily have today. So you would have to create programs to do that. And you also have a need to sort of expand the available spectrum options for those platforms. And so I think combining something like an NRDZ with a power platform would be a very powerful way of enabling that.

Douglas Sicker: I totally agree. And I'm going to turn to Tommaso and John for this next one. So [HighTechForum.org founder] Richard Bennett asked, I'm just going to read toward the end of it, which is, "Is it wise to give legacy systems a free pass while imposing the burdens of coexistence on the new entrants, as the spectrum sharing advocates seem to do?" And again, there's an assumption built into that question, I'll say.

But I think there's something interesting here, which is how do we deal with the legacy as we move forward? Whether it's poorly designed GPS receivers or anything else? How should we approach this and what's the way to it? Maybe that's outside our control and outside our expertise, because we're a bunch of techies, but I think if we're going to have [unintelligible] spectrum, Tommaso, you better figure this problem out.

Tommaso Melodia: I'm not sure that I have the solution. But certainly in terms of the question of whether it's wise to put the burden on newer [unintelligible], I'm not sure. It's sort of an incremental approach. You know, you start from a status quo, and you say, Okay, how do I introduce new capabilities while maintaining, in a sense, I say it in quotes, "backwards compatibility" with what exists? I think it's a practical way to approach that. I don't know that it's the only possible way, but it's sort of, from the art of the possible, in many ways.

John Kuzin: One thing I would add is, you know, if you if you look at the GPS receiver issue and even the radio altimeter issue, it was essentially interference due to blocking. And you could argue poorly designed receivers. And one of the things to think about in the future is as new bands are looked to be opened up for, you know, other uses, whether it makes sense as it's being done to have a mechanism perhaps with the C-Band auction, there could have been a fund for replacement of faulty radio altimeters, for example, as part of that, knowing that the big media and fiasco that ensued there, is one way of handling that. So I don't think they get a free pass, but it's definitely worth looking at. And as you all know, what grew out of that is now the FCC have a started a notice of inquiry regarding receiver performance.

And one of the things to look at is what should be done to prevent or to require future receivers that are being deployed now to implement something like, I don't know how you want to define it, but good engineering practices so that they have input filters and typical designs that are used today and they don't just put in something that basically is poorly performing just because it's low cost when it actually impacts others well outside their band of operation.

Douglas Sicker: Thank you, John. And I didn't have the pleasure or opportunity to hear the earlier parts of ISART, but I see a lot of good friends who think about these questions all the time. So I'd be surprised if, you know, how do we deal with grandfathered devices and how do we make things like time-limited leases like Bill and John worked on before, all of these sorts of concepts, integrated into solving this problem that was brought up.

But I'm sure we'll hear more at the closing session. I'm trying to find the one I've been moving around in my chat. Kumar [Kumar Balachandran, Day 3, June 15 - Panel: Risk-informed Interference Analysis] had a question I wanted to ask. Yeah. So how practical is fine-grained spectrum sharing close to radio interference in the wideband deployment? So I don't know, were the operators seeking high availability and all the other sorts of things? There's bigger question here, which is how fine-grained or how much do we want to pack it in; how should we be approaching this? And that's kind of like low-hanging fruit for doing some simple things. Whether it's listen-before-talk or other such things, which it's not probably going to get you fine-grained, it'll get you close. But how should we be thinking about this? And I guess the second part of it is, are there implications on what we are looking for small cells alone? Anyone want to pick up on that?

Tommaso Melodia: Maybe you can say one thing. I think the question of what's the right level of granularity? Obviously, it's a broad question that needs to be answered technically. Certainly today, in several systems you can allocate on pretty short time scales at the level of resource blocks. So it's pretty fine-grained.

And you can have a map of the different resource blocks that you want to allocate versus those that you don't want to allocate. So that can be done at least. There's obviously also a lot of computational and sensing problems related to that. But I think we certainly should explore all of these.

Douglas Sicker: I agree. So let me turn to Shannon. There was a question, and this might get you in trouble with all your sponsors, but what band should we be looking at?

Shannon Blunt: It's funny you say that because that is literally what I thought, too. I'm going to pass that. I don't really have a good answer and I would very much hesitate to just throw anything out there. I'm going to pass.

Douglas Sicker: I respect that. I threw some questions at you guys the other day and I don't know which ones I want to touch on, but I guess if you could each just say one sentence, what's the lowest hanging fruit? What should we be doing? What's the absolute? And I think you covered it in each of your talks in some shape or other.

But if you got to talk to the Assistant Secretary at NTIA or the chairman at the FCC or people on the Hill, what would you say? Well, we have John on, thank God. What should we tell John is an important thing that we should be pursuing at NSF? I'm going to call on people.

David, start.

David R. Jackson: Well, if it's NSF, I would say try new innovative approaches, even if they're a bit risky, go ahead and try them out and see how they work.

Douglas Sicker: And what would they be? What would be a particular technology? Is that active cancellation? Is that some form of that? What should we really specifically be trying to push to get the biggest bang right now in the space?

David R. Jackson: Well, that's just one of the areas that I'm familiar with. I'm sure there's many others. But yeah, I think in general, just innovative hardware approaches that could also augment all these software solutions. I think would be a good thing for the NSF to Fund.

Douglas Sicker: Tommaso?

Tommaso Melodia: I would say, I don't want to repeat things that have already been said, but only seek approaches that span hardware and software, as well as multiple disciplines within hardware and software. That's what we really need to make advances in. And I think it would be helpful to have programs that are a little larger than the classic NSF programs, just because that enables closer collaboration between various groups.

John Kuzin: John Yeah, as I said in my opening remarks, I would say one of the things to really consider is what Qualcomm has been advocating for is the traditional approach to opening bands, whether they're unlicensed or shared in particular, has been defining very simple technical rules. And the theory has been let a thousand flowers bloom. Well, billions of flowers have bloomed.

And now we're looking at the problem where there is so much active use in bands that can actually be improved upon. And we shouldn't just give up like is done sometimes where, oh, it's an unlicensed band and the rules are what they are. I think it's worth considering adopting rules, one of which, as I've said, is looking at synchronized access in these bands where you have slotted communications and when you're transmitting you have a much greater likelihood there won't be a collision and your communications will get through.

So what I would say is considering simple add-on, technology-neutral rules for the future to enable bands to continue to support increasing levels of communications, which I think is going to become essential. Because the bands are all occupied and there's great value in these low bands that have great propagation characteristics, and we need to look at ways to make the use of those bands better.

Douglas Sicker: Got it. I'd love to hear the details behind what that would look like, but I'll come back to you on that maybe sometime another day.

John Kuzin: Oh, no problem.

Douglas Sicker: Shannon?

Shannon Blunt: So you did kind of pose it as depending on who you're talking to here. So I'm going to answer two different ways. If we're talking more operational, I would, and this is reiterating what's already been said, but software driven capabilities, increasing dynamic capabilities, shorter time scales. You know, that's what's going to drive things, particularly in, again, systems like radar that have operated on, tended on slower time scales, being able to speed those up.

If we think of it from a different way, though, because you mentioned what would I talk to John about? So NSF, so okay, longer time frames. I think an interesting question is What happens when we get to the point where being more dynamic stops providing benefit, when we get to the point where there's no longer maneuver space and now we're all laying on top of each other.

We were in a similar type of panel discussion a couple of years ago. And Frank Roby, then Massachusetts Institute of Technology (MIT) Lincoln Lab, now Defense Advanced Research Projects Agency (DARPA) raised this question of what happens when there's no more maneuver space and we're all just laying on top of each other? What do we do? And that creates kind of a different perspective now.

I mean, I don't know. Does it become all sort of like CDMA (Code-Division Multiple Access) I don't know. But it's not an answer. It's just another question.

Douglas Sicker: Thank you. Charlie?

Charles Baylis: This is an interesting question. I used to read these books when I was a kid, like you be the coach. I don't know if any of you and your kids saw these books, but it would read you through a scene in a game of some type, and then it would say, you're the coach, you've got to make the decision and you don't know what actually happened.

So you make the decision and then you read what the coach actually decided. This is what I feel like right now. If I was a program manager, what would I do? Well, I mentioned before I think there's got to be a tranche here where we look at multi-levels. And so the question I think is twofold. The first one is, what's the new paradigm going to be?

I think we all have to agree on what's the paradigm of spectrum use going forward. And then once we agree on that paradigm, I would make a case that from what I've heard today and what you continue to hear, that things are moving in such faster timescales. I would call that adaptability and reconfigurability.

We have to be able to adapt to the environment. We have to be able to reconfigure quickly. So I think a decision has to be made in the paradigm whether that's already made or it needs to be researched further. And then the second thing is, I think there have to be multi-level fundamental research projects initiated. Where different people at the fundamental research level and moving forward to the applied level will possibly get together and work on multiple levels from policy all the way down to the circuit level and may overlap two or three of those levels, where people are working with one another so they understand the limitations of the previous levels and how they impinge on their own work and their own setting up of a paradigm. So, I would say that has to happen. We have to rally around a paradigm and then we need multi-level teams to look at that paradigm. And I think Shannon hit it on the head, we need to move to shorter time scales.

Douglas Sicker: Right. I, I want to we don't, we're not going to have time to actually dig in on it. But Nick also asked, you know, hey, does there need to be a national spectrum strategy, R&D strategy? And my personal opinion is, absolutely. And it really needs to be highly orchestrated and highly integrated so that we can actually solve some of these problems across the different services.

And, again, I think SpectrumX gets to that. There are some other research groups, too, but I think it's still too wide and unorganized, to be honest. Many of us know each other in the spectrum space, but there's just so much to be done and so much research and funding that needs to happen and organizing all these testbeds.

But I think it's a I think it's a very interesting issue, and I think it's one probably John Chapin thinks about quite often. So with that, we're at the end of our session. I want to thank the speakers and thank the audience and also thank Institute for Telecommunication Sciences (ITS) for hosting us. I really enjoyed the discussion that we had. I think we talked about some really relevant issues in terms of what we can do technology-wise. And I'm going to look forward to the closing session whenever that starts in like five or 10 minutes. So thank you, everyone.

David R. Jackson: Thank you, Doug.

Tommaso Melodia: Thank you.

Charles Baylis: Thank you, everyone.

6.4 Panel: Wrap-up and Roadmap

What are next steps? The panel moderators summarize the most important takeaways from the discussions and consider whether community consensus is possible on any well-developed idea or solution that was discussed and which areas or ideas warrant further research or stakeholder group involvement.

- *Moderator: Derek Khlopin, Deputy Associate Administrator, NTIA Office of Spectrum Management (OSM)*
- *Eric Nelson, Director (Acting), NTIA Institute for Telecommunication Sciences*
- *Giulia McHenry, Chief, Office of Economics and Analytics, Federal Communications Commission*
- *Edward Oughton, Assistant Professor of Data Analytics, George Mason University*
- *JP de Vries, Director Emeritus and Distinguished Advisor, Silicon Flatirons Center for Law, Technology, and Entrepreneurship, University of Colorado Law School, Boulder, Colorado*
- *William Kozma, Jr., Head of U.S. Delegation to ITU-R Study Group 3 and U.S. Chair of Working Party 3K*

- *Douglas Sicker, Senior Associate Dean for Computing and Professor of Computer Science, University of Colorado-Denver*

John Chapin: Okay. Welcome back, everyone. It's now time for the closing panel, chaired by Derek Khlopin. Derek is Deputy Associate Administrator in National Telecommunications and Information Administration's (NTIA) Office of Spectrum Management (OSM). Mr. Khlopin leads spectrum management efforts for the federal agencies, NTIA coordination groups such as Interdepartment Radio Advisory Committee (IRAC), and Policy and Plans Steering Group (PPSG) spectrum policy initiatives. Whatever good ideas come out of ISART, Derek is going to be a linchpin of helping those ideas transition into spectrum policy and spectrum management practice.

So it's great that he's able to join us today and engage in this discussion. Derek, over to you and the panel.

Derek Khlopin: Thank you very much, John [John Chapin, Day 4, June 16 - Technical Presentation: Fast Interference Management]. I appreciate the very kind introduction. I am extremely thrilled to be moderating this session. This is a fun one. We get to sort of wrap up, reflect on these past four days, about great sessions and keynotes. And then look forward and sort of wrap up and think about what we take from this and how we move forward.

You know, I'm excited and overall point I'll make here before I turn to my panelists is, I feel like we're at a bit of an inflection point in time and I think a lot of these discussions have talked about that. We've made tremendous progress and spectrum sharing, but it sort of feels to me like we really need the two, feels like we need a real breakthrough to take us to the next level, for example, to really enable to enable true, dynamic, real-time automated spectrum sharing.

I think we've taken these steps that are very important to look at Citizens Broadband Radio Service (CBRS) and others. But I think a lot of our conversations over the last few days have talked about the next big thing. And I think as we get to the second part of this panel here, I think we'll talk about what we really need to do to get there, to envision that over the next 10 years.

I think what I'd like to do here and again, so folks understand these are the moderators of the sessions that we've had throughout ISART. I think what I'd like to do is have the moderators reflect first on the sessions that they conducted and what some of the takeaways were and the conversations and reflect on that.

And then I think we'll go back through again and try to think about looking 10 years out on where we think these communications and sharing technologies are going or the frameworks are going and then the steps we need to get into to start making that happen. And as soon as possible start moving in that direction. So I'm going to kick it off.

I'm going to turn to first here Eric Nelson, who is sitting in for Bryan Tramont, who ran that panel. And Eric, do you want to talk about what your panel [Day 1, June 13 - Panel: Industry Lessons Learned from Spectrum Sharing] was and what some of those takeaways were?

Eric Nelson: Yeah, thank you, Derek. So the industry panel had quite a bit of material that they covered. There were a number of recurring themes.

You know, they've had experience for well over a decade working through a lot of these problems. So it was quite valuable to have people take real objective evidence to the table and be able to speak to that. I'll kind of walk through the things that I highlighted going through the recurring themes. The first that came up is the need for trusted agents.

Trusted agents provide multiple benefits. One is that they're a broker for information exchange. Information exchange came up over and over again. Both parties, both incumbents and entrants, need access to good, trustworthy data. Oftentimes, that data is either sensitive or proprietary. There are sometimes issues with the nature of that data, like with America's Mid-Band Initiative Team (AMBIT), there's actually classified information.

So, kind of pulling on that thread a little further, you really need to start that process early if you know that you're going to have to get into a lot of depth and detail, have access to sensitive data with legal frameworks involved. Greg Wagner [DSO DISA] in a different panel [Day 2, June 14 - Panel: Data Sharing and Transparency] brought that up. Data sharing isn't just a matter of sharing the data, but if it becomes a part of a policy or a rule, it oftentimes leads to data retention requirements.

And so you really have to do your homework and get the lawyers involved early to make sure that you have access to that. There is talk about who should be that trusted agent. There's AMBIT with the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) task group that was set up by the National Spectrum Consortium (NSC). And certainly they were highlighted as having done an excellent job in that band. But as well, you know, NTIA's Institute for Telecommunication Sciences (ITS) and Office of Spectrum Management (OSM) and the Federal Communications Commission (FCC) were highlighted as critical agents in that process.

I think the other thing that came up is at those early stages, we need to properly resource both organizations. And I'm with NTIA. So I'm a little biased in endorsing that, but obviously it's a good idea. There's a lot of legwork there. It's very time consuming and in our capacity as NTIA's research and engineering lab, oftentimes our core programs are about developing new capabilities.

And we put that into the research needed to develop the spectrum-sharing approaches and measurement systems and analysis techniques. The actual legwork of sitting down and working out the details of a spectrum-sharing solution requires additional resources. So that's something that everyone highlighted is the need to properly resource the organizations that are involved in the information sharing and set up and establish that trust between agencies early on in the process.

Another thing that came up is need for regular regulatory certainty. But part of the conflict there is we also need to evolve. So, it's kind of a kind of a conundrum there. If you want to change, but you don't know where those changes are going, how do you handle that? You want to establish the rules and the framework up front, but like Neeti Tandon [AT&T] mentioned in the panel, we don't want rulemaking occurring after an auction, for example.

So I've heard over the years the metaphor of a ratchet be brought up in that, perhaps you come out, you have your best data, your best information, you have your rulemaking. And then with time, what you do is see if additional studies, measurements and analysis can bring greater confidence in new approaches that enable an increased access to spectrum while protecting the incumbent.

So the ratchet idea is, unfortunately, you start conservative. You start with the best information, you start conservative with the expectation that we'll resource the kinds of studies required. So it's not just industry doing these studies, but incumbents that are involved, trusted agencies are involved so that you can do the studies and determine if you can kind of turn that ratchet and get a few more clicks out of it, so to speak, and get additional access through maybe modifications or evolutions in the approaches to sharing. And that was something that Neeti highlighted—exploit the technology.

Advanced antenna systems were mentioned. If we can gain more knowledge about various hooks and various features in advanced antenna systems that give us even more abilities to fine tune and tailor spectrum-sharing solutions for particular incumbents, then that's something that might be exploited to grant greater access again while maintaining the confidence from the incumbent-perspective that we're still protecting their critical services.

Neeti mentioned with that constantly evolving system, one of the problems is, the system is constantly evolving. She had mentioned that in the AWS-3 (Advanced Wireless Services in the 1695–1710 MHz, 1755–1780 MHz, and 2155–2180 MHz Bands) deliberations, there was what was called the randomized real deployment. And what that was kind of a real life network density kind of map that that one of the carriers provided and gave the folks at the Office of Spectrum Management Insights into the density of the deployment so that they could do their interference modeling.

She cautioned against wanting to constantly update that because it's a moving target. You know, clearly, if you if you start deploying a massive change in your network or perhaps you're going from a macro-cell deployment to a lot of small cells, you really have to factor that in. You know, ironically, in the AWS-3 deployments, I have personal knowledge from this, some of the modeling for small cells treated the user equipment being served by small cells in the same manner as user equipment of macro cells that might be powered up with higher powers. And so we weren't really taking advantage in that modeling of the capabilities of small cells. So perhaps you look at those major changes in the network, but you're not constantly looking at cell counts on a monthly basis, for example.

Another topic that came up is, is enforcement. Multiple times, just about all the panelists mentioned enforcement. Bill [William Davenport] mentioned that incumbents will build protective fortresses if they don't trust that enforcement will work. And so naturally, people will start reacting to an environment if they don't have trust in the environment. And we really don't want to have that. So, how do we make sure that we're building enforcement into these new rulemakings and new sharing schemes up front, just like you build security in up front? You know, Mark Gibson mentioned that there was talk about maybe the Spectrum Access System (SAS) could be a bounty hunter, was the term used, and he said that's not a good approach. And then Bill Davenport came back and said, well, perhaps the Automated Frequency Coordination (AFC) could preemptively address issues before enforcement is even needed. So you could look at tuning the systems and making preemptive, adaptive changes to the actual uses in the sharing schemes so that you don't have to bring enforcement folks in to bear on the problem.

So that's a wrap-up. I'll have more to say in detail as we proceed.

Derek Khlopin: Thank you, Eric. That's terrific. Yeah, a lot there. Certainly this panel jumped all over the place, which is important with the policy implications of all this stuff. I'm going to next turn to you, Giulia, to talk about the economics panel. And, again, sort of an open-ended question on some takeaways there, what some of the conversation was.

And as I mentioned to the others, I think we'll then in later on discussions sort of look forward to next 10 years. But what are some of your takeaways from that session? Thanks.

Giulia McHenry: Absolutely. Thanks, Derek. And sorry for being late. I apparently translated time zones wrong. So I am sort of winging this. So let me reflect. I think the best part about the economics panel [Day 2, June 14 - Panel: Economics of Spectrum Sharing] was really that it was a pretty diverse panel, both in makeup but also, frankly, in opinions. So, I think we kicked it off with Martin Weiss [University of Pittsburgh], who was talking about spectrum anarchy.

So really focused at the local level. You know, how can we improve usage at a local level by essentially sort of lifting rules, if you will? And then we moved on to Sarah [Sarah Oh Lam, Technology Policy Institute], who had a fascinating proposal, thinking about ways that one could use a Special Temporary Authority (STA) and essentially create a market for STAs. [indiscernible] I think more than thinking through the legislative challenges that might be created there.

But the idea, I think, is this concept in highlighting the point that there may be demand for fairly short-term usages for which one could create a market that could, in fact improve usage of the spectrum. And then we heard from Edgar Rivas, who works for Senator Hickenlooper [CO] really talking about some of the challenges and what they are looking for in terms of coordination.

What they are looking for in terms of being able to get some revenues from the spectrum or looking for cooperation and highlighting some of the data-driven decision-making that the Hill is looking for going forward. And then I think Carolyn Kahn [MITRE] did a really nice job on an approach that we should think about.

And for those of you who are aware of how programing works, Carolyn suggested a more incremental approach to making rules that looks at taking rulemaking stage-by-stage. And how can we do a better job of improving usage that way? And then finally, Greg Rosston wrapped it up talking about use it or share it and adding that concept.

And so I think it was highly diverse, a lot of different ideas, but I think the takeaways are there are a number of solutions and a number of potential tools in the toolbox. And it's just a matter of sort of finding the right tools for the right problems. So I'll leave it there and wait for more questions.

Derek Khlopin: Sure. Thank you, Giulia. And you're right, that is diverse. And the right tools and how to prioritize amongst a lot of good ideas. I mean, that's hard. You know, a lot of the challenge sometimes for sure. Ed, I'm going to turn to you next in your panel on data sharing and transparency. And, to talk about your takeaways there and then who the panelists were and the highlights of their conversation.

Ed Oughton: Thanks. Fantastic. Thank you very much. So the Data Share and Transparency panel [Day 2, June 14 - Panel: Data Sharing and Transparency] was really trying to look at those engineering, technical, administrative and system solutions that could help us improve the current level of data sharing and transparency. I think we could all probably admit that we could do better within this area, and therefore we need to put a little bit of motion forward [indiscernible].

I think there were really four points that came out of this, and the first one was on virtualization, which I think was very exciting, as some of the panelists talked about their fantastic engineering. That solution is in the cloud. The whole telco industry is moving towards the centralization of this processing activity. And I think that's exciting because what we currently lack is … a lack of evidence recorded in a frequency band in space and time.

And I think that this move towards that kind of centralization may provide a new opportunity to kind of gather that data. There's lots of issues here. So we're going to have the same kind of national security and privacy issues. We're going to have the same issues with the operators being worried that this is going to reveal that competitive advantage in the marketplace, of how they do their networks, things like this.

But, you know, if we kind of preemptively think about what may be useful to support regulatory decisions and other decisions, in a few years' time there may be the opportunity to put forward enough new data standards for recording that data and actually moving some of that data in aggregated forms so that it's not quite as revealing to some other location where that data can be stored, essentially, and then that might be really useful for the future.

And then I think secondly, the thing that came out of the panel was actually the fact that MOUs (memorandums of understanding) are already in place and data sharing is taking place. It's just a very long and protracted process. Particularly if government has to share that data because that is going to involve a lot of legal review, essentially. So I think that's something which could go on, but I do think that we don't actually have to have the true datasets shared, to a certain extent, for a lot of uses. Just knowing the distribution of shapes and some of the underlying parameters would enable us to kind of generate our own synthetic datasets, which is kind of the third point, which I want to get to, which some of us spoke on in great detail.

[The third point] is that we have the ability to generate these datasets for people working in the spectrum science area. And that gives us an opportunity to not deal quite with the underlying real data that has this privacy and security issues, but to generate something synthetic that can be validated and be broadly correct, but which still doesn't introduce a lot of more detailed and nuanced problems that we have when we work with, especially explicit spectrum data.

And then I think just finally rounding up for my fourth point, it's that we had this theme through the panel about spectrum data science. And I think just the fact that this is as much an art as a science is kind of worth recognizing. We all know that we end up making assumptions such as a priori assumptions about how the world works, we build our models, and we never go back and explore the variations, or we rarely do. Then we have all of these embedded uncertainties in the results that we produce. So I think trying to move to a position where we can interrogate each other's models in greater depth would be really good for overcoming that and recognizing that ultimately these are discussion tools. We're always going to get a model which provides us with the exact answer. I don't want to get into that metaphor again, but you know all models are wrong.

But ultimately, this is important for us to reflect on, that these are discussion tools and that we should be able to share them and look at what we've each done and then ultimately have a discussion around how that may affect the results. And so what I'm hearing from other people, on the panels who are in government or other agencies or the private sector, they've actually said that when they sit down with their engineers, we go through this process, they find the common ground and they find out where the disagreement is on the merits of the solution in place to overcome that. So I think that there are positives to that.

And I think the final point, just picking up on that force data science one, is that data needs to be turned into meaning. And if we do collect all of this wonderful data from virtualized infrastructure, then ultimately we need people to be able to turn that into something which is relevant to decision-making in government and industry, so I'll send it back to you. Thank you.

Derek Khlopin: Thank you, that's terrific. That that was a great, great a great panel session for sure. Now, JP, I'm going to turn to you next. I know you spent a lot of time thinking about this, risk-informed interference analysis as we look to solve these intractable interference disagreements or perceived interference agreements that have been out there forever; we butt our heads up against that. So do you want to take it take it from here and talk about that session? Thanks.

JP de Vries: Mm. Thanks, Derek. Yeah, it was a wonderful experience and a great honor to actually speak with these five people [Day 3, June 15 - Panel: Risk-informed Interference Analysis]—Rob Henry from MITRE Corporation, Omar Al-Kalaa from the Food and Drug

Administration (FDA), Kalle Kontson from Johns Hopkins, Nick LaSorte from NTIA OSM, and Kumar Balachandran from Ericsson. They all came from very different perspectives but they all think about risk.

So in a very important way, this is a very limited view. And you can take it with that context. But I was very encouraged and frankly, I was somewhat surprised that there was something of a consensus that the kinds of approaches that are commonly used in risk assessment like probability, assessing likelihood, thinking about impact, doing statistics, it's like, yeah, sure, not a problem.

Everybody just takes that for granted. And it was almost a non-issue at least for the people on this panel that, yeah, there are all these methods and we use them, whether they were in industry or whether they're in government. So the fact that it was no big deal was important and was a big deal for me.

I think that there was another message which was in a way related to this, which is that communities that used to do things differently can adopt risk-based analysis. So if you look at the FDA, for example, or actually we were going to have a panelist from the Nuclear Regulatory Commission and the person from MITRE, Rob Henry, spoke about this.

There are many industries where worst case is, or used to be, the way in which everybody operated. But if you frame the method properly by talking about the outcomes and the mission and what you're trying to achieve, rather than focusing on risk versus worst case, the stakeholder community's come around to it. I think that there were common themes that actually we've heard from some of the other panels as well, obviously.

And you can see this in the structure of the conference. The organizers know this, this whole question about the importance of data exchange, the importance of transparency and all the things that actually go along with that with evidence-based approaches like peer review, like reproducibility. Those are all important things. However, they take time. A number of panelists mentioned, you know, yeah, but this takes time. And I think some of these processes are like inverse dog years. It takes a lot longer for that organism to do things. They live more slowly than humans do. So institutions live more slowly than humans do. So things take time.

The other thing, which I think was important, and actually I'll pick up on a point that Ed made, a phrase that he used, which was turning data into meaning. And so when one thinks about objectives and when you actually look at the challenges of these processes, where there are multiple stakeholders, you say, well, let's think about the impacts. Well, different people worry about different impacts, and they worry about them differently, and they assess what the meaning of a result is differently. There are always going to be, and there are inevitably conflicts and tussles and, I'll leave more detailed comments about this for the forward look.

But I think one of the things that struck me was that evidence-based, science-based methods only go so far, even if everybody is a well-intentioned scientist or engineer people will have different assumptions because they have different perspectives. They may even use the same software, but they will come to different conclusions and they will interpret the implications differently.

That's a feature. It's not a bug, but in order to work with that feature, we need to have institutions where people can come together and have those conversations.

Derek Khlopin: Thank you, that's great. A really thoughtful reaction to that panel, no question. So, to keep it going here, Billy, I'll turn to you and your panel on standardization of propagation modeling. Always a challenge. But then I know that's certainly something ITS has spent a lot of years thinking about and talking about. So you can take it from here. Thanks.

Billy Kozma: Yeah, thanks, Derek. So, during the course of the panel [Day 3, June 15 - Panel: Model Standardization - Propagation Case Study], I took away four key themes. We had people from industry, government, and academia and there were four ideas that we circled around. Although interestingly, sometimes I would argue, folks in different agencies talked to the same point, but from a different perspective, and I'll mention that.

But the first thing was you really need to establish open and frank conversations. I mean, no surprise when you're dealing with engineering and talking about this, but you really need that kind of open conversation, and it needs to be technically founded. Once you veer off from a technically based conversation on these matters and just being frank about what you're trying to solve, what some of the other panels talk about, you start to see those biases and different perspectives come in.

But if we can be up-front we can be effective. It was mentioned that all the panelists have been involved in standardization and sometimes sharing scenarios in different aspects, whether international or within the U.S. And there's even acknowledgment in some cases they didn't start off well the conversations. But if they sat down, they said, we're just going to have a technical discussion. Let's lay the facts out. Let's talk engineer to engineer, essentially, you can make progress. You can work the problem in that way if you keep it grounded.

And really that leads into the second thing, that a couple other moderators here talked about, which is transparency. The data that you're collecting, the methods you're using, it needs to be transparent to establish that kind of trust, have those conversations. This was brought up by a variety of panelists, such as Dr. Salous [Durham University (UK)] bringing up the fact that when you present data, your measurement needs to show everything you need to capture system information, all the information you're capturing on the measurements to be able to present that and to have a discussion on that.

Dr. Arefi [Reza Arefi, Intel] brought up that when you present data that's limited or shown just in brevity, that causes problems because then people have to fill in their own assumptions as to those missing pieces. And sometimes then you end up having to maybe reject it or maybe not be able to integrate that completely into the analysis you want to do. And that's again, that's where you risk veering off from that. Let's have a frank technical discussion because now you have to fill in gaps. If we do things and we capture everything and we put everything on the table, that really is how you work the problem.

Andy Clegg [Google] brought up that you really need some flexibility when you start rulemaking. This is a little about outside standardization, but it has an impact. And he brought up how with SAS, the models were baked into the rulemaking themselves. So when you lock yourself in from the beginning and restrict yourself, you're there's not a lot of places you can go.

And this was actually brought up in a variety of different panels. Paul Tilghman [Microsoft] brought it up in the data panel [Day 2, June 14 - Panel: Data Sharing and Transparency]. He said we would do things differently in the SAS then if we did it today than we did it in past. But because the rulemaking and everything was so structured, you were just limited. Even if you had all the data, even if you understood everything is going on, you're kind of putting up some real tight guardrails at that point.

Tony Rennier [Foundry Inc.] brought up the point that as you work this with the flexibility, don't try to tackle everything at one time, look at the problems, break them down to, what I would say, small atomic units, estimate essentially their impact or their size, and take one at a time and work one at a time and incrementally move the process forward. You don't need to solve the whole thing on Day 1.

And lastly, this is the one that I think some of the panelists talked to a similar point but from a different perspective as to where they're coming from, and I need to see JP's panel but I have a feeling that it crossed over to that, which is the idea of taking some risk.

Andy Clegg brought up the idea that we didn't have any interference within the 3.5 GHz SAS band. Maybe we should essentially start what amounts to start running experiments, cranking up power and trying to push those limits and trying to see what happens. You need that kind of trusted environment among everyone willing to undergo that in a structured manner.

That's one perspective of how he's looking at it, but that same idea is I think is also valid from some of the other perspectives the panelists brought. Because really what you're saying is we want to collect real-world data. Andy phrased it kind of in a risk, like let's essentially run experiments and let's push the limits until we see interference.

But that's really no different than saying, okay, we have something deployed, let's collect real world data. Let's run controlled experiments on a live system to gather information. And I think there's an opportunity to do those in real time. Set up a nice structure, understand what you're collecting and gather information, and use it as a feedback when we start to improve modeling and improve approaches. I really think there's a there's an opportunity to do that. Of course, you need that kind of foundation to get to that point, that collaborative environment there.

And then lastly, really one of the things, and this is no surprise to anyone, that really was an undercurrent to all of this is these are hard problems. They take time. You know, Eric, when he talked about starting with a conservative approach and you iterate it. But you have to allow time.

So whether that's time before we actually get to auctions and deployment to work on some of these problems, to set a foundation, that's ideal. But you really can't compress this and expect to have optimized your results at the end. It just takes time. Whether you're collecting measurements, long-term data as to the deployment you need to allow the process.

And I know that can be frustrating to certain parties that are involved in these things. But that's just what is required to some extent. Or else you need to understand what the trade-offs are to not allowing that. So I'll stop there. Thanks.

Derek Khlopin: Yeah, great. Thank you. Really appreciate it. For this initial part, Doug, I'll turn it over to you. And I think your panel is probably the most fresh in folks' mind since we just finished your technical enabling session. Thanks.

Doug Sicker: Thank you Derek. Sorry. They're cutting grass outside. I hope it's not too loud in the background. So I first want to thank Mike Cotton and John Chapin for sending me notes. I haven't really gotten the time to think about what I heard over the last hour and a half of my session [Day 4, June 16 - Panel: Technical Enablers for Evolving Regulatory Processes]. But I have some notes and I have some thoughts about it, you know, so I'm hoping you all got to attend the last session.

What we were really focused on is How can we innovate in the hardware and software and the systems and in the data to improve spectrum management, to make a more dynamic system? And I love the problem. I love the area. And the best part of it is that there's so much happening technology wise. And we just took a cut across a couple of different areas because we couldn't represent the whole space of technology, spectrum, innovation.

We had Charlie Baylis [Baylor University], who looked at reconfigurable front-ends and what you could do at the antenna element. And this is one of these really critical areas, obviously in the radio chain, what you could do to improve Electromagnetic interference (EMI) mitigation. We had Shannon Blunt [University of Kansas} talk about software-defined radars and more controllable radars and what can happen in that space.

We had David Jackson [University of Houston] talk about a couple of active EMI cancellation techniques, of which there are many others to be considered. We also had Tommaso Melodia [Northeastern University] talk about system-of-system optimization and how do you then use control data that you could be extracting and sharing. And then lastly, we had John Kuzin from Qualcomm talk about the more synchronous access in both license and unlicensed.

And you can just see by cutting across those that these are all at very, very different levels in terms of the radio stack, in terms of systems, in terms of data-intensive. And it just highlights this opportunity. But then we pivoted and quickly talked about what are some of the challenges in the space.

And I think we heard it from the other chairs of the panel just in the last half an hour that it's a hard space to move in and it's a complex space to move in. And so we had asked the one question, and I think I'd like to start here, which is what shouldn't we be doing?

And to start with a double negative, it was we shouldn't not be doing nothing, or it's a triple negative. We've got to do stuff. We've got to get moving and we shouldn't be doing this theoretically, or at least not entirely. We should be really thinking about how to pull this into physically meaningful representations. How to do testbeds, how to think about moving toward a national spectrum strategy.

And I think this is a really critical point that was brought up in the questions. And I think that this realization that solving each of these things in these little silos as we've been trying, improves each of those little silos or the adjacency to the silos. But this is a much, much, much bigger problem. And so rich from a from a technology of data perspective.

The other thing that was stressed on during the "what not to do" is moving away from the term NIMBY (Not In My Backyard). So, absolute interference protections. Which I think 20, 30 years ago that was a stronger assumption. We've moved the needle on that, but there's still kind of a challenge there.

And I think that this then gets into the issue of trust. And ultimately, anything that we do in the technology space, anything that gets integrated into the policy space, has to be built on some meaningful trust framework. And that's going to be one of those ones why I do believe we need to have a lot of experimentation, a lot of testbeds and a strategy to integrate this so that it can be believed and be accepted.

So we had a nice discussion also about what's the biggest bang. What could we do, quickly? And a couple of themes came out of that, which was we really need to start thinking about that integration from hardware to software to policy. How do we get that? How do we get that pipeline connected? And how do we feed that with data? And how do we feed that with the right data to solve the right kind of problems?

And that kind of also went to that whole issue of what do we do moving forward and how do we start thinking about this from a coordinated perspective? And, one of the things that came was if we agreed on different paradigms of use and we agreed on different approaches from a technology perspective, we could do much better cross-collaborative research.

And National Science Foundation (NSF) is trying to encourage this, but I think it has to be at a much, much bigger scale. And we heard hints along those lines. I'm going to try to look down at my notes as I'm talking. I apologize. There were a couple of little nuggets that I thought were really important, like Shannon Blunt talked about the evolution of radars. That we shouldn't be thinking that radars are going to look like what they look like now or what they looked like 10 years ago, that they might evolve in terms of their operation in the spectrum band.

And, however this plays out, the radar side, the interference mitigation tools as well as the comms or any other kind of device, that this is going to be an intensely computational problem. And we're going to need to be thinking about that as we start ramping up into this this new paradigm. Any of the assumptions that we've made about how things are operating, we should probably really pull back from that. Whether it's power levels of any kind of service, whether it's protection levels, whether it's the legacy devices, we need to start rethinking that as we move on into the operational mode for dynamic spectrum management.

Some of the other things that I thought were interesting that came out had to do more with this idea of add-ons in the spectrum policy space. As we get this new technology, how do we incorporate that in? And John Kuzin described models where we really need to start building in assumptions about the device and about the operation and other such things, which JP would agree we've had many, many conversations about this over the last 20 years. But it gets to this idea that the policy probably is going to look different as we get much more dynamic spectrum devices.

And we should expect that the policy needs to really evolve and be a much different looking beast than it has been for the last 100 years. And while that wasn't said explicitly in the panel, it was certainly implied a whole bunch of different times by all the panelists. But it's going to be a new world. And I think that's the theme of this whole ISART this year, which is how do we move to a more dynamic spectrum paradigm?

And I'll close with that. Thank you.

Derek Khlopin: Doug, that's great. In fact, I think some of the things you said set up a nice transition for part two of the panel here. I want to take a quick moment to let participants know we're going to open up a poll here. So hopefully folks can participate. We're really looking at two questions that are on an iterative regulatory process on whether you think it's beneficial and then whether that is risky or not?

So again, it's a chance to take a look at that. That would be great. And then so going back to the panel and building on what Doug said there again, because I think you did talk about that the answer is we can't do nothing. We need to take some steps.

And the challenge here and also the silos, in a way a lot of these panel sessions are siloed themselves, and this is an opportunity to have a discussion to bring some of this together. So if we think sort of 10 years out and where we may be evolving to or maybe even more importantly, where we hope to evolve.

I mean, if you knew exactly what it would like in 10 years, if you had the money, you could make some investments. But I think it's going to where we want to go, where we could go. And then what are some aspects of our ecosystem or our processes, frankly, that we should get a jumpstart on.

And, you know, I mean, this collectively for the ecosystem, but frankly, for the spectrum regulators and policymakers, too. Because at the end of the day, we need to enable this. And we need to do it collectively. So this is, as you said there, Doug, the challenge of this ISART and why this was teed up. And now we have a chance to maybe think about a little bit of a roadmap, if you will. And again, I know we can't address everything, but maybe some key points, key thoughts or points that folks have. And I guess for simplicity, I'll just go back to the original order.

Eric, I'll turn to you first, your thoughts and then. And again, if folks want to build off what someone else says or ask them a question, of course, do that as well, too. Thanks. So, Eric, you need to come off mute.

Eric Nelson: I don't remember hitting that button. Sorry about that. Yeah, thank you. Kind of going back to a comment Billy made, I think to look forward 10 years, we really have to kind of start with rulemaking and go backwards.

And one of the things that's been kind of a constant part of discussion, that folks at ITS have kicked around, what's worked over the years? There are things that we know take time. Billy's in the propagation space and he'll tell you it takes a good 3 to 5 years to put together a good model to get the data, develop the model, to validate it, and then to get stakeholder acceptance of it.

So if you need that model, you really need to start laying the foundation to get those building blocks in place. Propagation is probably the longest pole in the tent, but the EMC models as well. There's a plethora of models in the AW3 band. I think I counted at one point like eight different models for exactly the same thing, and really none of them had been validated.

You have to really highlight the work that Defense Information Systems Agency (DISA) Defense Spectrum Organization (DSO) did with their Spectrum Sharing Test and Demonstration program. We [ITS] proposed the idea of what are some experiments that could be done to validate those models? And we used AWS-1 as a proxy, it's an adjacent band. And so now we have that experience.

We can look at other bands that are similar in nature and technology and maybe drive experience from them. But we also know that it takes a year or two to pull together a framework. And each time we do this, we should be building validation in and we should be building in standardization, not just the propagation models, but also standardization of the EMC models. We really, really need to drive toward a common framework of modeling tools.

I think as you go through all the discussions, each band has its own particular needs and incumbencies that you go back to, like the risk-informed assessment. Those key parameters are going to vary from one incumbent type to the next in. And we shouldn't forget as well, for spectrum sharing we need to be looking at the commercial side. What is the impact of the incumbent on the commercial receiver?

And that's work that the Hill Air Force Base project that Department of Defense (DoD) is running, saying what effect will the commercial system have on the DoD radars. But vice versa, radars put out a lot of power. So we want to also understand that. So I think with each one of these, we're gaining additional knowledge. We are with time, gaining confidence in various building blocks.

And we're getting a better understanding of how long it takes to develop them. We really have to kind of lay those all out on Gantt chart and say, well, if this takes three years, let's get started now. Let's get the resources that we need. Make the argument to the appropriators to get those resources, get that research started.

And it's not just something that ITS does; there's the National Science Foundation, there's industry, this is a joint research effort. These models ultimately have to have stakeholder acceptance and the agencies need to be at the table developing them as well. But, we've got the tools and a lot of experience here in the last 10 years to really take a look back and figure out where we stand and how we can keep drilling down and improving the toolkits and getting them standardized and getting them accepted and making them available for everyone to use, which is going to speed this process up.

And that's ultimately what we're trying to accomplish.

Derek Khlopin: Thank you, Eric. Now, that's good. I mean, you hit on, I think, one of the fundamental challenges, where we want to standardize these processes as much as we can, while at the same time you have the variables with particular bands. And trying to minimize what those variables are will help provide some of that ongoing consistency.

Really good points there. Giulia, I'll turn to you next for some thoughts on this sort of future looking question. Thanks.

Giulia McHenry: Thanks, Derek. It's a very good question. And, I think I would like to just amplify the concept to the extent we want to be thinking in the future several years. Particularly when we're thinking about any federal agency, one of the important issues will be funding. And so certainly that is an aspect and I think that's one, turning to our panel, that Edgar Rivas raised. But I think some sort of funding streams, and we know where the funding comes in D.C., would be very helpful to enable that sort of future-looking research that I think we need to be taking these more iterative approaches and individual steps.

But looking at our panel, I will say one of the major takeaways more broadly, I think from my experience has been that you've got to start thinking pretty specifically before you can really start to implement something. So I think looking for where are the opportunities to make this happen in the future.

Where are the bands? I think that would that's going to be an important question looking down the line. And thinking about them from more of an economic perspective so that by the time we get to the economics and the auctions and how to assign it, we're really thinking about a band. So coming up with some applications I think could be very helpful.

But I think all of these baby steps—getting better research, putting together agreed upon models of interference—all of these pieces will become important. And then, thinking about the economics, I think we need to think hard about How do we keep the value of the spectrum? As we're thinking through applications, recognizing that uncertainty, particularly in certain contexts, can alter the value of the spectrum. So, thinking about how can we continue to create sufficient certainty and understand better from industry where they need certainty and from the agencies where they need certainty to find that middle ground, where there might be room for more of an iterative approach. I think I'm going to stop there.

Derek Khlopin: Yeah. That's great, Giulia. I really appreciate your response. Ed, I'll turn it to you next.

Ed Oughton: Thank you, Derek. I think my experience in policy is that we're always very reactionary to the next thing that we need to work on. That means the data collection is very reactionary. So, we need to make a decision in government, we need to go out and get some data if we don't have it. And that means we need to ask operators for the data and we need to get that in some sort of standard way that is public, hopefully anonymous and also allows you to aggregate it together. I think that there is something exciting in here if there isn't already some sort of framework to do this where we can, hopefully, capture more of this data because of the ongoing virtualization infrastructure. And I think, just picking up on the point that Doug made about moving towards an iterative regulatory process, in my eyes, that means potentially integrating more real-time data because you're going to have the data in real time, as there is this whole area now of mulcasting, where you are integrating multimodal data. So we see this in economics, we've done it with shipping data.

I've done work using satellite data to estimate mobile users spatially and because there's such amazing new dimensions to all of these data sources, we're getting spatial technical imagery at multiple revisitation rates per day. There's all these new types of data and we could combine that with other spectrum data that will be able to get stored in the cloud.

So I think that there's a lot of scope to be had here if researchers can work out how the pieces to puzzle fit together, essentially. So that ultimately we can get meaning from all these different data sources. That's an exciting challenge for researchers, but I think also my experience in government tells me there would really be beneficial outcomes in having evidence on spectrum usage across time, space, [indiscernible], and things like this, because I don't see that currently in play at the moment.

So, over to you Derek. Thank you.

Derek Khlopin: Thank you. Great. I appreciate that. And JP, I'll return to you in a second here. I'm going to just add in the mix here a question that came in from a participant on do we need a new President's Council of Advisors on Science and Technology (PCAST) report? So, I think that comes up. I thought about that. I can't believe it's been a decade.

So that was actually 2012. And, that report, for folks who remember, had some other good impacts including I think being some of the key thinking for CBRS even. So, just for folks if they want to put that in the back of their minds, too, as they're responding. But, JP, I'll turn to you next. Thanks.

JP de Vries: Thank you. Yeah. So, the question of what are things going to look like in 10 years? The cynical answer is pretty much like they look today, because, you know, actually, I'm spending time on the FCC's receivers notice of inquiry. The last one they did was 2003 which is 20 years ago, near as damn it.

So the glass half full view though, and I guess I feel optimistic, is that something does seem to be shifting. But then one doesn't get up in the morning unless you believe that. There are three things that I think looking forward came out of the panel for me. One is how we spread know-how. The second is how we create places to resolve differences.

And the third is a thought about you thinking about risk management when we think about iteration. So to the first point, I mean, one of the things that was very clear in the panel, you asked the obvious question, so what is risk analysis? How do you do it? Give me an example. And the answer is there are lots of ways of doing it, and it depends on the circumstances.

It depends on the problem. It depends on the stakeholders. It depends on many things. But there are people who do this. And so I think one of the things that I hope will happen, particularly in risk analysis, but other fields too, over the next, let's say, five years, is that we actually spread the knowledge. There are other industries and regulated industries that have been doing risk assessment for 40 years.

So there's a lot of know-how that we can benefit from. There are also experts in our field, many of which were on the panel, people like Omar Al-Kalaa, and Nick LaSorte, and Rob Henry, and Kalle Kontson, who are doing risk analysis for spectrum today. But so far, they are the leading edge. So the question is, how do we actually spread the know-how?

One of the things that occurred to me looking at ISART every year these wonderful tutorials. And so maybe there should be an ITS institute, which actually will pick a theme for a year and actually run lectures, curriculum. You know, actually, if you want to do a risk analysis, just go and look on the people who spoke on the panel as your faculty. And put together a way for the community to get educated and then to share experiences.

Then the second point I wanted to make, and this was about resolving differences. This is an idea that Kumar Balachandran raised, which is obviously when one does risk assessment or coexistence in general, different people interpret the results of their studies differently. And it takes time to resolve that within a particular industry. So for example, within 3rd Generation Partnership Project (3GPP), there are long arguments that go on a lot, you know, people bring their models, they differ, in the end, maybe you sort of like pick a number in the middle somewhere. It's much harder when we're talking about different industries. There aren't standards bodies that I know of that really cross communication and aviation, for example, or communications and radar,or radar and earth observation science.

Every country is different. Every region is different. The Europeans, though, have a mechanism that has worked. In some cases, they have the European [that is, Electronic] Communications Committee (ECC) that brings together people. They do studies in Europe. They have ETSI (European Technical Standards Institute), which is actually supported by the European Commission [European Communications Office (ECO)]. But it's not a European Union thing, but it's a place where everybody can come together and develop standards.

So the question going forward is where do those kinds of conversations happen in the U.S.? There are places where they do happen. CSMAC (Commerce Spectrum Management Advisory Committee) is one place, but a related question that came up in our panel several times is this takes resources. It came up today as well. People have to invest a lot of time. And so it's not something, to some extent, we try and get things for free. We get the TAC (Technological Advisory Council)—a bunch of volunteers, CSMAC—a bunch of volunteers. Do we have secretariats to really support them? How do we do this going forward?

The third point I wanted to make was to talk about risk management, which is something that the panel didn't really get into. It was one of the many topics we only touched on, but we talked about risk assessment, which is what you do beforehand. Then once you have a deployment, you need to keep managing the risk because stuff will happen and stuff will change.

And the philosophy of risk management, I think, is something we can learn from. It also links in with the whole question of enforcement and remediation. Things will change. They get better sometimes; they get worse sometimes. We had examples of both. And so how do you accommodate those? One speculation or way is you might think about having more flexible rules.

Obviously, you don't want to give the FCC the ability to say, we've changed our mind; the rules have just changed. But you might be able to do some of that at least through a risk management process or perhaps even through an enforcement process.

Derek Khlopin: Thank you. That's great. I'm going to keep it rolling here. Billy, to you. Thanks.

Billy Kozma: Yes, thanks. I think the one thing that kept being touched on and that has been proven in the past is really the idea of openness. And I would even press farther to perhaps than how our panelists said it. They talked many times about openness between the organizations working the problem. I would even venture to some extent to go farther out on the limb and say even openness to the public.

So, Chrysanthos Chrysanthou of the FCC talked about how he got his start working with Bertoni [mid-1980s at Polytechnic University with Dr. Bertoni] and some of that work was around overbuilding, diffraction and stuff decades ago. It was a good idea. And then you had this idea, this theory being developed, and now only in the past five years, maybe, you have essentially coming into a world of people sharing for free, ubiquitous Lidar data [Lidar—Light Detection and Ranging—is a remote sensing method used to examine the surface of the Earth].

And now you have the information of where buildings are and vegetation is. Now you have this theory that was being developed, people sharing in a different field; the information is open. And he talked about how the FCC was working on modeling, applying this to this sort of data. And so the more open we are, and not openness just at the end of the process publishing the final model or the final standard in 3GPP or an International Telecommunication Union (ITU) Study Group 3 recommendation, but incrementally in their steps—publishing and being open both with your measurement data and your validation sets and the modeling approaches, even if they're not complete.

But the progress being made I think is important because you can get a cross-pollination of different fields. Like we're very specialized but engineers. It breaks the stereotype a little bit, but when you really talk to them, there's a lot of creativity and a lot of ideas. And they say, "Well, if I only had this from over here, or this from over here."

And I think really a lot of improvements are going become some of that cross-pollination of different fields, not just propagation. You have to look at the bigger picture. We're sharing data. Other people are sharing data. And I think that's going to facilitate a lot of new ideas and new ways to approach problems and solve them.

And that's really going to be critical. And then by putting it all out there ourselves, like I said, incrementally, allows people like Dr. Salous in universities, or I didn't see the panel before this one but I know there's a bunch of people in universities, then to essentially come in unbiased and take a look at this data and run their own analysis, run their own simulations on this and give feedback. Now, when you are open, you introduce noise into the system and that's a risk we just have to manage. But there's a lot of upside benefits to doing that. I think we are moving slowly in that direction, but I think that's going to really help us make some gains into this kind of iterative process.

Derek Khlopin: Thank you. That's great. So, Doug, I'll give you a chance to kind of bring us home here. And then I will give everybody a 30-second lightning round if they want to make final comments.

Doug Sicker: Thanks, Derek. I hope my audio is doing better. I apologize for that. I want to start with the other question that came in the PCAST report. Yes, I think it's time for a new PCAST report and I'll explain why. We had the National Broadband Plan that had a heavily licensed view of spectrum and moving that ahead.

And we had PCAST, which was a very different view. I think it's time to set this kind of national strategy and these types of reports are perfect for it. They get the ball rolling. They almost never live up to their potential. They almost never cover all of the things that you want that comes out of them.

But at the very least, it goes to that point that was raised before, which is we have a very distributed set of entities working in very distributed silos. We have research that's funded, but in a non-coordinated manner. We have opposing interests. So we need something to set the tone. If we're going to say we're moving toward a more iterative and a more dynamic spectrum management policy, we're going to have to start and say, well, what do we mean by that?

And I think that kind of report, a national report could do that. Then, I think from a technology perspective, this is a hard nut to crack. As technologists, we dig in and try to solve problems. And they might be problems that have small impact. It might be a problem that has a huge impact.

So we need to understand where in the bands, and what should we be doing, and what technical problems should we be solving? And really invest nationally in that so that we can build understanding of risk and improve trust and do all the other things. But we need to start it now. So that when the time comes for whether it's gigahertz spectrum, or a reallocation of lower bands, or whatever it might be, that we have some meaningful data and something to have some faith in.

But I don't think we're going to be able to do any of these sorts of things without a framework at a national level to say, let's start moving ahead. And these are the challenges, these are the opportunities. Let's pick a few of them. We'll get DoD and NSF and others to coordinate and use ITS as a mechanism as well to try to say, hey, we've got great technology, where does this fit in? And we know that we're underutilizing the spectrum. Let's change that.

Derek Khlopin: That's great. Thank you. Yeah, the issue of coordination just has to be the key. I know it's come up a little bit, but at NTIA with the administration, we really are going to, produce a national spectrum strategy. And it's been elusive and it's hard. And I think that's a key part.

But I hear this as we want to break down these barriers and bring things together, we talk about R&D and spectrum sharing. So I know that's a hard task in front of us. I think the funding one is, again, to silos. We all have our individual funding requests and we go through the appropriations process.

We have hearings. There's markups this week on the Hill and we have our IIC [Incumbent Informing Capability] and there's so many funding requirements pulling from the SRF [Spectrum Relocation Fund] here. You know, we've had this dream for years of how we put more money from spectrum auctions back actually into the spectrum regulatory processes. And that's been a challenge.

Because the Capitol/the Hill wants lots of money for other things including deficit reduction. So a lot there. And the other one I think of is talent. I mean, obviously, all of us participate in some of these events and are really working on trying to bring in the next generation, the younger generation of expertise.

We need a lot of it and we need it a lot of it in a lot of different places. So I want to thank everyone unless anyone has a quick little comment they want to make. I think Giulia is waving her hand.

Giulia McHenry: Thanks, Derek. This is a follow up to Pierre [JP] and Doug's points. I think actually one of the things that came up on our panel, which I actually really liked as a proposal, was from Carolyn Kahn who talked about using an agile approach to spectrum management. And I think that concept is neat, particularly because as the government knows what it means, but you know that almost in many ways provides like a framework within which to have this conversation.

And an answer to, how do we do this quick, or how do we create an interim approach? And I think it was highly insightful for her to have thought about that. And I just want to highlight that when we're thinking about what's the process or what's the framework that we put in something that's iterative, the agile process actually works nicely.

Derek Khlopin: Yeah. Great, point. Anybody else.

JP de Vries: Yeah. Just to pick up on, on that point about agile, it's an interesting one. You know, we will have lots of scrums [laughter]. Actually, since one of my traditions is to always disagree with Doug no matter what he says, no matter how good his ideas are. Let me say that we don't need another PCAST report.

Actually, we do. But for the sake of argument, what these reports give us is feast and famine. We have this big strategy and then 10 years pass and then there's nothing and then, oh, my God, we've got another strategy. I think what would be helpful is what Julia just said, which is to have a process where we get together not every two weeks, but whatever, where we actually iteratively have a set of plans that get updated every year.

Now, that takes a lot of work and takes a lot of time. And where is the money going to come from? But I think that would be much more useful in the long run than doing something big every 10 or 20 years.

Doug Sicker: I stand corrected as always with JP.

Derek Khlopin: That's great. In our conversations on a strategy, we actually agree in the sense that it's really the implementation plan and implementation that's more important than the strategy itself. Because if you produce a nice strategy and it sits on a shelf you have to actually...

Doug Sicker: Yeah. So again, the value of PCAST reports or any of these sorts of things is it's a top-down sort of thing. Everyone kind of looks at it, you can cross agencies that's real. But I agree. I think Julia's approach is right too. I also like the term agile far better than iterative. As a computer scientist iterative means to a point of with an end. That you do it to [as in conditional or count controlled iterations]. And so iterative doesn't work for me but agile, I like that. I like that kind of perspective.

Derek Khlopin: Awesome. Thank you. Well, I know we are out of time, so I'm going to have to wrap here. I did want to say we did put the poll out there on whether this iterative process would be beneficial: 55 percent say it would be beneficial. At the same time, 56 percent say it's a little risky.

I want to thank all of the panelists. This was a great conversation, a great wrap-up. I think we do have a final wrap-up coming here. But thank you, everyone. And enjoy the rest of the day.

6.5 Closing Remarks

Eric Nelson, Director (Acting), NTIA Institute for Telecommunication Sciences

Eric Nelson: Okay. So we find ourselves at the close of another ISART. We wish we could do these every year. They're extremely valuable. We certainly hope this conference has been informative to you all.

As we heard from Assistant Secretary Davidson, the National Telecommunications and Information Administration (NTIA) is involved in the development of a national spectrum strategy and is updating the MOU between NTIA and Federal Communications Commission (FCC). This is critical to establish ground rules and a framework to work within going forward.

We covered all the factors this week to work within that framework to evolve spectrum sharing and regulation, industry lessons learned, economic factors, data sharing and transparency, risk-informed interference and analysis, model standardization, and technical enablers. And like I pointed out in the wrap-up panel, I really think that, going forward, we need to combine all of these and make them active considerations in all the future [spectrum] sharing studies that we do going forward.

Clearly, there's a lot to digest here. It's time to reflect further how to move forward. So, months of planning are required to organize a conference of this nature. So I want to highlight those efforts.

Our technical chair, Mike Cotton, from the Institute for Telecommunication Sciences (ITS), has been our go-to guy for ISART going back to 2010. Mike leads the Telecommunications Theory Division at ITS. That group oversees research on a host of internally- and externally-funded programs in its focus on spectrum sharing, ranging from electromagnetic compatibility, modeling and analysis, propagation modeling to spectrum monitoring. And they also support NTIA's Office Spectrum Management (OSM) in their research support needs. Mike took the lead in developing the conference theme and provided us a comprehensive framework for consideration.

Our General Chair, Rebecca Dorch, is ITS's Senior Spectrum Policy Analyst. Rebecca brings both legal training and a background at the FCC's Enforcement Bureau to the table. Rebecca oversaw the entire planning process and, believe me, there's a lot of work there, and she worked extensively with Mike to flesh out this year's theme and program. Her policy analysis background was critical in coordinating with the policymakers in Washington to ensure that we push the envelope but keep within legal bounds that are available to us.

ITS's Publications Officer worked behind the scenes, assisting with logistics, contracting, the website, scheduling and, of course, editing the conference materials. So, thank you to Lilli Segre for that assistance.

The Technical Committee was instrumental in calibrating this year's program and bringing additional experience and perspective to our attention. Dr. Greg Wagner and Joy Cantalupo of the Defense Spectrum Organization (DSO), as well as newly retired Howard McDonald, formerly of the Defense Spectrum Organization, have worked in this space for years and could point to successes in Advanced Wireless Services-3 (AWS-3; comprising the 1755 to 1780 MHz and 2155 to 2180 MHz bands), with the Spectrum Sharing Test and Demonstration (SSTD) program, and helped us extrapolate to more agile processes.

Finally, Dr. John Chapin, Special Advisor for Spectrum, National Science Foundation (NSF), brought perspective gleaned in industry, academia, and government to our attention. John could always be counted on to weave together a lot of ideas, which often made us pause and reformulate the program as we developed it.

So, special thanks to the Planning Committee. Excellent job!

Our session moderators also did a lot of heavy lifting. Working from our initial call for input, they too added their perspectives and honed the topics. They called their networks and plowed through the literature to identify speakers who could address these topics. Most importantly—and it was quite evident all these conference sessions—they exercised intellectual honesty in making sure that diverse viewpoints were reflected—viewpoints that sometimes didn't agree with their own.

So thank you to Rebecca Dorch, Bryan Tramont, Giulia McHenry, Edward Oughton, JP de Vries, Billy Kozma, Doug Sicker, and in our wrap-up, Derek Khlopin, for helping us pull together all these sessions.

Our keynote speakers, Charles Cooper, Evan Kwerel, and Fred Moorefield provided us excellent viewpoints from their work in spectrum management, economics, and defense communications. Thank you to you too.

Next, thanks are in order for our panelists, who are, unfortunately, too numerous to call by name. As I mentioned in my opening remarks, ISART differs from many technical conferences in that we bring in subject matter experts and ask them to focus on the focus on the prescribed themes. Naturally, we draw from their work experience and research, but many times they don't have ready-made material and have to spend a considerable amount of time pondering their contributions. It was obvious they did their homework. This has been an exceptional four days of discussion. Finally, thanks to the audience for the excellent engagement, provocative questions, and feedback. We have a lot of homework to do. Excellent job to all.

So where do we go from here? Well, the planning committee will be conducting a hot wash. Obviously, we will capture items related to the mechanics of the conference. Moreover, we're going to review all of the questions and all of the answers that were given, capture the best points, revisit the call for input and document what we've learned.

ITS's annual research planning cycle kicks off in about a month, and the findings will definitely be considered there. We'll also be coordinating with OSM on topics that might be integrated into our research support for OSM. Finally, we'll consider ideas generated here at ISART 2022 that were particularly promising and make sure they get into our after-action summary.

It's not too late to share your perspective. Please let us know how we did. And also share your thoughts on how we might move forward, both with the conference itself and with respect to this year's theme.

Finally, let's talk ISART 2023. As I mentioned in my opening remarks, next year's conference will be coordinated with ITU-R (International Telecommunication Union Radio Communication Sector) Study Group 3 Working Party Meetings—boy, that's a mouthful—and the topic will be radiowave propagation. If you work in this space, we'd like to hear from you. We will start planning ISART 2023 tomorrow.

With that, thank you all. And see you next year here in Boulder. Take care.

NTIA FORM 29
(4-80)

U.S. DEPARTMENT OF COMMERCE
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION NO. SP-24-573	2. Government Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE ISART 2022: Proceedings of the 19th International Symposium on Advanced Radio Technologies: Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making		5. Publication Date August 2024 6. Performing Organization Code NTIA/ITS.D
7. AUTHOR(S) Institute for Telecommunication Sciences		9. Project/Task/Work Unit No. 3102012-300
8. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Telecommunication Sciences National Telecommunications and Information Administration U.S. Department of Commerce 325 Broadway Boulder, CO 80305		10. Contract/Grant Number.
11. Sponsoring Organization Name and Address National Telecommunications & Information Administration Herbert C. Hoover Building 1401 Constitution Ave., NW Washington, DC 20230		12. Type of Report and Period Covered
14. SUPPLEMENTARY NOTES		

15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The topic of the 2022 International Symposium on Advanced Radio Technologies™ (ISART 2022), which took place fully virtually June 13, 14, 15, and 16, 2022, was “Evolving Spectrum-Sharing Regulation through Data-, Science-, and Technology-Driven Analysis and Decision-making.” The stated goal was to chart a roadmap and gain consensus for technical and regulatory means that can foster spectrum sharing innovation, optimization, and economic opportunity. Pre-recorded tutorials provide six overviews of the current U.S. regulatory process to establish spectrum sharing and overviews of four lessons learned from use cases and past regulatory efforts. The symposium featured NTIA Assistant Secretary Alan Davidson; three keynote addresses; two technical presentations; and six technically substantiative panels designed to present viewpoints of multiple stakeholders, including industry experts, technologists, scientists, and government representatives. A wrap-up panel identified key conference takeaways and potential next steps for ways to consider actualizing a national strategy for spectrum sharing. The text of these proceedings is taken from transcriptions of video recordings. A best effort has been made to correct spellings of names and terms of art, but it is not an “edited” transcript.

16. Key Words (Alphabetical order, separated by semicolons)

Advanced Wireless Services-1 (AWS-1); Advanced Wireless Services-3 (AWS-3); Citizens Broadband Radio Service (CBRS); Federal Communications Commission (FCC); Department of Defense (DoD); Interdepartment Radio Advisory Committee (IRAC); interference; propagation modeling; spectrum auction; spectrum management; TV White Spaces; U-NII, usufructuary rights

17. AVAILABILITY STATEMENT	18. Security Class. (This report)	20. Number of pages
☒ UNLIMITED.	Unclassified	269
☐ FOR OFFICIAL DISTRIBUTION.	19. Security Class. (This page) Unclassified	21. Price: N/A

NTIA FORMAL PUBLICATION SERIES

NTIA MONOGRAPH (MG)

A scholarly, professionally oriented publication dealing with state-of-the-art research or an authoritative treatment of a broad area. Expected to have long-lasting value.

NTIA SPECIAL PUBLICATION (SP)

Conference proceedings, bibliographies, selected speeches, course and instructional materials, directories, and major studies mandated by Congress.

NTIA REPORT (TR)

Important contributions to existing knowledge of less breadth than a monograph, such as results of completed projects and major activities.

JOINT NTIA/OTHER-AGENCY REPORT (JR)

This report receives both local NTIA and other agency review. Both agencies' logos and report series numbering appear on the cover.

NTIA SOFTWARE & DATA PRODUCTS (SD)

Software such as programs, test data, and sound/video files. This series can be used to transfer technology to U.S. industry.

NTIA HANDBOOK (HB)

Information pertaining to technical procedures, reference and data guides, and formal user's manuals that are expected to be pertinent for a long time.

NTIA TECHNICAL MEMORANDUM (TM)

Technical information typically of less breadth than an NTIA Report. The series includes data, preliminary project results, and information for a specific, limited audience.

For information about NTIA publications, contact the NTIA/ITS Technical Publications Office at 325 Broadway, Boulder, CO, 80305 Tel. (303) 497-3572 or e-mail ITSinfo@ntia.gov.