2014

Technical Progress Report
Institute for Telecommunication Sciences
Boulder, Colorado

U.S. DEPARTMENT OF COMMERCE
NTIA
NATIONAL TELECOMMUNICATIONS & INFORMATION ADMINISTRATION

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Institute for Telecommunication Sciences
FY 2014 Technical Progress Report

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Assistant Secretary for Communications and Information
National Telecommunications and Information Administration
United States Department of Commerce

March 2015

“Scientific research supported by the Federal Government catalyzes innovative breakthroughs that drive our economy”.[1]

The Institute for Telecommunication Sciences is an Office of the National Telecommunications and Information Administration, an agency of the United States Department of Commerce.

The Department of Commerce creates the conditions for economic growth and opportunity by promoting innovation, entrepreneurship, competitiveness, and stewardship informed by world-class scientific research and information

The National Telecommunications and Information Administration serves as the President's principal adviser on telecommunications and information policy matters, and develops forward-looking spectrum policies that ensure efficient and effective spectrum access and use.

The Institute for Telecommunication Sciences performs telecommunications research, conducts cooperative research and development with U.S. industry and academia, and provides technical engineering support to NTIA and other Federal agencies.

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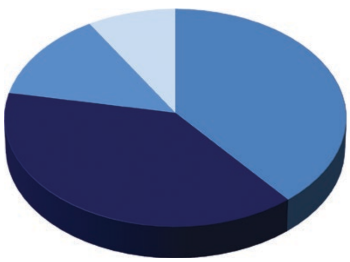
1. Executive Office of the President. Office of Science and Technology Policy. Memorandum for the Heads of Executive Departments and Agencies, Increasing Access to the Results of Federally Funded Scientific Research, February 22, 2013. (Accessed http://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf December 9, 2014.)

Contents

> *"The Nation benefits from Federal government funding for basic and applied research in areas in which the private sector does not have the economic incentive to invest and a public benefit exists."*[1]

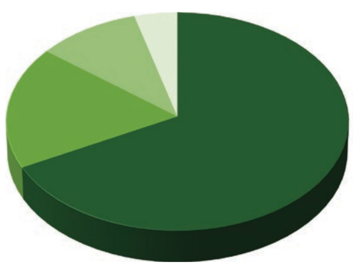
At a Glance ...

Research Areas Funded in FY 2014



- Enhancing Spectrum Utilization
- Public Safety Communications Interoperability
- Improving Telecommunications Network Performance
- Propagation Modeling

Research Funding Sources in FY 2014



- Interagency Agreements
- Direct Appropriation
- Fees
- CRADAs

Tech Transfer in FY 2014

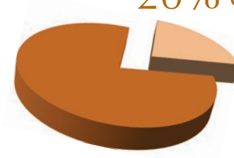
ITS participated in 60 CRADAs

685 people downloaded the VQM software

Other software/data were downloaded 1206 times

ITS publications were downloaded 7705 times

184 people downloaded video from CDVL



20% of CRADAs were with small businesses

1. Executive Office of the President of the United States, Memorandum for the Heads of Executive Departments and Agencies, Science and Technology Priorities for the FY 2015 Budget, July 26, 2013. Accessed http://www.whitehouse.gov/sites/default/files/omb/memoranda/2013/m-13-16.pdf December 8, 2014.

The Institute for Telecommunication Sciences

The Institute for Telecommunication Sciences (ITS) serves as a principal Federal resource for the conduct of basic research on the nature of radio waves, generating and communicating new scientific understanding of cutting-edge telecommunications technology and systems to promote continuous improvement of telecommunications network performance. ITS is the research and engineering laboratory of The National Telecommunications and Information Administration (NTIA), an agency of the Department of Commerce (DoC). It is located on the Department of Commerce Boulder Laboratories campus in Colorado, sharing advanced laboratory and test facilities with the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA).

ITS research supports the Department of Commerce key strategy of fostering advanced communications technologies to strengthen the Nation's digital economy. ITS is recognized as one of the world's leading telecommunication research laboratories.

- Basic research enhances scientific knowledge and understanding in cutting-edge areas of telecommunications and information technology to improve the performance of telecommunications networks.
- Applied research, testing, and evaluation help drive innovation and development of advanced technologies and services, contribute to improving public safety communications, provide technical input to NTIA policy development and spectrum management, and help to resolve specific telecommunications problems of other Federal agencies and state and local governments.
- Cooperative research and development agreements (CRADAs) with industry and academia leverage Federal research resources by providing technical assistance to the private sector that promotes innovation, entrepreneurship, and commercialization.
- Leadership and technical contributions to national and international telecommunications fora help influence development of standards and policies to support the full and fair competitiveness of the U.S. communications and information technology sectors.

Areas of Research

- **Enhancing Spectrum Utilization:** Design, develop, and operate state-of-the-art systems to measure spectrum occupancy trends and emission characteristics of Federal transmitter systems, and to identify, analyze, and resolve radio frequency interference in Federal systems; perform measurements and analysis to improve spectrum management practices and policies, troubleshoot and resolve interference issues, and define technical parameters such as transmitter emission limits, frequency offsets, or separation distances for proposed rulemakings in support of new spectrum uses/sharing requirements.
- **Public Safety Communications Interoperability:** Systems engineering, planning, and testing of interoperable communications systems (e.g., voice, video, and data) to foster nationwide first-responder communications inter-connectivity and interoperability at Federal, state, local, and tribal levels.
- **Improving Telecommunications Network Performance:** Investigate and assess broadband wireless telecommunications system components, evaluate network survivability, and assess system effectiveness in national security, emergency preparedness, military, and commercial environments.
- **Propagation Modeling:** Develop and validate, through scientific theory and measurements, improved radio propagation models for various radio bands and environments and promulgate them to industry, other agencies, and national and international standard bodies. Apply these and existing propagation models towards the assessment of new spectrum sharing techniques and the development of improved dynamic frequency management and spectrum sharing systems.

Accomplishments

ITS telecommunication engineering studies support the Department of Commerce strategic objective to increase scientific knowledge and provide information to stakeholders to support economic growth and to improve innovation, technology, and public safety. These research and engineering efforts provide new, expanded scientific understanding of telecommunications technologies and systems to enable improved telecommunications performance and optimization of Federal agencies' use of spectrum for communications, radars, and satellites. The results of ITS research help promote a more agile regulatory environment and position U.S. industry for international leadership in telecommunications technology.

Center for Advanced Communications (CAC)

In May of 2013, NTIA and the National Institute of Standards and Technology (NIST) entered into a formal agreement to document their intent to collaborate in the establishment of a new Center for Advanced Communications (CAC). The goal of the CAC is to leverage the critical mass of NIST and NTIA research and engineering capabilities concentrated in the Department of Commerce Boulder Laboratories to

- Promote the development of innovative spectrum sharing technologies that are crucial to efforts currently underway to identify 500 MHz of spectrum for mobile broadband wireless uses
- Develop and promote the technologies and best practices that are essential to hardening the Nation's communications infrastructure to withstand the threats of natural disasters, cyber attacks, and terrorism
- Provide a single focal point for engaging both industry and other government agencies on advanced communication technologies, including testing, validation, and conformity assessment

The Center for Advanced Communications promises to become a unique national asset that will provide the infrastructure necessary for effective engagement and collaboration with industry, academic, and government partners necessary to effectively and efficiently address current and future advanced communications challenges. Initial efforts in fiscal year (FY) 2014 both identified new areas of research to be undertaken and expanded the reach of existing projects through multi-disciplinary collaboration.

- Four initial projects were identified in FY 2014 that would benefit from collaboration between ITS researchers and researchers from NIST's Communications Technology Laboratory (CTL), ranging from the refinement of propagation prediction models for improved accuracy in new applications to the development of advanced semi-conductor manufacturing techniques for enabling millimeter wave radio design.
- A new propagation measurement system was developed and applied to assess propagation losses due to clutter (i.e., man-made structures and foliage). Measurement data produced by this system supported Federal Communications Commission (FCC) rulemakings to implement an innovative and comprehensive framework to authorize a variety of small cell and other broadband uses of the 3.5 GHz Band on a shared basis with incumbent Federal and non-federal users of the band. It also supported similar rulemakings for spectrum sharing between commercial users and Federal incumbents in the AWS-3 bands.
- Remote sensor control and data backhaul capability using commercial-off-the-shelf components was designed, developed, and tested, allowing deployment in FY 2014 of the first operational data collection node on the Spectrum Monitoring Sensor Network, an initiative undertaken in response to the recommendations of the Wireless Spectrum Research and Development Senior Steering Group (WSRD SSG) for using spectrum monitoring, data, and analysis to improve spectrum utilization. The sensor, deployed near Norfolk, VA, will monitor the 3.5 GHz maritime radar band on a continuous long-term basis.
- In FY 2014, ITS engineers began design work on a web-based Spectrum Engineering Tool (SET) that will automatically analyze any interference issues that might be presented by potential sharing scenarios. The work was funded by five agencies that are incumbents in the 1695 MHz and 1755 MHz frequencies that were auctioned beginning on November 15, 2014, and will continue through FY 2019.

Enhancing Spectrum Utilization

NTIA continues to advance strategic initiatives to make additional spectrum available for commercial wireless use and to meet the increasing radio spectrum needs of both Federal and commercial users in the U.S. as efficiently and effectively as possible. ITS promotes these initiatives by conducting, through ITS's reimbursable authority, engineering studies on behalf of other Federal agencies on in-band and adjacent band interference and interference mitigation techniques. Several such studies were conducted in FY 2014.

- ITS executed a set of urgent electromagnetic compatibility tests between LTE and radar equipment in the 3.5 GHz band in support of an FCC Notice of Public Rulemaking (NPRM). A Navy radar was assessed for susceptibility to interference from proposed LTE systems in the band. In turn, an LTE eNodeB was assessed for tolerance to pulsed radar signals. These measurements made it possible for NTIA/OSM to determine that interference into the radar receiver represented the limiting case for shared use of the band, thereby furthering the rulemaking process by focusing the remaining research efforts.
- Detailed emission spectrum measurements were performed on two Navy radars that use spectrum at 3.5 GHz. The spectrum and pulse-characteristic measurements were published; they show how these radars occupy spectrum that will be shared with new systems pending an FCC rule-making. Publication of these results moved the rule-making process forward.
- Building on the experience of the measurement and modeling effort in the 3.5 GHz band, ITS engineers developed a methodology for synergistic measurement, model-development, and simulation studies to generate reliable interference protection criteria (IPC) for spectrum-sharing in other bands.

Public Safety Communications Interoperability

The Public Safety Communications Research (PSCR) program, a joint effort between ITS and NIST/CTL, addresses four key areas of public safety communications interoperability: (1) development of qualitative and quantitative public safety communication and information-sharing requirements that are accepted nationally by the public safety community and industry; (2) identification and development of interface standards that satisfy defined user requirements through leadership and direct technical contribution to national and international standards bodies focused on public safety communications; (3) research, development, testing, and evaluation of concepts, products, and services for long-term interoperability solutions as well as interim improvements; and (4) research and development to accommodate technical gaps that emerge during the entire process. PSCR operates in close and constant coordination with public safety practitioners to develop standards, technologies, and test methods to ensure interoperability of land mobile radio and broadband systems used by public safety and justice communities, public service, and land transportation agencies and to develop information technology standards that public safety can adopt to ensure interoperability for information sharing.

- Intense participation by PSCR staff in the 3GPP standards development process on behalf of FirstNet during FY 2014 resulted in Proximity Services and Group Communications requirements being included in the final agenda for 3GPP Release 12 and Mission Critical Push to Talk being included in the final agenda for 3GPP Release 13. These features are critical to ensuring that LTE can meet public safety's requirements and a prerequisite to allowing FirstNet to offer mission-critical voice (MCV) on the new Band Class 14 nationwide interoperable public safety communications network when these capabilities become available.
- The Public Safety Broadband Demonstration Network entered into seven new CRADAs; in FY 2014, 51 active CRADAs were in place to allow public safety practitioners and vendors to test the deployment of LTE systems in a multi-vendor environment. Tests were conducted in FY 2014 on Quality of Service, priority, and preemption.

Improving Telecommunications Network Performance

ITS research to improve the performance of the telecommunications network end-to-end includes development and assessment of methods to improve the quality of transmission. ITS is a world leader in the development of subjective and objective measures of transmitted audio and video quality. ITS audio and video laboratories develop and demonstrate perception-based audio and video performance assessment tools for critical new areas including Internet multimedia conferencing, advanced television, and wireless services. The tools, and the advances associated with them, are rapidly transferred to government, industrial, academic, and individual users via the release of NTIA-developed software toolkits and open-literature publications.

- ITS efforts led to a new ITU Recommendation that expands the applicability and reduces the minimum costs of subjective testing of the quality of transmitted media. ITU-T Rec. P.913, "Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment," was approved in January 2014.
- In FY 2014 the Audio Quality Research Program developed two new schemas for assessing the performance of objective estimators of speech intelligibility, audio quality, or video quality. This work has very direct and practical application in understanding when to use, and how extensively to rely on, objective quality estimators.

Propagation Modeling

The ability to accurately predict the behavior of radio waves through propagation modeling is fundamental to the ability to plan wireless communication system deployments, assess spectrum-sharing proposals, and develop improved dynamic frequency management and spectrum-sharing systems. ITS continues to build on almost a century of effort in Department of Commerce radio research labs to develop and validate, through scientific theory and measurements, improved ultrawideband, wideband, broadband, and narrowband radio propagation models for various radio bands and environments and promulgate them to industry, other agencies, and national and international standard bodies.

- The ITS-developed Propagation Modeling Website (PMW) is a customizable collection of propagation models housed in a user-friendly environment on a GIS platform and used by multiple Department of Defense (DoD) agencies. In FY 2014, ITS added significant enhancements to HF and VHF propagation modeling capabilities to the PMW and successfully upgraded the intranet sites of its DoD clients to take full advantage of those enhancements.
- In September 2014, the U.S. sent the largest delegation in recent history to the Working Party meetings of The International Telecommunication Union Radiocommunication Sector (ITU-R) Study Group 3 (SG 3), which proposes international standards for modeling radio propagation. The U.S. delegation, which included six ITS engineers, submitted 17 technical contributions on various engineering issues and subject areas. In particular, ITS engineers volunteered to lead the Correspondence Group on Building Entry Loss. This group is critical to LTE deployment across the world and represents millions if not billions of dollars in potential commercial development.

ITS engineer Paul McKenna (podium, right) chairs a meeting of ITU SG 3-M. Christopher Behm and Patricia Raush (foreground) also participated. Photo by Joel Dumke.

Technology Transfer

Technology transfer to the private sector aims to rapidly integrate Federal research outcomes into the mainstream of the U.S. economy to fuel new economic growth and enhance U.S. competitiveness in the global marketplace. From the Stevenson-Wydler Technology Innovation Act of 1980 to the February 2013 Office of Science and Technology Policy Memorandum on Increasing Access to the Results of Federally Funded Scientific Research, there has been an increasing emphasis on "stimulating improved utilization of federally funded technology developments, including inventions, software, and training technologies, by State and local governments and the private sector.[2]" Innovation fostered through technology transfer multiplies the economic and societal impact of Federal research and development investments.

"Innovation fuels economic growth, the creation of new industries, companies, jobs, products and services, and the global competitiveness of U.S. industries. One driver of successful innovation is technology transfer, in which the private sector adapts Federal research for use in the marketplace."[1]

There has also been a parallel push to leverage research investments within the Government by taking advantage of provisions of the Economy Act of 1932 that allow Federal agencies to use the resources of other agencies through interagency cost-reimbursement agreements. Technology transfer between Federal agencies provides an economical and effective means of leveraging Federal research investments, allowing other agencies to reap the benefits of the expertise, equipment, and facilities of which ITS is the steward.

Federal partners reimburse ITS for the cost of research conducted under an interagency agreement, but—unless restricted or classified—the results are released into the public domain for the benefit of other researchers, both public and private. Interagency agreements thus extend the impact of Federal funding by eliminating duplicate research efforts in Federal laboratories and at the same time making more research available for technology transfer.

ITS is a member of the Federal Laboratory Consortium for Technology Transfer (FLC), a nationwide network of about 300 Federal laboratories organized in 1974 and formally chartered by the Federal Technology Transfer Act of 1986 (FTTA). The FLC provides an interagency forum to develop strategies and opportunities for linking laboratory mission technologies and expertise with the marketplace.

The principal means by which ITS transfers the fruits of federally funded research efforts to the private sector and other government agencies are:

- Cooperative research and development agreements (CRADAs)
- Interagency research and development agreements
- Technical papers and royalty-free data and software releases
- Conferences, workshops, and symposia
- Collaborative standards contributions

ITS world-class facilities and capabilities shared through CRADAs and interagency agreements include:

- Audio and Video Quality Laboratories
- Public Safety RF Laboratory
- Public Safety Audio & Video Laboratories
- Radio Spectrum Measurement System (RSMS)
- Table Mountain Field Site & Radio Quiet Zone
- Propagation Prediction Modeling Services

1. Presidential Memorandum — Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses, October 28, 2011. Accessed http://www.whitehouse.gov/the-press-office/2011/10/28/presidential-memorandum-accelerating-technology-transfer-and-commerciali December 8, 2014.
2. 15 U.S.C. § 3702 (3).

For more information contact: Brian D. Lane, (303) 497-3484, blane@its.bldrdoc.gov

Cooperative Research and Development Agreements

CRADAs provide an extremely flexible vehicle to facilitate the transfer of commercially useful technologies from Federal laboratories to the non-federal sector. They protect proprietary information, grant patent rights, and provide for user licenses to private entities. They also provide the legal basis for shared use of Government facilities and resources with the private sector.

In FY 2014, ITS participated—as it has for a number of years—in CRADAs with private-sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. CRADAs provide insights into industry's needs for productivity growth and competitiveness that enable ITS to adjust the focus and direction of its programs for effectiveness and value. The private industry partner benefits by gaining access to the results of research in commercially important areas that it would not otherwise be able to undertake.

Major contributions to rapid introduction of new socially constructive communications technologies have been achieved through CRADAs in which ITS was a partner. Recent CRADAs have allowed ITS to contribute to the development of new products and services in the areas of high resolution laser radar (LADAR), autonomous networks for unmanned aerial vehicles (UAVs), and broadband air-interface and core network capabilities for Long Term Evolution (LTE) mobile communications.

A PSCR Broadband Demonstration Network antenna panel (right) mounted at 84 meters on this 300 meter tower, plays a role in RF interface bandwidth testing. Photo by Ken Tilley.

Public Safety 700 MHz Broadband Demonstration Agreements

The vast majority of CRADAs ITS has entered into in the past four years are the Public Safety 700 MHz Broadband Demonstration Agreements. These agreements allow vendors, including equipment manufacturers and wireless carriers, who intend to supply 700 MHz LTE equipment and service to public safety organizations to operate various elements of an LTE network in the PSCR test bed and over-the-air (OTA) network (both hosted and managed by ITS) to test interoperability of public safety communications equipment under simulated field conditions, with the participation of public safety practitioners.

At the close of FY 2014, 51 CRADAs were in place under this program. The CRADAs protect the intellectual property of vendors and manufacturers, encouraging participation in testing that simulates real multi-vendor environments in the field. This is the first government or independent facility in the U.S. capable of testing or demonstrating public-safety-specific LTE implementation requirements.

CRADAs for the Use of Table Mountain

Established in 1954, the Table Mountain Field Site and Radio Quiet Zone is a unique radio research facility that is ideal for conducting radio experiments due to its physical characteristics and legal designation as a radio quiet zone. It supports a number of radio research activities—studying the effects of radio propagation on digital signal transmission, environmental and man-made noise; verification of antenna propagation models; and the development of measurement methods needed to assess efficient spectrum occupancy and usage, for example—as well as gravity, magnetism, solar radiation, laser, and other research. The site and its facilities are fully described in the ITS Tools and Facilities section on page 79.

Partnerships and cooperative research activities with other entities are encouraged at the site. In addition to ongoing ITS basic research, other Department of Commerce laboratories collocated on the Boulder Labs campus maintain ongoing research efforts on the site. Other research is performed at Table Mountain by Federal and non-federal entities under specific project agreements. CRADAs allow private industry to use this facility to test and optimize new and improved products prior to bringing them to market and allow access to other research organizations. Access to Table Mountain particularly benefits small businesses, who would otherwise be unable to perform research that may be crucial to bringing a product to market. Interagency agreements allow agencies other than Commerce to also take advantage of this unique Federal resource for testing and research that requires radio quiet. In FY 2014, ITS participated in five CRADAs involving use of the Table Mountain Field site, three of which were with small businesses.

AdHoc UAV Ground Network (AUGNet) Test Bed

The University of Colorado is experimenting with communication networks between low-cost small unmanned aerial vehicles (UAV) similar to model radio-controlled airplanes and ground-based radios. The networking is used to coordinate UAV activities and the goal is to develop autonomous "flocking" where the UAVs collectively and autonomously complete sensing and communication tasks. This project is part of the Ad hoc UAV Ground Network (AUGNet) research activity which is part of the Research and Education Center for Unmanned Vehicles (RECUV) at the University of Colorado. This CRADA allowed the university to use the Table Mountain Field Site as a field location to safely and accurately test these technologies; test data and reports were shared with ITS, providing ITS insights into wireless network operations using commercial-off-the-shelf (COTS) wireless LAN equipment.

A member of the University of Colorado Boulder Small Combined Unmanned Aircraft (SCUA) team launches a craft for a test flight from the Table Mountain Field Site dish antenna platform. One of the two 18.3 meter parabolic dish antennas on the site is visible in the background. Still image taken from a video by Dominique Gaudyn.

Adaptive Tactical Laser System Testing

Nutronics, Inc. develops adaptive optical (AO) system solutions for laser propagation through turbulence. Understanding and controlling laser propagation is critical to development of advanced laser radar and imaging technologies as well as optical communication systems. Nutronics' Adaptive Tactical Laser System (ATLAS) is an innovative variation of a compensated beacon adaptive optics (CBAO) system that provides improved focusing of the beam on the target in high temporal and spatial bandwidth operation. This CRADA allowed Nutronics to safely test the functionality of the ATLAS beam control system during product development. The Table Mountain field site is an ideal test location for laser applications because of its very flat surface and the ability to safely test and evaluate performance over an extended area that encompasses a broad range of turbulence conditions.

Installed Performance of Antennas Under Test

FIRST RF Corporation is a small business that designs and manufactures radio antennas and systems. This CRADA allowed FIRST RF to use the Table Mountain Field Site as a field location to fully test the functionality of new antenna designs during product development. Antennas under test may be used in communications, electronic warfare, direction finding/geolocation, or radar systems for body-borne, ground vehicular, fixed-site, airborne, and space platforms. FY 2014 activity on Table Mountain included testing for new antenna technology being developed under two Small Business Innovative Research (SBIR) programs funded by the U.S. Army. FIRST RF testing makes extensive use of the turntable system.

Laser Radar (LIDAR) Testing

Lockheed Martin Coherent Technologies entered into a CRADA with ITS to engage in field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar at the Table Mountain Field Site. The instruments being tested use light detection and ranging systems (LIDAR), an advanced remote sensing technique that uses pulsed laser light instead of radio waves (radar) to detect particles and varying conditions in the atmosphere. The technology is used, among other things, to improve flight safety by detecting hazardous winds and aircraft wakes. Testing in FY 2014 included exercising lab-grade hardware prior to advancing the technology towards engineering, testing more hardened systems prior to head-to-head field competitions, and testing of more fully engineered systems that allowed almost real-time upgrades to the ladar systems under test. Table Mountain's unique topography provides an excellent setting for collecting test data on systems designed for use in ground or air applications under different atmospheric conditions, while easily varying targets, ranges, and sensor configurations.

Laser Radar (LIDAR) Testing for Degraded Visual Environments

Areté Associates is a small business that develops and produces responsive, innovative, and cost-effective remote sensing solutions. Areté is developing a variety of new technologies to combine imaging from passive electro-optical (EO) sensors and active laser radar (LIDAR) sensors to provide high resolution three-dimensional imagery that can be transmitted over limited bandwidths for the U.S. Department of Defense. This CRADA allowed Areté to use the Table Mountain Field Site as a field location to safely test and demonstrate these technologies in atmospheric conditions and at distances relevant to potential applications.

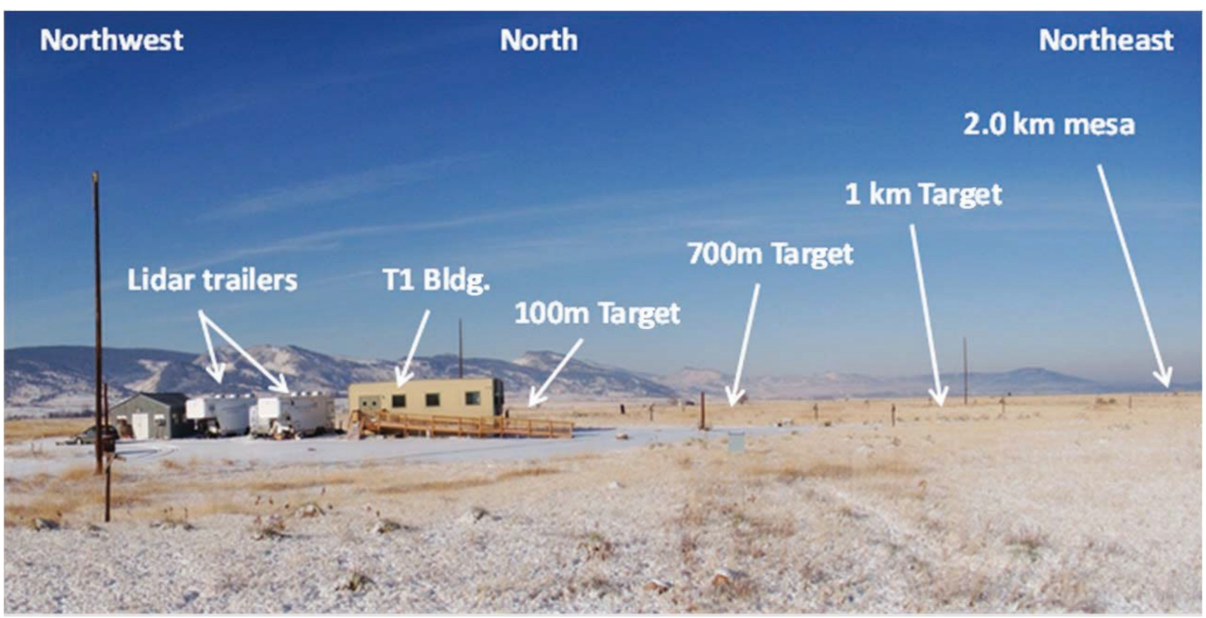


Table Mountain test facility showing Lockheed Martin Coherent Technologies lidar trailers near building T1. Unobstructed target locations from 100 meters to 2 km distant are used to test lidar systems under development in real world environments. Photo courtesy Lockheed Martin Coherent Technologies.

For more information about Table Mountain contact: Wayde Allen, (303) 497-5871, wallen@its.bldrdoc.gov

Interagency Agreements

The Economy Act (31 U.S.C. §1535) authorizes Federal agencies to enter into agreements to obtain supplies or services from another Federal agency. Interagency agreements offer important benefits to Federal agencies, including the ability to leverage unique expert or specialized resources. ITS staff expertise in propagation modeling and ITS-developed propagation modeling software, staff expertise in accurate spectrum measurement and the specialized radio emission measurement equipment of the ITS Radio Spectrum Measurement System, and the Table Mountain Field Site and Radio Quiet Zone are some of the unique resources that ITS makes available for the benefit of other agencies.

In FY 2014, ITS entered into over 30 interagency agreements with 14 different agencies. Research funded under these agreements includes propagation modeling, electromagnetic compatibility and interference analysis of new or proposed systems, development of interference mitigation strategies, and engineering analysis and support for standards development for evolving technologies. Increasingly, such studies support planning for spectrum reallocation or sharing.

Several public safety communications research projects were funded by the First Responder Network Authority (FirstNet), the National Institute of Standards and Technology Communications Technology Laboratory, and different offices of the Department of Homeland Security. ITS tasks under these agreements include engineering analyses, technical feasibility studies of emerging technologies, development and validation of interoperability standards, and laboratory and field measurements.

ITS provided similar services to two Operating Administrations of the Department of Transportation: to the Federal Railroad Administration Office of Research and Development to improve railroad telecommunications efficacy, and to the Federal Highway Administration to determine the potential impact of sharing in bands occupied by that agency's communication systems.

The Department of Defense and the National Weather Service of the National Oceanic and Atmospheric Administration entered into agreements with ITS to use the Institute's unique expertise in propagation modeling to provide specialized radio propagation prediction tools for coverage and interference prediction.

The U.S. Air Force, the U.S. Navy, the U.S. Coast Guard, and the office of Emergency Communications of the Department of Homeland Security entered into various agreements with ITS to perform radio spectrum emission measurements on new or proposed equipment.

For more information about individual agreements see Government Projects on page 90.

Interagency Case Study: ITS Expertise

In January 2007 a National Research Council (NRC) report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," ranked a satellite mission to map global soil moisture on an ongoing basis as the highest national priority for future Earth science and observation missions. Soil moisture (and soil ice content in colder areas) is a primary determinant for plant growth—and thus agricultural productivity. It is fundamental to monitoring, tracking, and predicting drought and desertification over large areas. Its accurate measurement and mapping is critical to forecasting current and future food production capacities worldwide. It also strongly affects weather and climate over continental regions, controls the susceptibility of large land areas to flooding, and has a major effect on human health over wide regions. Accurate, rapidly updated soil moisture data, the report said, were urgently needed for a variety of national and international security purposes.

In 2010, NASA entered into an IA to engage ITS subject matter expertise on interference effects in radar receivers to identify radar waveforms that would not produce interference in terrestrial radars for a proposed orbital radar. ITS provided rapid-response development of custom hardware and software, a scientifically robust test plan, interference tests and measurements, analysis of measurement data, and input into a re-design of the proposed orbital radar that also reduced its cost and complexity. The $85,000 IA with ITS made possible completion of a several hundred million dollar space mission to fulfill a critical national priority.

Building on limited satellite-based soil-moisture mapping demonstration missions, the NRC called for full-up deployment of a highly capable mission that would churn out worldwide soil moisture data with the best possible resolution, sensitivity, area coverage, and update rates. SMAP (Soil Moisture Active Passive) would require two instruments: a passive radiometer and a sophisticated soil moisture mapping radar. The radar would transmit high-power pulses down to the Earth's surface and measure the differential strength of echoes returning from drier and wetter soils. Pulsing hundreds of times every second for years on end while flying more than 600 km (400 mi) above the Earth, the radar would be the beating heart of SMAP; without it, the soil moisture mission would not work.

The best radio band for radar soil moisture measurements happens to be 1200–1400 MHz. Electromagnetic waves at these frequencies penetrate vegetation above the ground and then move fairly deeply into the soil beneath the plant cover. Once they are beneath the surface, they reflect much more strongly from wet soil than from dry soil, obviously a crucially important feature for a soil-mapping mission; SMAP would need to operate in this radio band. But these frequencies, called L-band in the U.S., are also ideal for long-range surveillance and tracking of aircraft by terrestrial radars. Worldwide, many air traffic control, air surveillance, and air defense radars operate in this band.

Studies by ITS (e.g., NTIA Technical Report TR-06-444) had shown that signals from satellite transmitters can be strong enough to interfere with terrestrial radars, masking aircraft and other targets. Even prior to the NRC report U.S. agencies were concerned about possible interference effects from similar space missions. When the L-band SMAP radar was first proposed, objections to the use of such a high-powered orbital radar in that band threatened to kill the project before it could (literally) get off the ground.

An NTIA expert in radar interference effects, consulted about the level of threat posed by the proposed SMAP emissions in 2008, concluded that the SMAP emissions might pose a borderline threat to terrestrial radar operations, potentially masking airborne targets in long-range continental surveillance radars. The extent of the threat was hard to determine because the proposed SMAP time-on to time-off pulse ratio (or duty cycle) fell into a range that had not yet been tested with those types of radars.

The NASA Jet Propulsion Laboratory (JPL) decided that SMAP needed to be put onto a sound footing by definitively identifying radar pulse characteristics that would not interfere with terrestrial radars. In early 2010, JPL and ITS entered into an IA to identify such pulses. Within a month, ITS project engineers developed a plan for measuring the interference characteristics of SMAP-like pulses in long-range radar receivers. They also developed

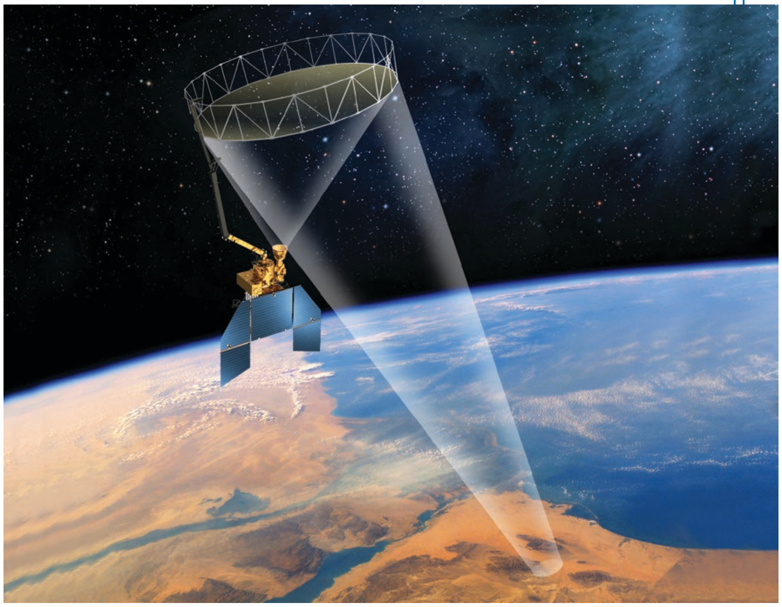
Enables a Critical NASA Space Mission

pulse-generation hardware and software for the tests, verified the performance of the testing system at the ITS Boulder lab, coordinated access to three types of long-range L-band radars at a facility in Oklahoma, and arranged a testing protocol that would progressively work through combinations of pulse widths, intra-pulse frequency-tuning (called chirping), and pulse repetition rates on each type of L-band radar to determine which pulse parameter combinations would cause little (or no) interference to the radars. Testing on all radars was completed in just 10 working days.

ITS and JPL engineers analyzed the acquired data to find combinations of pulse widths, chirps, and repetition rates that would allow the SMAP mission to succeed without interference to terrestrial radars. While it was found that the originally proposed SMAP waveform would cause interference to the radars, some combinations of pulse parameters and judicious frequency hopping were identified that, combined with the intermittent scan pattern of the SMAP radar antenna across the Earth's surface, would cause little to no interference in the terrestrial radars.

Using the information from the data acquisition and analysis, JPL substantially re-engineered the SMAP radar. Not only were SMAP's pulse parameters adjusted, but the radar transmitter was re-designed to use a single high-powered amplifier (HPA) in place of the originally envisioned pair. In the end, the radar would not only cause little or no interference to the terrestrial radars, it would also have a simpler, lighter-weight, and more robust overall design.

After design review with ITS engineers in December 2010, JPL moved forward with fabrication and testing of SMAP, including its radar, and it was launched into orbit at 6:22 AM local time on January 31, 2015, to map worldwide soil moisture for years to come. JPL was able to engage ITS's subject matter experts, expert field-testing engineers, and world-class engineering capabilities where and when those capabilities and expertise were critically needed to make this NASA project possible..



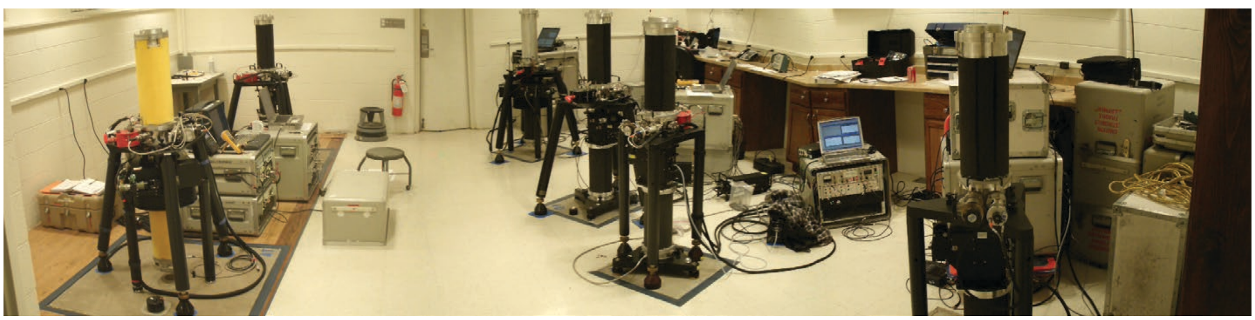
Artist's rendering of the SMAP satellite orbiting 685 km (427 mi) above the Earth with a visualization of the swath of data streaming to Earth on L-band transmissions. Image courtesy of NASA/JPL-Caltech.

SMAP launch from Vandenberg Air Force Base on a Delta II booster at 6:22 AM local time, 31 January 2015. Photograph by Frank Sanders.

Interagency Agreements for the Use of Table Mountain

Other Federal agencies, particularly NOAA and NIST laboratories collocated with ITS on the DoC Boulder Laboratories campus, enter into interagency agreements with NTIA to use the Table Mountain site for research activities to be conducted either by their own or ITS researchers.

NOAA's National Geodetic Survey (NGS) Operations and Analysis Division operates the Table Mountain Geophysical Observatory (TMGO) on the site. In addition to having only a low uniform slope and relatively homogeneous underlying ground, Table Mountain is also seismically quiet, making it a very good location for NGS to base the absolute gravimeter and superconducting gravimeter programs. The programs support NGS's maintenance of the National Spatial Reference System, the GRAV-D program, and other research efforts to monitor temporal gravity change. The observatory has become a major center for intercomparisons of absolute gravity meters, with space for up to ten instruments operating simultaneously on separate and isolated piers. NGS hosted such an intercomparison in September 2014 with six agencies from the U.S. and Canada. NGS also has a Continuously Operating Reference Station (CORS), one of over 2000 stations that provide Global Navigation Satellite System (GNSS, also called GPS) data to support three-dimensional positioning, meteorology, metrology, space weather, and geophysical applications throughout the U.S.



Intercomparison of absolute gravimeters. Photomontage courtesy NGS.

The Central UV Calibration Facility (CUCF), a joint project between NOAA and NIST, provides highly accurate and long-term repeatable calibrations and characterizations of UV monitoring instruments. CUCF's Table Mountain Test Facility has several UV instruments and provides a useful test bed for intercomparisons, including annual spectroradiometer comparisons.

NOAA's Earth System Research Laboratory Global Monitoring Division maintains a SURFRAD (Surface Radiation) Network monitoring station on Table Mountain. SURFRAD stations perform ground-based measurements of upwelling and downwelling solar and infrared radiation; ancillary observations include direct and diffuse solar, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters. Data are available near real time by anonymous FTP and over the Internet. Observations from SURFRAD have been used for evaluating satellite-based estimates of surface radiation and for validating hydrologic, weather prediction, and climate models.

The National Geomagnetism Program of the U.S. Geological Survey (USGS) of the U.S. Department of the Interior operates a Magnetic Observatory on Table Mountain. In addition to serving as a site for routine collection of magnetometer data, the Table Mountain observatory also functions as the Program's test bed for on-going operational developments. USGS data are used to model and map the global magnetic field in cooperation with the international community of geomagnetism and various satellite programs. Regionally, USGS data are used to support aeromagnetic surveys and directional drilling programs for the oil and gas extraction industry. USGS data are also used by the pipeline and electrical power grid industries and for academic studies across a broad range of geophysical sciences.

Technical Publications

Historically, ITS has transferred research results to other researchers, the commercial sector, and government agencies through publication of results either directly as NTIA publications or by submission of articles to peer-reviewed external scientific journals or conferences. Many of these publications—both NTIA reports and monographs and peer-reviewed articles in external venues—have become standard references in several telecommunications areas. "A Guide to the Use of the ITS Irregular Terrain Model [ITM] in the Area Prediction Mode," a 1982 report that describes a radio propagation model for frequencies between 20 MHz and 20 GHz (the Longley–Rice model) developed, validated, and first computerized at ITS, has been among the top five most popular downloads for many years, including FY 2014.

Topic Distribution of FY 2014 Publication Downloads

Spectrum Measurements	25%
Propagation Modeling	23%
Video Quality	21%
Interference Analysis	18%
Audio Quality	6%
Other	6%

Technical publication remains a principal means of ITS technology transfer. Increasingly, these publications are read over the Internet rather than in hard copy. All NTIA publications released since 1978 have been made available through the ITS public Web site as downloadable PDF files. Publication files are tagged with standardized metadata to assist Internet searches, and the ITS Web site offers advanced search capabilities to locate relevant publications by keyword. ITS publication PDFs were downloaded over 7,700 times in FY 2014.

An internal peer review process managed by the ITS Editorial Review Board (ERB) ensures the quality of new publications. In FY 2014, ITS authors published 12 NTIA Technical Reports and Memoranda that were peer-reviewed through the ERB process and six journal articles or conference papers that underwent both ERB review and additional peer review outside ITS.

In addition to formal technical publications, ITS experts are also frequently invited to participate as speakers or presenters at technical conferences, workshops, and symposia. A list of FY 2014 presentations and publications with citations and abstracts begins on page 81.

Conferences, Workshops and Symposia

PSCR Roadmap Workshop

On November 13–15, 2013 the Public Safety Communications Research (PSCR) program hosted a public safety broadband roadmap workshop at the U.S. Department of Commerce Boulder Laboratories for 150 participants representing public safety, industry, government, and academia. The three-day workshop gave participants the opportunity to help shape PSCR's Public Safety Broadband (PSBB) communications research; ideas captured during the workshop will help to inform future PSCR work. The focus of the workshops was to develop technology roadmaps for public safety broadband research and development investments over the next 5-10 years. Participants discussed forward-thinking possibilities for interconnected communications where scene information is instantly shared among responders and where machine learning is enabled by cognitive communication systems to provide quick analysis and reaction to incidents. The outputs of definition and prioritization exercises will guide PSCR's research investments in the near- and mid-term. More information and materials are available at http://www.pscr.gov/about_pscr/highlights/pscr_psbb_roadmap_workshop_112013/2013_pscr_psbb_roadmap_workshop.php.

Interoperability Meetings

ITS Division P hosted the National Council of Statewide Interoperability Coordinators (NCSWIC) and the Wireless Public SAFEty Interoperable COMmunications Project (SAFECOM) Executive Committee meetings in Boulder, CO, February 5 and 6, 2014.

Video Quality in Public Safety Workshop

ITS provided invitational travel support for over 30 public safety practitioners to attend the Fifth Video Quality in Public Safety (VQiPS) conference—sponsored by the Department of Homeland Security Office for Interoperability and Compatibility—in Houston, TX, April 29–May 2, 2014. Attendees were able to learn about new video technology and interact with the global community of first responder video users, manufacturers, and researchers. Case studies and policy discussions gave attendees a shared understanding of the VQiPS tools available to the end user community, an increased awareness of new video technologies, and insight into how first responders use video in the field. More information and materials are available at http://www.pscr.gov/about_pscr/highlights/vqips_2014/houston/vqips_workshop_april_2014.php.

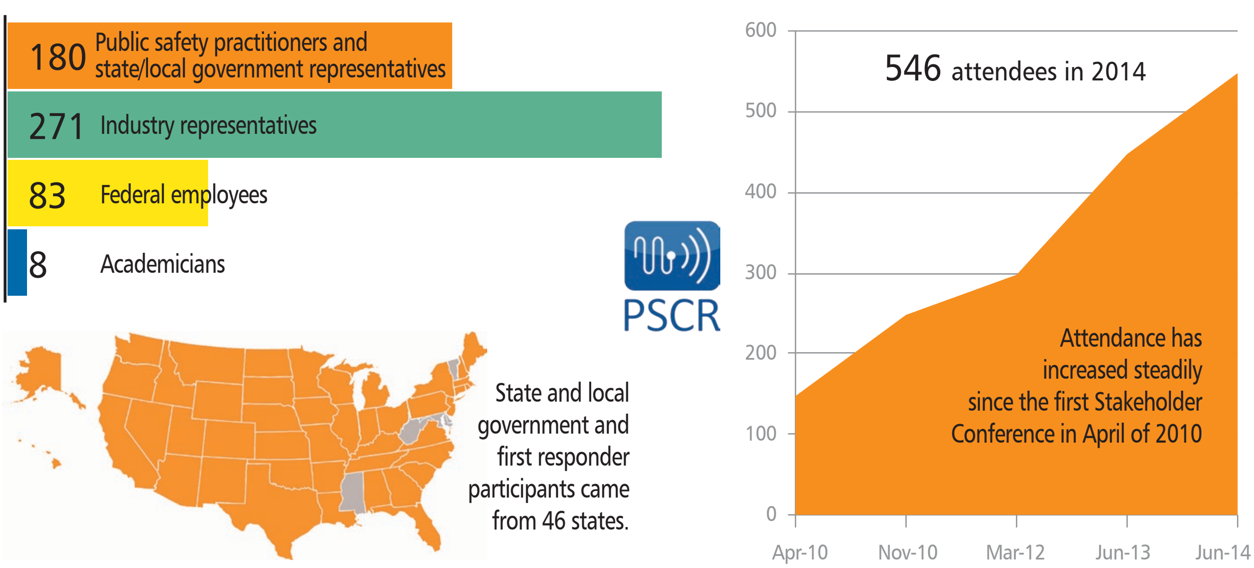
Public Safety Broadband Stakeholder Conference

As a partner with NIST in the PSCR program, ITS co-hosted the program's latest Public Safety Broadband (PSBB) Stakeholder Conference in Broomfield, CO, June 3–5, 2014. This was the fifth face-to-face stakeholders' meeting for the PSBB 700 MHz Band Class 14 Demonstration Network, with over 500 attendees from public safety, Federal agencies, industry, and academia.

Conference attendees benefited from the collocation of the FirstNet June Board Meeting at the conference hotel the morning of June 3. The FirstNet Board Meeting was webcast live into the PSCR Conference Room. Following the Board Meeting, Dereck Orr of NIST and Andrew Thiessen of ITS, co-managers of the PSCR program, opened the stakeholder conference alongside newly announced FirstNet Chairwoman, and keynote speaker, Sue Swenson. Swenson described four key work themes for FirstNet going forward: 1) Execute, 2) Engage, 3) Communicate, and 4) Collaborate. Other keynote speakers were Daniel Cotter, Director of the Department of Homeland Security Office for Interoperability and Compatibility, and Acting Department of Commerce Deputy Secretary Dr. Patrick Gallagher.

Participants were briefed about FirstNet efforts related to the build out of the National Public Safety Broadband Network (NPSBN) as well as testing progress on the PSBB Demonstration Network. ITS briefings covered in-building testing and extended-range cell testing, video quality and the Video Quality in Public Safety (VQiPS) tool for video requirements recommendations, audio quality and the ITS-developed Articulation Band Correlation Modified Rhyme Test (ABC-MRT) tool and audio library to speed speech intelligibility testing, and public safety broadband requirements and standards development. More information and materials are available at http://www.pscr.gov/about_pscr/highlights/psbb_062014/2014_psbb_stakeholder_conf.php.

2014 PSCR Stakeholder Conference Attendance



Enhancing Spectrum Utilization

Spectrum is a physically limited asset, but wireless data usage continues to grow at exponential rates. To make more spectrum available for use, current users need to share spectrum with new users, find innovative ways to shrink the footprint of the spectrum reserved for their exclusive use in time or space, use wavelengths previously considered unsuitable for radio communication, or do all three. Enhancing spectrum utilization means finding ways to increase the number of users who can effectively operate in each band, as well as inventing equipment that can effectively operate in previously unused bands. Research to enable the fullest spectrum utilization provides the technical foundation necessary to "unlock the value of otherwise underutilized spectrum and open new avenues for spectrum users to derive value through the development of advanced, situation-aware spectrum-sharing technologies."[1]

> *"America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum."*[1]

ITS is recognized nationally and internationally as a leader in spectrum utilization technical studies. The laboratory performs measurements and analyses of spectrum usage by individual and aggregate spectrum systems. Based on measurements, theory and analysis, ITS also develops models and simulations for spectrum system performance by individual systems and interactions between radio transmitters and receivers. The Institute applies these capabilities for the Center for Advanced Communications (CAC), direct-funded NTIA projects, and sponsor-funded projects. Sponsors are other government agencies (under IAs) and private sector entities (under CRADAs).

Center for Advanced Communications (CAC)

The CAC was created to investigate and initiate collaborative efforts in spectrum research between NIST and ITS using the highly successful Public Safety Communications Research (PSCR) program as a model. ITS has extensive experience performing spectrum measurements and analysis for spectrum sharing studies including ultrawideband, broadband over power line, dynamic frequency selection, and dynamic spectrum access, while NIST performs world class metrology to help improve measurement techniques. Through a series of information exchanges, reviews of existing research programs, and assessments of current spectrum regulatory activities, the project team selected spectrum monitoring, clutter loss measurements, and millimeter wave research as kickoff collaboration projects.

Electromagnetic Compatibility Studies

Electromagnetic compatibility (EMC) studies examine the totality of spectrum usage by radio transmitters and receivers and the interactions between different radio systems. They point the way forward for radio systems to successfully co-exist together, directly sharing spectrum bands with each other and operating efficiently in adjacent bands. EMC experiments help define technical parameters such as transmitter emission limits, frequency offsets, or separation distances for proposed rulemakings in support of new spectrum uses/sharing requirements. They can also be used to develop receiver and sensor performance requirements for improved spectrum sharing and efficiency.

Interference Analysis and Mitigation

Interference analysis and mitigation studies provide the data needed to continuously improve the technologies that allow users to gracefully share the same radio space or operate in adjacent bands. Ideally, these studies are carried out prospectively, while new equipment or new sharing regulations are still under

1. The White House, Presidential Memorandum: Unleashing the Wireless Broadband Revolution, June 28, 2010. Accessed http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution January 9, 2014.

development. Sometimes, however, they are needed to trace to its root cause interference experienced in situations that were previously thought to be safe for sharing and to devise mitigation strategies.

Spectrum Measurements

While EMC studies characterize the emissions of different devices, spectrum measurements characterize the radio space in which they operate. Spectrum measurements do not identify individual transmitters, but catalog the amount and nature of the electromagnetic radiation present in the radio spectrum over a specified period of time in a specified geographic location. This description of the existing radio spectrum environment is used to identify opportunities for increased utilization as well as to describe the background radio noise against which intentional transmissions will have to be made secure and resilient.

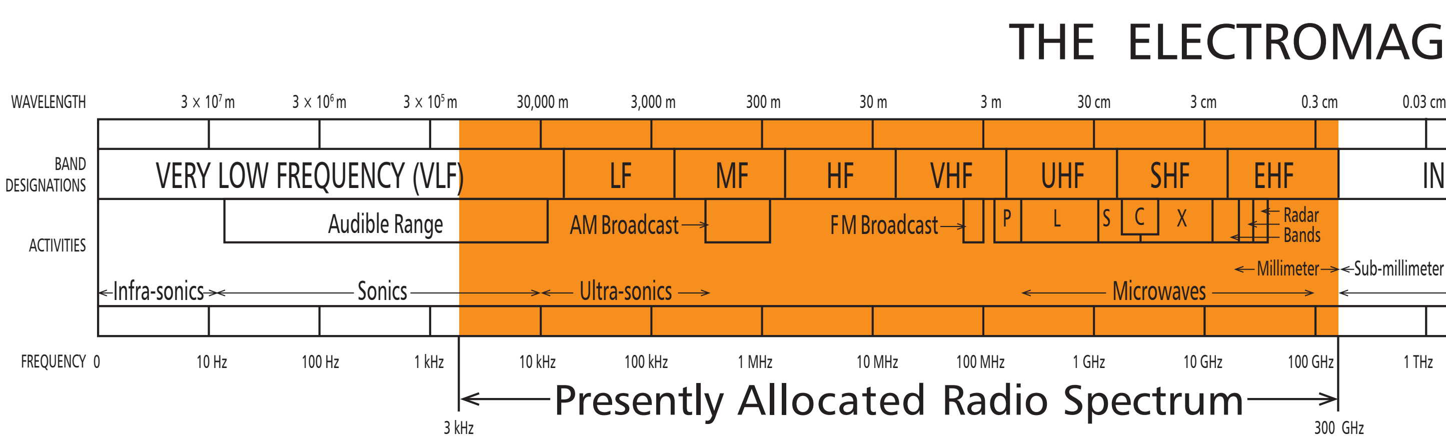
Radio waves are made to carry information by varying the wave's amplitude, frequency, and phase within a frequency band. They range from hundreds of meters to about one millimeter in length, corresponding to about 300 GHz to 3 kHz in frequency, and there are significant variations in the behavior of waves of different frequencies. This is why certain frequencies are more desirable "real estate" for certain purposes. To discover innovative ways to cram more information streams into each segment of the spectrum, and to make those streams resilient and robust no matter what frequency they travel on, we must continuously deepen our understanding of the behavior of radio waves and the radio environment.

Spectrum measurements also describe the current occupancy of different bands. This allows regulators to plan realistic strategies for increasing utilization, and it allows product designers to plan strategies to protect desired transmissions from other traffic in the neighborhood. While the behavior of radio waves is a physical constant that can be measured almost anywhere, occupancy varies geographically. Not only is the spectrum predictably more crowded in urban than in rural areas, but the frequencies and amplitudes of the traffic vary with proximity to airports, littoral areas, centers of research, etc.

National and International Standards Development

Data from ITS research is also used to support the development of national and international standards for radio devices. Strong and unbiased standards support fair competition in the information and communications technology sector.

Technical standards establish common norms for technical systems—uniform engineering criteria, methods, processes, and practices that promote competition and interoperability. Standards define the parameters of permissible emissions from different transmitters to reduce the probability that unwanted radiation interferes with other users. Standards define the characteristics of transmission envelopes so that devices



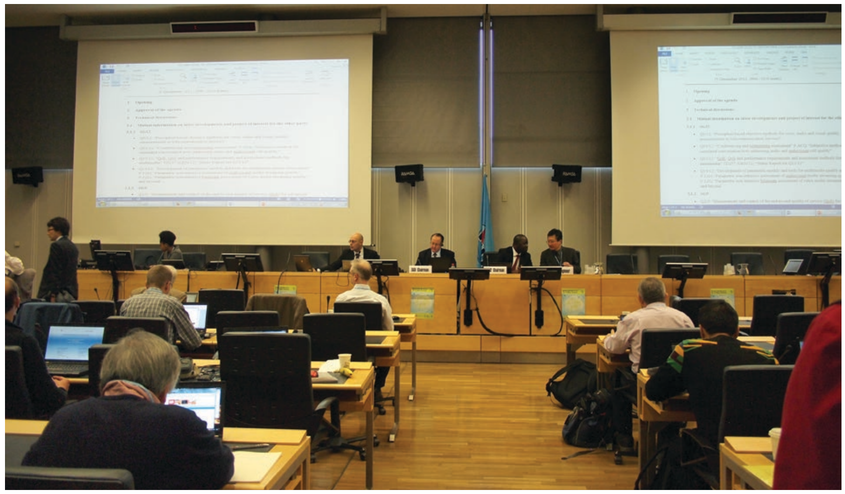
The International Telecommunication Union Radio Regulations allocate radio bands from 3 kHz to 300 GHz to different radio services. In the U.S. only frequency bands between 9 kHz and 275 GHz have been allocated. The U.S. Table of Frequency Allocations is the official compilation of spectrum allocations in the United States. NTIA also publishes from different manufacturers can interoperate predictably. Participation in standards development organizations (SDOs) helps influence domestic and international telecommunications standards and policies to support U.S. industry and the Administration's spectrum sharing initiatives and needs.

In cooperation with other interested U.S. government agencies and industry groups, ITS participates in national and international telecommunication standards development. ITS submits, and coordinates the formal review and approval of, recommendations on emerging mobile radio technologies, broadband network performance, radio propagation prediction, and radar systems.

Other offices of NTIA participate in the same standards bodies in different, non-technical capacities. As representatives of the U.S. Administration, NTIA/ITS staff who hold SDO leadership and membership roles advocate globally for communications technology standards and policies that encourage competition and innovation. Under agency reimbursable agreements, ITS staff also continue to support other Federal agencies with development of telecommunication specifications, standards, proof of concept and demonstration measurements, interoperability analyses, technical and economic impact assessments, and prototype development. Positions held by ITS staff in national and international SDOs are listed on page 87.

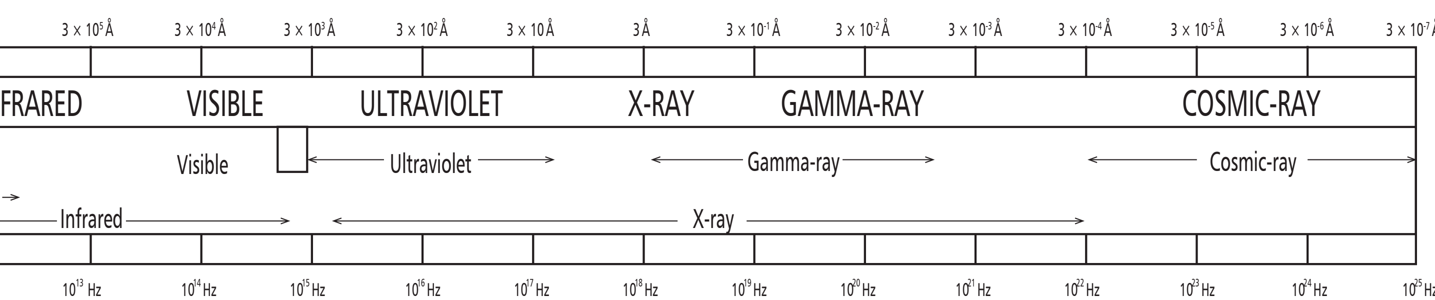
At a Glance: FY 2014 ITS SDO PARTICIPATION

36 positions on 30 different bodies in 6 SDOs, including 11 Chair/Co-chair positions



As International Chair of ITU-T Study Group 9 (Broadband cable and TV), Arthur Webster of ITS Co-chaired the Joint Plenary Session of ITU-T SG9 and SG12 during the December 2013 meetings at ITU Headquarters in Geneva, Switzerland. Behind the podium are, left to right, Stefano Polidori (ITU-T SG9 Advisor), Arthur Webster (SG9 Chairman), Kwame Baah-Acheamfuor (SG12 Chairman), and Hiroshi Ota (SG12 Advisor). Photo by Al Morton (AT&T).

NETIC SPECTRUM



a visual representation of that table as a poster that shows through color codes the parts of the radio spectrum allocated to each type of radio service. To view the PDF of the poster or to find out how to obtain a hard copy, visit http://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart.

> *“By taking advantage of and leveraging the critical mass of NIST and NTIA research and engineering capabilities concentrated in Boulder, Colorado the Department of Commerce will create a unique national asset that will provide the infrastructure necessary for effective engagement and collaboration with industry and government partners that is required to effectively and efficiently address current and future communications challenges.”*[1]

Center for Advanced Communications

The 2010 Presidential Memorandum “Unleashing the Wireless Broadband Revolution” outlined a number of initiatives to be undertaken by different Federal agencies in pursuit of expanded wireless broadband access to promote “America’s future competitiveness and global technology leadership.”[2] While immediate attention focused on the initiative to free up 500 MHz of additional spectrum for wireless broadband use, the memorandum also addressed the need for new technologies to fully, robustly, and efficiently exploit that spectrum. The Secretary of Commerce, in consultation with other Agencies, was directed to work through NTIA to “create and implement a plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies.”[2]

In response to that directive, in June 2013 NTIA and NIST signed a memorandum of understanding that laid the foundations for the Center for Advanced Communications (CAC), a cooperative research effort that aligns the world-class advanced communications capabilities of both organizations. CAC unites key research and engineering activities from two Department of Commerce sister agencies under an umbrella of national excellence for collaborative research and engineering. One of CAC’s objectives is also to coordinate and tackle several national priorities outlined in the Presidential Memorandum “Expanding America’s Leadership in Wireless Communications,”[3] such as monitoring and supporting advances in new spectrum sharing technologies and policies. Work began in FY 2014 on critical new spectrum measurement initiatives, radio analysis tools, capabilities, and test-beds that support accelerated development, testing, and deployment of advanced communications technologies for commercial and government sectors.

Spectrum Monitoring: A CAC goal is to conduct spectrum monitoring over the entire lifecycle of new radio technologies, from the earliest proposals for spectrum sharing, to conformity assessment of newly deployed systems, to longer term surveillance testing which regulators may use to support enforcement actions. Toward that end, the Spectrum Monitoring Pilot Program was initiated in 2013 to investigate the efficacy of spectrum monitoring in support of research and spectrum regulatory proceedings.

Simulating Spectrum Utilization Scenarios: To determine if sharing is even feasible in specific bands under specific circumstances, policy makers planning for enhanced spectrum utilization through sharing depend on predictions of the performance of communications technologies that may not yet exist and of existing technologies in environments in which they have not previously operated. Propagation prediction is usually an empirical process that depends on measured data to validate prediction models; where this data is not available, researchers turn to software simulations.

Millimeter Wave Research: Many projects to enhance spectrum utilization focus on frequency bands that can best be exploited by current technology and are consequently both the most coveted

1. National Institute of Standards and Technology Fiscal Year 2014 Budget Submission to Congress. Accessed http://www.osec.doc.gov/bmi/budget/FY14CJ/NIST_Budget_to_Congress.pdf February 17, 2015.
2. The White House, Presidential Memorandum: “Unleashing the Wireless Broadband Revolution,” June 28, 2010. Accessed http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution March 31, 2014.
3. The White House, Presidential Memorandum: “Expanding America’s Leadership in Wireless Communications,” June 14, 2013. Accessed http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio February 17, 2015.

and the most crowded—the so-called “sweet spot” for current cell phone technologies. Millimeter wave research focuses on developing new technologies capable of operating in frequency bands that cannot now easily or cost-effectively be used for cellular services.

Clutter Loss Measurement: Clutter losses are the additional pathloss caused by man-made structures and foliage—over and above those predicted by terrain based propagation models. These effects had not been considered by the Commerce Spectrum Management Advisory Committee (CSMAC) working groups which evaluated opportunities for spectrum sharing in the 1695–1710 and 1755–1780 MHz bands. In FY 2014 ITS responded to this by initiating a limited clutter loss measurement activity using a new precision RF data logger we had recently developed. In this instance, we identified an opportunity for NIST statisticians to review our preliminary findings and suggest improvements to test design and data analysis. A joint project was established for FY 2015.

NASCTN Support and Table Top Exercise: A planned functionality under the CAC is the National Advanced Spectrum and Communication Test Network (NASCTN), envisioned as single point of access to a network of government, academic, and commercial capabilities able to coordinate the use of intellectual capacity, modeling and simulation, laboratory, and test ranges to meet national spectrum interests and challenges. One important task for NASTCN is coordination of spectrum sharing involving Department of Defense (DoD) communications systems. While the organizational structure of NASTCN is still a work in progress, multi-agency NASTCN meetings began in FY 2014. ITS, CTL, and DoD engineers reviewed existing processes and methods for developing tests and measurements of proposed spectrum sharing scenarios. The goal was to identify process improvements for coordination amongst key stakeholders, and develop a framework for creating more complete, rigorous test procedures. This approach is envisioned to lead to more broadly accepted test results. The team produced a swim lane process flow diagram illustrating the various stages of the process including test screening, spectrum community awareness, test planning and execution, as well as after-action process review. The process was evaluated in a table top exercise to better understand the objectives, Concept of Operations (CONOPs), procedures, scenario, environment, challenges, schedule, and planning responsibilities. The exercise revealed an estimated five month period to accomplish a typical spectrum sharing study, highlighting the need for streamlining. The plan is to implement this process with an actual spectrum sharing study in FY 2015 to identify further process improvements.

ISART: CAC will also sponsor the 14th International Symposium on Advanced Radio Technologies (ISART). Traditionally hosted by ITS, ISART brings together participants from government, academia, and industry to discuss ground-breaking developments and applications of advanced radio technologies. The topic of improved spectrum modeling, simulation, test, and measurement was selected. Potential refinements in key aspects of electromagnetic compatibility studies that could realistically yield, in a one to two year time frame, significant improvements in both the speed and quality of the spectrum sharing studies while providing a greater degree of confidence in predicted outcomes will be considered. The feasibility and projected return on investment of longer term (3-5 years) research proposals will also be deliberated. The goal is to increase sharing of Federal spectrum by identifying scientific and technological factors that would facilitate more rapid compatibility studies and permit more extensive commercial sharing of the spectrum while protecting mission critical Federal spectrum dependent systems. This would be achieved through improved models, simulations, tests, and measurements subjected to more robust verification and validation processes.

ISART
INTERNATIONAL SYMPOSIUM ON
ADVANCED RADIO TECHNOLOGIES
CENTER FOR ADVANCED COMMUNICATIONS

For more information contact Eric D. Nelson, (303) 497-7410, enelson@its.bldrdoc.gov

> *"The NTIA shall design and conduct a pilot program to monitor spectrum usage in real time in selected communities throughout the country to determine whether a comprehensive monitoring program in major metropolitan areas could disclose opportunities for more efficient spectrum access, including via sharing."*[1]

Spectrum Monitoring

Exploding demand for wireless broadband access has prompted U.S. government initiatives to make more frequencies available for commercial broadband applications. Desirable radio spectrum has been mostly allocated in the U.S., leaving two basic ways to make more spectrum available: (1) open frequency bands to shared use or (2) relocate incumbent users to other bands. In both cases, the density of systems in space, frequency, and time will increase. Without adequate planning and precautions, this creates a higher probability of interference events, increased risk for incumbents and investors, and a reduction in spectrum value.

Measured spectrum occupancy is useful information for planning, engineering, and enforcing new spectrum sharing and relocation scenarios. With some standardization and the development of best practices to ensure data quality, measured spectrum data could be made available alongside license and assignment data to improve the quality and quantity of information available for planning by policy makers, spectrum managers, and investors. In the engineering phase of a transition process, real-time and historical measured spectrum data could be used to check assumptions, validate propagation and usage models, and field test dynamic coordination schemes and technologies. After a sharing or relocation authorization, open and transparent use of relevant spectrum data can play a critical role in interference resolution and enforcement in the increasingly dynamic and complex interference environment.

Long-term and continuous acquisition of spectrum data, i.e., spectrum monitoring, is currently being performed by industry, academia, and government for a variety of purposes.[2] There has been little effort, however, to collect, extend, and curate this information for the benefit of all. The organizations acquiring spectrum data use a wide variety of data types to suit their purposes. The means of acquiring the data also varies and there is no one-size-fits-all approach. With all these disparate sources, types, and methods, there is a need for infrastructure and standardization to aggregate and achieve full collective value of the data.

The COTS Sensor R&D Lab includes a screen room (left) for conducting tests in a shielded environment. Setting up equipment for a test are team members (left to right) Mike Cotton, Heather Ottke, Linh Vu, and Brent Bedford. Photo by L. Segre.

A pilot project to develop spectrum monitoring capability

1. The White House, Presidential Memorandum: "Expanding America's Leadership in Wireless Communications," June 14, 2013. Accessed http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio February 17, 2015.
2. Networking and Information Technology Research and Development (NITRD) Program, Wireless Spectrum Research and Development Senior Steering Group, "Understanding the Spectrum Environment: Data and Monitoring to Improve Spectrum Utilization," WSRD Workshop V Report, August 2014. Accessed https://www.nitrd.gov/nitrdgroups/images/8/80/WSRD_Workshop_V_Report.pdf February 18, 2015.

to meet this need is one of the first research efforts undertaken under the umbrella of the CAC. Its goals are to (1) develop an infrastructure to acquire and amass spectrum monitoring data and make it available to the spectrum community in near real time via the Internet, and (2) establish best practices for the acquisition of spectrum data.

Measured Spectrum Occupancy Database (MSOD)

Toward the first of those goals, ITS is developing a distributed Measured Spectrum Occupancy Database (MSOD) architecture in collaboration with NIST/CTL Gaithersburg. The architecture will enable industry, academia, and government agencies to host MSOD instances and contribute spectrum data to the overall program. MSOD will allow access to the system's measured spectrum occupancy database through a web-based user interface. Users will be able to query MSOD via a Web service or view and download data with a browser-based data visualization application. In the visualization tool, band occupancy statistics over long time intervals will be available to inform policy discussions (Figure 1). Near-real-time amplitude versus frequency data will also be available for spectrum coordination and enforcement purposes (Figure 2).

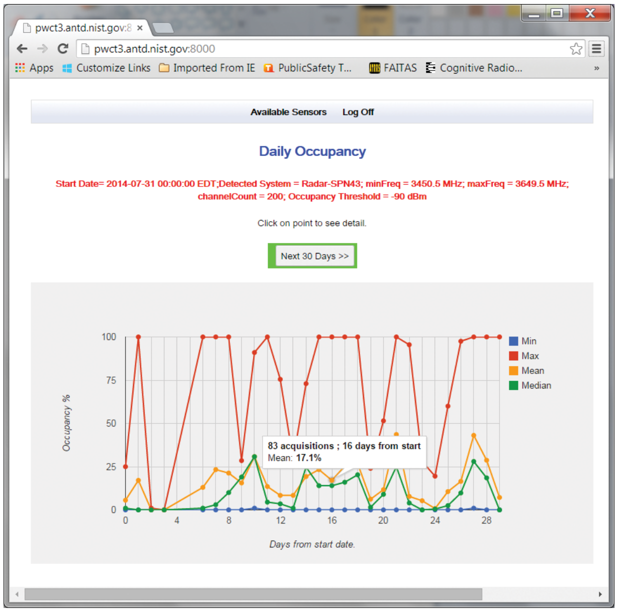


Figure 1. Screen capture of daily band occupancy view.

RF Sensor Development and Deployment

Toward the second goal, we are also pursuing RF sensor development and deployment. Sensor hardware and software are being designed to detect well-defined system transmissions in specified frequency bands, e.g., LTE at 0.7 GHz and 1.7 GHz and pulse radar at 3.0 GHz and 3.5 GHz . Novel aspects of the sensor designs include: (1) local calibrations to indicate health of sensors in the field and to measure system noise level; (2) a standard format for the transfer of calibrated measurements from the sensor to the repository; and (3) benchmark tests on commercial-off-the-shelf (COTS) sensors and software defined radios (SDRs) to assess capabilities and limitations.

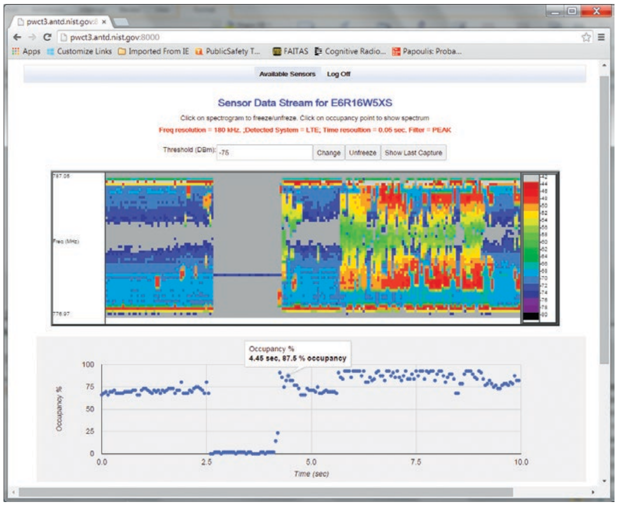


Figure 2. Screen capture of live streaming data view.

A radar sensor prototype was tested in the lab and deployed at Virginia Beach in August 2014 to monitor the 3.5 GHz maritime radar band. In FY 2015, we plan to build and deploy three additional 3.5 GHz sensors at Key West, San Diego, and San Francisco. These installations will also be used to monitor the 2.9 GHz to 3.1 GHz Radionavigation bands. These bands are being quantitatively assessed by NTIA's Office of Spectrum Management as part of its effort to identify bands that can be opened for sharing or reallocation to free up 500 MHz of Federal and non-federal spectrum for commercial broadband use.

For more information contact Michael Cotton, 303-497-7346, mcotton@its.bldrdoc.gov

Simulating Spectrum Utilization Scenarios

Continued pressure on spectrum resources from new wireless services makes performance prediction of scenarios more important than ever. A spectrum utilization scenario describes the two radio services being proposed for operation in the same or adjacent bands and the rules they will be required to observe. Examples of spectrum utilization scenarios that must be explored include broadband radio services (BRS) such as LTE being placed in bands adjacent to a radar band or radars being moved to a band with other radars. It is not feasible to predict the performance of all the possible spectrum utilization scenarios with field tests. For expediency, we must turn to software simulations, which initially are validated by comparisons with available field tests of operational systems.

Radio System Software Simulation

In FY 2014 ITS identified and procured a radio system software simulator (more fully described in the Tools and Facilities Section on page 76) to determine allowable interference to noise power ratio (INR) interference protection criteria (IPC). With the system in-house, we made significant progress verifying simulations of systems operating with and without interference from well characterized additive white Gaussian noise (AWGN) or continuous wave (CW) signals.

Figure 1. PPI display when Gaussian noise interference is present. The artificially generated targets are visible as regularly spaced bright green tics at 180 degrees bearing.

To gain confidence in the software simulations, we have begun emulating previous interference tests made in the field. In FY 2014 ITS engineers completed field tests of interference effects of BRS transmitters on the operation of an SPN-43 air-marshalling radar. In these tests, engineers varied BRS interference power as they measured probability of detection (Pd) by counting the number of artificially generated targets visible on the radar planned position indicator (PPI) screen. They also repeated the tests with AWGN and CW interference signals.

Figure 1 shows the PPI display with AWGN interference present. The artificially generated targets the engineers count to measure Pd are visible as regularly spaced bright green tics at 180 degrees bearing. Figure 2 compares the simulated results to a curve fit to measured results. The y-axis or ordinate represents Pd. The x-axis or abscissa represents INR. The green curve used a theoretical threshold voltage while the blue curve used a constant false alarm rate (CFAR) algorithm to compute the threshold voltage. In general, there is very good agreement between measured and simulated AWGN results.

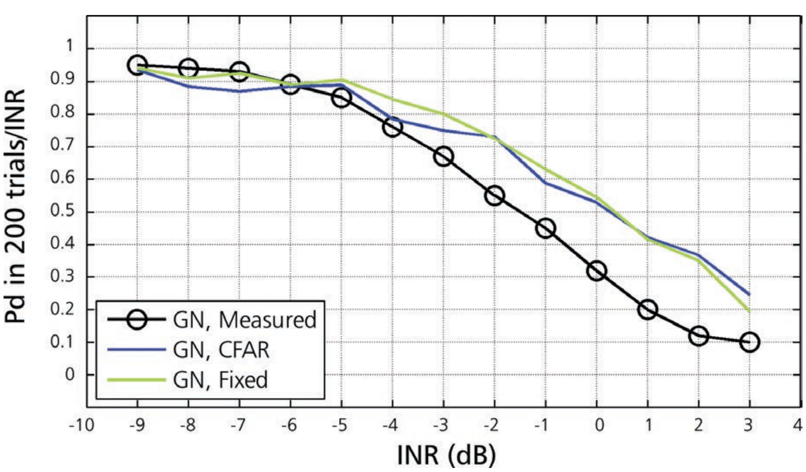


Figure 2. A comparison of simulated Pd degradation compared to a curve fit to measured results.

Our success in emulating the effects of AWGN interference encouraged us to expand our comparisons to include time division duplexed LTE signals in FY 2015. We also plan on replicating spectrum utilization scenarios where radars have the potential to introduce interference into

LTE systems and where radars have the potential to introduce interference into other radar systems.

Aggregate Interference Power

Future BRS system base stations are expected to densely blanket metropolitan areas. With an average of 18 simultaneous users per base station, there is some concern that the combined or aggregate power emitted by their equipment will be debilitating to other systems that operate at or near the BRS frequencies. In some spectrum utilization scenarios, the victim receiver may be a Federal communications or radar link.

In FY 2014 ITS began developing an aggregate interference model that can predict the distribution of mean power present at a victim receiver. These results are useful for establishing geographic zones which exclude BRS transmitters and corresponding user equipment (UE). The model will include antenna gain patterns, terrestrial and ground-to-air propagation attenuation models, building attenuation models, and clutter attenuation models. For accurate modeling of the BRS system, the model will also include UE power control and radio resource scheduling algorithms which some have suggested have a strong effect on the mean power distribution.

Currently the model tessellates the metropolitan area into hexagonal base station coverage areas, randomly sprinkles UEs within the coverage areas, calculates the power each UE emits, and predicts the aggregate power cumulative distribution function (CDF) at the victim receiver location. An example for a simple spectrum utilization scenario and resulting CDF are shown in Figures 3 and 4. The distribution was created from running the aggregate model 1000 times.

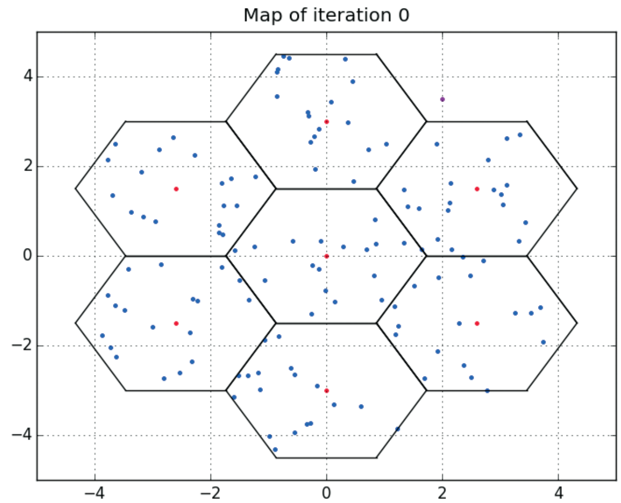


Figure 3. Spectrum utilization scenario with tessellated hexagonal coverage area. Base stations are the red dots in the middle of the hexagons, UEs are the blue dots in the hexagons, and the victim receiver is the red dot at the top right outside the hexagons.

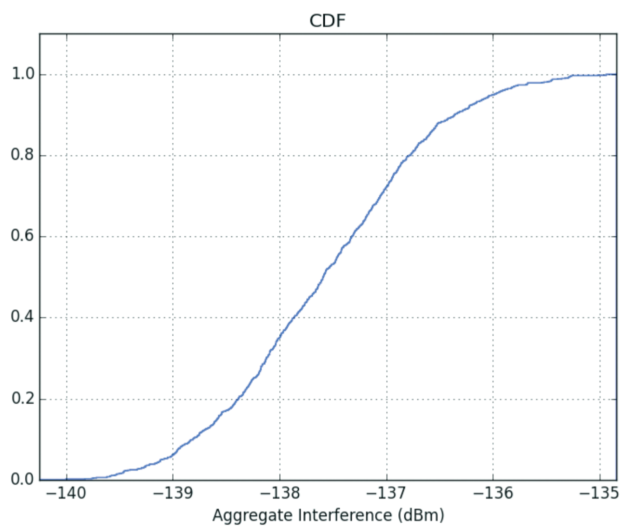


Figure 4. Aggregate power CDF at the victim receiver.

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Millimeter Wave Research

While previously reported projects seek to alleviate spectrum shortage by enabling shared use of some spectrum bands, this CAC project seeks to extend wireless connectivity into the millimeter wave portion of the radio spectrum, which is not currently being used for cellular broadband. The use of this spectrum requires new technology and methodologies for wireless devices.

This work is a joint effort between ITS and a larger NIST project called Enabling Gigabit Wireless Connectivity. The millimeter wave portion of the project takes advantage of ITS radio propagation research and NIST expertise in standards development and metrology to perform the basic research that will lead

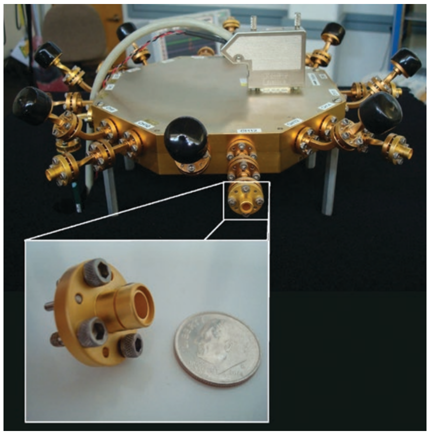

Figure 1. 83 GHz antenna array with 16 scalar-feed-horn antennas (a single antenna is shown in inset). The hexagonal housing holds 16 low-noise amplifiers and multiplexer. The antennas with the black covers are pointing up at 45°; horizontal antennas have no covers.

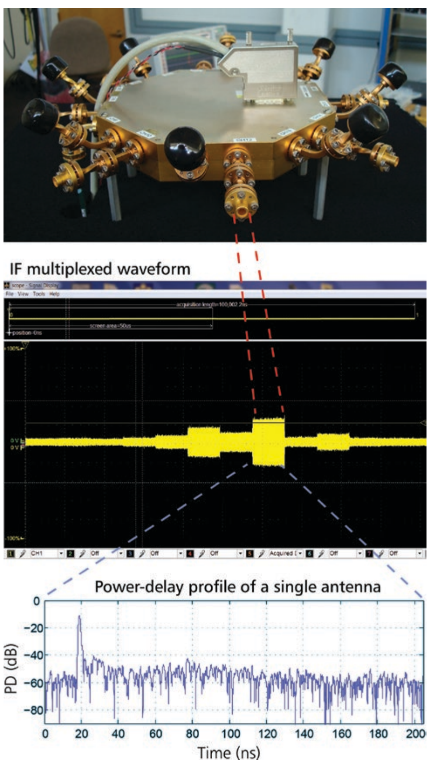

Figure 2. An RF signal from a single receive antenna element (top photo) is digitized after downconversion to intermediate frequency (IF, middle plot). The digitizer record contains the IF signals from all 16 antenna elements. Received code words are extracted from the IF record and processed to yield the power delay profile for each antenna element and angle-of-arrival (bottom plot).

to standards for the use of the millimeter wave spectrum and standards for the equipment that will use it.

The millimeter wave spectrum can offer over 1,000 times the bandwidth of the existing cellular radio spectrum and relieve capacity problems being encountered by 4G system. Besides increased capacity, evolving concepts for 5G systems foresee the need for greatly reduced latency in communications. This issue can also be addressed using millimeter wave technology.

Millimeter wave propagation data and measurement based channel models are seen by industry leaders and standards bodies as a key requirement for development of this new technology. 5G systems will use complex antenna arrays that will be able to transmit and receive signals in many directions using narrow beams and small antenna apertures. These antenna arrays will be able to reduce interference and compensate for millimeter wave propagation impairments.

ITS and NIST have partnered to develop a robotically controlled channel sounder capable of operation at 83.5 GHz with 2 GHz of instantaneous bandwidth. To measure signals from different angles of arrival within the coherence time of the mobile channel, the sounder is equipped with a custom designed antenna array capable of switching antenna elements in 25 ns.

This array has 16 antenna elements which can receive signals in an omni-directional pattern with vertical directivity extending from -22.5 degrees to +67.5 degrees (Figure 1). The signals from each of the antenna elements are combined using a fast switching multiplexer built into the central part of the array body. This arrangement, coupled with a state–of–the-art arbitrary waveform generator at the transmitter, millimeter wave RF sections, and fast digitizer allows collection of radio channel impulse response data and angle of arrival information. Figure 2 shows an impulse data record collected at 83.5 GHz using the antenna array and multiplexor. Data collection is achieved in a mobile untethered mode using a robot capable of autonomous navigation.

Presently the system has been tested and is operational. Preliminary data is being analyzed for development of new channel models. In addition, a 28–38 GHz system has been procured and is being bench tested. A 60 GHz system has also been designed which will be capable of beam steering at a transmitter array.

Other components of the project include the metrology methods capable of calibrating modulated signal sources up to 100 GHz using an electro-optical probe and the extension of the NIST antenna range to characterize antennas above 100 GHz.

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Electromagnetic Compatibility Studies

Electromagnetic compatibility (EMC) studies use models, simulations, tests, and measurements to characterize the emissions of different radio devices for many purposes. EMC studies are undertaken to develop interference protection criteria (IPC), which define interfering signal levels that allow a communication system to continue to operate without being significantly compromised. They can also be used to develop algorithms for detection and avoidance that equipment in shared bands can be programmed to limit interference by recognizing and avoiding the emissions of other devices. EMC studies typically work with models for radio system interactions; these models are checked and informed by extensive sets of measurement data that validate critically important assumptions about radio system characteristics and performance.

ITS works with NTIA's Office of Spectrum Management (OSM) to perform EMC studies to inform spectrum management policy and procedures. Of special interest in FY 2014 were studies to inform sharing decisions in the 3.5 GHz band, where radars may be asked to share spectrum with other radars or non-radar communications services. In FY 2014, ITS was also asked to assist the Department of Transportation Federal Highway Administration (FHWA) to begin a complete EMC analysis to evaluate the impact of a proposal to open to sharing by unlicensed devices spectrum now in use by a critical FHWA communications system.

To reduce the complex electromagnetic environment to a judicious number of parameters so that cooperation can be forged between two users being asked to share spectrum, simulation, analysis, and testing are performed iteratively. Decisions based on these standard engineering practices can help assure that the communications needs and requirements of all users of shared bands can be met.

FY 2014 ITS Electromagnetic Compatibility Studies

Outputs

- *Detailed measurements of transmitter emissions*
- *Detailed measurements of receiver performance in the presence of radio interference*
- *Development of interference-performance models for receivers*
- *Determination of IPC based on results of measurements and modeling analyses*
- *Propagation modeling for spectrum sharing*

Background

The U.S. Administration has called for opening 500 MHz of radio spectrum for new uses and applications. This 500 MHz is supposed to be found at frequencies below 5 or 6 GHz, meaning that 8 to 10 percent of existing spectrum in that range may ultimately be affected by this effort. But in many cases, incumbent systems will need to continue to use their existing allocations. It is therefore likely that most or all of this "new" 500 MHz of spectrum will need to be utilized via sharing between unlike types of radio systems (new and incumbent) that have not previously shared spectrum. Since it would be generally unworkable to simply begin to operate new radio systems in the same spectrum as incumbents without prior coordination, technical methods are required to determine in advance the conditions under which sharing can be achieved in any given band without inter-system interference. When sharing conditions are understood, spectrum sharing technical systems, protocols, and rules can be developed for each shared band.

EMC Studies in the 3.5 GHz Band

In FY 2014, ITS undertook a major effort to develop the technical bounds for interference-limited sharing between new and incumbent systems in a candidate band for spectrum sharing, 3550–3650 MHz (called the 3.5 GHz band). Important incumbents in this band include radars, especially on ships. New LTE systems will probably eventually share the band with the radars. But before any LTE systems are deployed in the band, rules must be developed for spectrum sharing, and those rules will depend on understanding the conditions under which the LTE and radar systems interfere with each other.

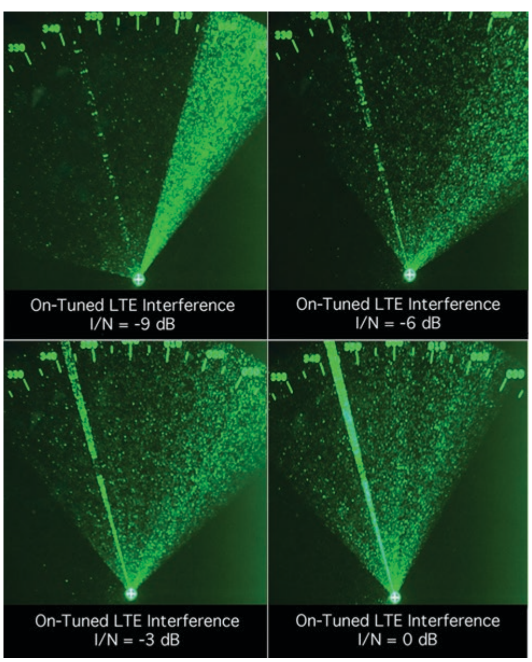
ITS, working with OSM, developed a plan for the 3.5 GHz spectrum sharing measurements and analysis. The plan called for emission spectrum measurements of both LTE and radar transmitters. Those measurements would show the amount of power that transmitters of either service would couple into receivers of the other service as a function of the amount of off-tuning between the respective transmitters and receivers. ITS and OSM shipped suitcase measurement systems to LTE and radar locations in Maryland, Virginia, and Colorado, where their engineers:

- Measured LTE (FDD) and LTE (TDD) emission spectra with over 100 dB of dynamic range
- Measured incumbent radar emission spectra with 120 dB of dynamic range
- Measured the effects of radar interference on LTE (FDD) and LTE (TDD) links as a function of interference power level
- Measured the effects of LTE interference on radar receivers as a function of interference to noise (I/N) level in radar receivers

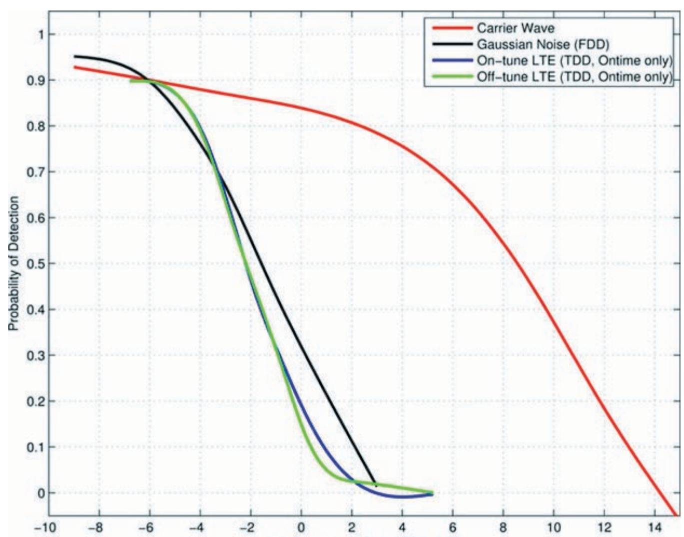
The results of these EMC studies were analyzed and published as NTIA Technical Reports in a timely fashion. ITS and OSM together performed all of this ground-breaking EMC work in less than twelve months.

Model Development

Using the results of the measurements, other ITS engineers began development of theoretical models of radar-to-LTE and LTE-to-radar interference. Those models' results are now in publication. With the measurements having validated the model results, ITS engineers will use those models to examine 3.5 GHz



LTE interference effects on an air-search radar receiver.



LTE-to-radar interference-effects curves generated from ITS measurements. The probability of detection of radar targets is graphed as a function of the LTE signal's interference-to-noise (I/N) ratio in the radar receiver, along with Gaussian interference used as a control and as a proxy for LTE (FDD).

spectrum sharing between systems that do not yet exist, or to which access is unavailable, for the purpose of moving band sharing forward.

The synergistic measurement and model-development and simulation work described here at 3.5 GHz is being paralleled at ITS with measurements and modeling in other bands at 1300 MHz, 1700 MHz, and 5 GHz. All of these studies are (and will be) used to generate interference protection criteria (IPC) for spectrum-sharing systems, and those IPCs will in turn be used to produce spectrum-sharing rules and protocols. ITS engineers will use this approach for years, and perhaps decades, to come to enable more and better spectrum sharing across all radio bands.

ITS Radar Program

Outputs

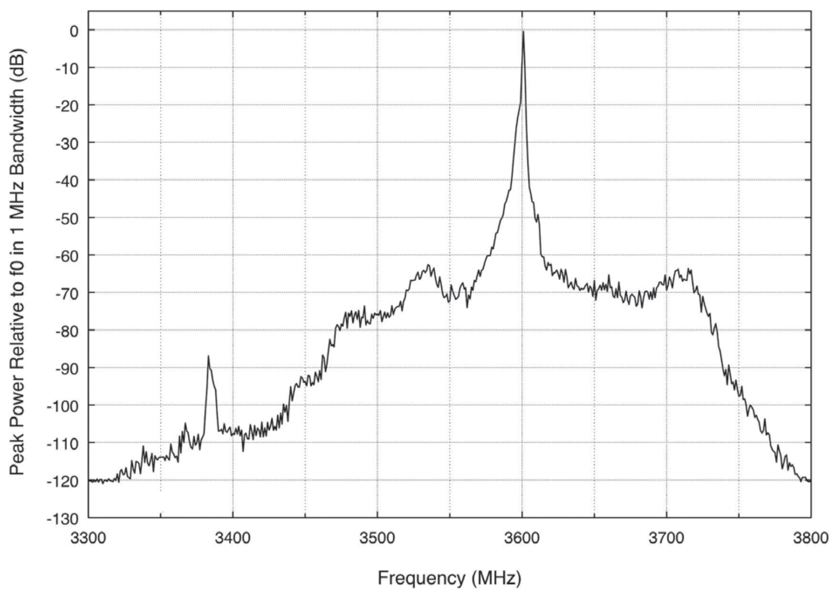
- *Highly detailed measurements of radar emissions*
- *Analysis of radar emissions for spectrum-sharing, spectrum-compliance and electromagnetic compatibility studies*

Background

The U.S. allocates almost one-third (31%) of spectrum below 3700 MHz on a primary or secondary basis to radiolocation (radar) systems; nearly the same spectrum fraction (30%) is allocated to radar operations at all frequencies below 6 GHz. Historically, radar systems were thought not to be good candidates for spectrum sharing with other systems due to their high peak-power transmitter levels (often more than a gigawatt of effective isotropic radiated power) and their receivers' susceptibility to interference from other systems. Moreover, the specialized requirements of radar design (including considerations for adequate propagation factors and antenna size limitations) mean that radar systems cannot simply be designed for, confined within, or reallocated to just one or two bands below 6 GHz: U.S. radar allocations below 6 GHz are distributed across five major spectrum bands whose boundaries are unlikely to change.

EMC Studies of Radar Emissions

The search for 500 MHz of spectrum for new uses at frequencies below 6 GHz has forced a reconsideration of spectrum sharing between radars and non-radar systems; some radar spectrum will need to be shared. This requires careful and thorough electromagnetic compatibility analyses between radars and non-radar systems, including highly accurate and detailed characterization of radar emissions. Because radar emissions only match theoretical predictions down to about 40 dB below radar peak power levels, and because compatibility issues can crop up at levels of at least 90 to 100 dB below radar peak power, radar characterizations for spectrum sharing must



Example of a wide dynamic range radar emission spectrum measured with custom-designed NTIA/ITS hardware and software (from NTIA TR-15-510).

be accomplished through measurements of radar emissions.

To perform accurate measurements of radar emissions, ITS develops, builds, maintains, and operates a unique, wide-dynamic range radar emission measurement system. Using a unique combination of lab-developed hardware and software, ITS engineers routinely measure radar emissions with a dynamic range exceeding 120 dB across the entire microwave spectrum. The system is field-deployable as a suitcase capability and in the Radio Spectrum Measurement System (RSMS, page 76). No other Federal agency or private sector entity has equivalent radar emission measurement capability. Historically, this capability has been used to maintain a set of radar emission spectra for major and minor radar systems in the U.S. inventory.

In FY 2014, ITS performed wide-dynamic range measurements on two major radar systems that operate in and adjacent to the 3.5 GHz band that has been identified by the FCC for future spectrum sharing. The radars' emissions were measured at field sites and the collected data were published in an NTIA technical report. OSM, the FCC, other government agencies, and the private sector are using those data to develop spectrum-sharing systems in existing radar bands.

The ITS radar program goes beyond merely measuring radar emissions. New spectrum sharing rules must not only protect new communication systems from radar emissions, but also protect radar receivers from interference caused by communication transmitters newly introduced into radar bands. To inform those rules, ITS applies its unique expertise in the measurement and analysis of interference effects and threshold levels in radar receivers. ITS engineers routinely inject interference from new communication systems into radar receivers, under controlled conditions, to determine the power levels at which interference signals cause radar receivers to fail to detect targets. For safety, these tests are typically performed using desired radar targets generated by ITS engineers to emulate live targets.

In FY 2014, ITS engineers conducted such interference-effects measurements on a Navy radar, and published the results in an NTIA technical report. Those results, along with results from similar but reverse-direction interference measurements in which ITS engineers injected simulated radar signals into LTE receivers, are being used by OSM, the FCC, other government agencies and the private sector to determine the rules that will be implemented for spectrum sharing in the 3.5 GHz band.

Related Publications:

- *F.H. Sanders, J.E. Carroll, G.A. Sanders and L.S. Cohen, "Measurements of Selected Naval Radar Emissions for Electromagnetic Compatibility Analyses," NTIA Technical Report TR-15-510, Oct. 2014. Available http://www.its.bldrdoc.gov/publications/2781.aspx.*
- *F.H. Sanders, J.E. Carroll, G.A. Sanders, R L. Sole, R.J. Achatz and L.S. Cohen, "EMC Measurements for Spectrum Sharing Between LTE Signals and Radar Receivers", NTIA Technical Report TR-14-507, Jul. 2014. Available http://www.its.bldrdoc.gov/publications/2760.aspx.*
- *G.A. Sanders, J.E. Carroll, F.H. Sanders and R.L. Sole, "Effects of Radar Interference on LTE (FDD) eNodeB and UE Receiver Performance in the 3.5 GHz Band", NTIA Technical Report TR-14-506, Jul. 2014. Available http://www.its.bldrdoc.gov/publications/2759.aspx.*
- *F.H. Sanders, J.E. Carroll, G.A. Sanders, R.L. Sole, "Effects of Radar Interference on LTE Base Station Receiver Performance," NTIA Technical Report TR-14-499, Dec. 2013. Available http://www.its.bldrdoc.gov/publications/2742.aspx.*
- *F. H. Sanders, R. Sole, B. Bedford, D. Franc, and T. Pawlowitz, "Effects of Interference on Radar Receivers, NTIA Report TR-06-444, Sep. 2006. Available http://www.its.bldrdoc.gov/2481.aspx.*
- *F.H. Sanders, R. L. Hinkle and B. J. Ramsey, "Measurement procedures for the radar spectrum engineering criteria (RSEC)", NTIA Report TR-05-420, Mar. 2005. Available http://www.its.bldrdoc.gov/publications/2450.aspx.*

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EMC Analysis for the DSRC

Background

The dedicated short range communication system (DSRC) is a short to medium range intelligent transportation system communication service that supports both public safety and private operations in vehicle-to-vehicle and vehicle-to-infrastructure communication modes on the Nation's roads and highways. In 1999, the FCC allocated spectrum at 5850–5925 MHz (also known as the U-NII-4 band) for DSRC systems intended to improve roadway safety. Recently, this band has been identified as a prime candidate for sharing with U-NII devices.[1] The Federal Highway Administration (FHWA) asked ITS to perform an EMC analysis to determine if U-NII devices can share the spectrum without causing harmful interference to the DSRC devices that are the primary users of the band. Live test data was collected for comparison to analysis predictions. The goal of this effort is to ensure that systems developed for use in this band are compatible with each other and the environment in which they are used, and that sufficient spectrum is available for new DSRC systems.

EMC Analysis

First, ITS conducted a survey of potential interference sources operating in and adjacent to the 5850–5925 MHz band. 802.11ac devices were selected to represent typical parameters and characteristics of the type of U-NII devices that would be operating in that band if it were opened for unlicensed use. To evaluate sharing strategies to ensure that the unlicensed devices do not interfere with the DSRC, the licensed and primary services, it was first necessary to determine the required parameters for an EMC analysis of both the DSRC and the other systems in the environment. These would be input to the analysis models.

For the transmitter or interference source, these parameters include: operating frequency, transmitter power, transmitter emission bandwidth with roll-off of the emission spectra at the band edges, antenna gain and patterns, feed losses, and modulation. For the receiver or victim, these parameters include: operating frequency, sensitivity, modulation, bandwidth with sufficient information to characterize rejection outside of the receiver bandwidth, antenna gain and patterns, and interference to desired signal ratio for desired victim receiver performance. The particular parameters to monitor to determine if the DSRC is being interfered with include the received signal strength indicator (RSSI) and the packet error rate (PER) outputs of the DSRC. Where sufficient information was not available, devices were bench tested to determine the parameters necessary for an EMC analysis, which would include in-band and out-of-band responses to frequency scanned signals. A representative model was selected for each device.

Performing a complete EMC analysis involves identifying existing and future scenarios of the communication systems in the environment that may affect the DSRC. Input from the FHWA, the auto industry, and the organizations involved in the development of the 802.11ac standard is incorporated into the test scenarios in order to apply the analysis models appropriately. The scenarios contain geometries representative of worst case situations that would occur in a real environment that includes interference from U-NII 802.11ac devices to the DSRC devices in vehicle-to-vehicle and vehicle-to-roadside infrastructure scenarios.

It is important to identify issues and characterize radio frequency (RF) propagation in the roadway environment as needed for planning, spectrum issues, EMC analysis, standards development, and conformance testing. Propagation modeling for both DSRC and the unlicensed devices in the roadway environment requires specialized models due to the ultra-short distances and very low antenna heights of both the DSRC devices and the U-NII devices. It is also necessary to identify antennas, indoor versus outdoor use, antenna heights, separation distances, and propagation through various building materials and foliage. Separation distances include those between the transmitters and desired receivers and between the interference source and the desired receivers.

1. Federal Communications Commission, "Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band," Notice of Proposed Rulemaking, ET Docket No. 13-49, FCC 13-22, 78 Fed. Reg. 21320 (2013) (to be codified at 47 C.F.R. 15) (proposed Apr. 10, 2013).

There are three suitable models to address this range of antenna heights and separation distances for this analysis: the NTIA/ITS developed Undisturbed-Field Model, the NTIA/ITS developed Undisturbed-Field Empirically-Derived ITS-UFED Model, and the ITU-R model described in Recommendation ITU-R P.1411. All of these have been previously verified and validated with measured data. ITS identified the appropriate interference, analysis, and antenna models based on the selected scenarios that will be used in conjunction with the three propagation models identified to determine frequency dependent rejection, assess interference potential, and determine protection distances.

The results from the analysis models are compared to data from tests using scenarios determined by FHWA and ITS. This thorough communications and EMC analysis of the test data identifies whether it is necessary to modify the model input parameters of the systems or re-evaluate the initial assumptions; the analysis is rerun as necessary until the model output matches the live test data. This iterative process verifies the analysis procedure and gives confidence that the approach will provide realistic and reliable results. With this confidence, the analysis results can be applied to other scenarios that will not be verified with actual testing due to time constraints. This approach allows researchers to extrapolate and assess many more potential interference interactions than would otherwise be possible.

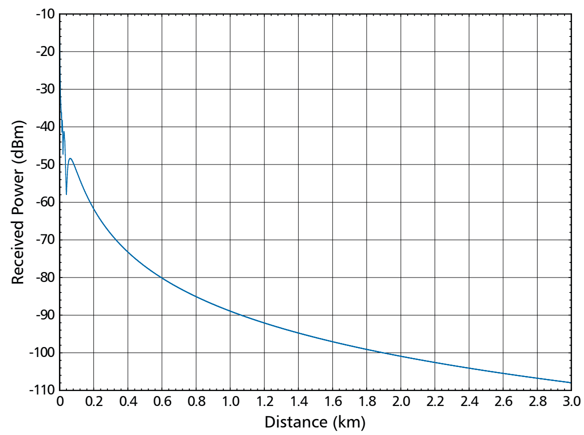

Figure 1

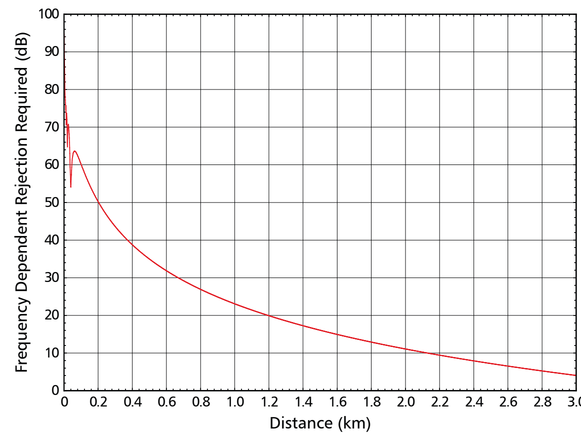

Figure 2

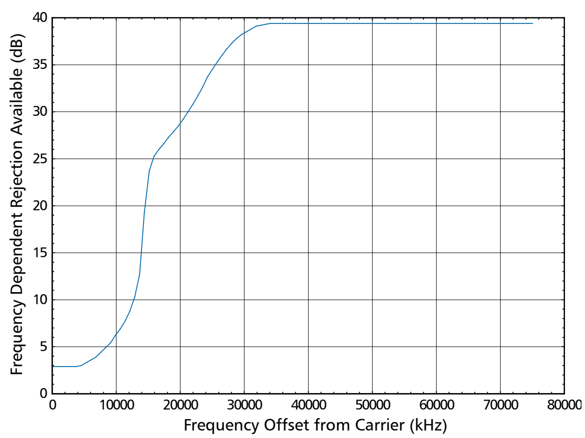

Figure 3

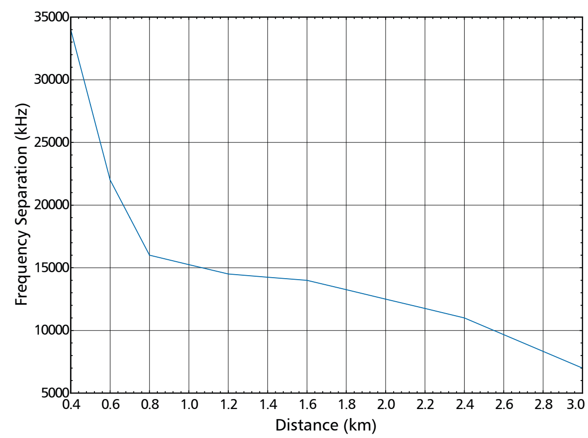

Figure 4

Figure 1 shows received interference power versus distance at a victim receiver computed using a unique short-range propagation model developed at ITS. In Figure 2, Figure 1 received interference power and the receiver sensitivity were used to compute the amount of frequency dependent rejection versus distance required to avoid interference. Figure 3 shows the amount of frequency dependent rejection available from the frequency separation between the interference source and the victim receiver. Figure 4 shows the frequency separation required versus protection distance needed to avoid interference.

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"Spectrum sharing brings challenges of its own, requiring careful coordination between users to avoid harmful interference."[1]

Interference Analysis and Mitigation

The first directive of the 2010 Presidential Memorandum "Unleashing the Wireless Broadband Revolution" called for NTIA to work with the FCC to make 500 MHz of Federal and non-federal spectrum available for wireless broadband use by 2020.[2] "To wring abundance from scarcity,[2]" and because many Federal users who operate in the most desirable spectrum bands have complex and expensive systems that cannot be easily relocated within the time frame allowed, NTIA proposed sharing as a "fast track" solution in a number of bands.[3] Other entities tasked with examining how we might "wring abundance from scarcity," such as the President's Council of Advisors on Science and Technology (PCAST) and the U.S. Government Accountability Office, also emphasized that spectrum sharing is both necessary and challenging.

Proposals for spectrum sharing between commercial and Federal users look to emerging technologies to enable interference-free sharing between entrants and incumbents. In some bands, the onus will be on entrants to devise and adopt those technologies, since incumbents may be either difficult or impossible to update due to their cost, complexity, or location. Safety-of-life systems such as radars or satellites used by the FAA, the U.S. Coast Guard, and the National Weather Service are good examples.

While it is critical that these safety-of-life systems be fully protected, entrants into bands where such devices operate must also be able to reliably operate in the presence of these systems to fully exploit the bandwidth that is being made available to them. Effective spectrum sharing and spectrum reallocation can only be accomplished if both legacy and new services operating in the same or adjacent bands can be protected from interference. First, the interference potential in both directions must be understood and quantified. Then mitigation methods can be devised, tested, and standardized.

ITS is a recognized leader in radio frequency measurements and analysis for interference diagnosis and mitigation. Particular areas of expertise range from accurate measurement and characterization of emissions from transmitters of all kinds to complex simulation and modeling of proposed communications scenarios. Interference analysis and mitigation requires skilled application of these and other areas of expertise. From root cause analysis that traces experienced interference to its source, to developing complex mathematical models capable of driving multi-parameter simulations to prevent interference in systems under development, other Government agencies and private entities look to ITS for help to make sharing work.

ITS performs measurements, analyses, and simulations for interference prevention and mitigation for other Government agencies via interagency agreements (IAs) and for private entities via cooperative research and development agreements (CRADAs). These agreements provide benefits for both the Government and the private-sector partners. In addition to performing measurements and analyses on request, ITS engineers transfer knowledge to other agencies and the private sector through training in spectrum measurement, analysis, and modeling techniques developed over more than half a century of research.

Studies for interference analysis and mitigation performed in FY 2014 are described in the following pages. Some were performed as part of the basic telecommunications research mission of ITS, others in support of Government or private research partners under IAs and CRADAs.

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1. J. Furman and J.P. Holdren, "Making the Most of the Wireless Spectrum," The White House, Office of Science and Technology Policy, July 20, 2012. Accessed http://www.whitehouse.gov/blog/2012/07/20/making-most-wireless-spectrum February 17, 2015.

2. The White House, Presidential Memorandum: "Unleashing the Wireless Broadband Revolution," June 28, 2010. Accessed http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution March 31, 2014.

3 U.S. Department of Commerce, NTIA, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands," October 2010. Accessed http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf March 31, 2014.

Coast Guard Spectrum Reallocation Study

Objectives

- *Determine interference protection criteria*
- *Develop interference testing methodologies*

Background

Despite the focus on sharing to accommodate new services that can potentially increase business productivity and enhance the private lives of citizens, spectrum reallocation is often necessary. However, reallocating services to bands near legacy services or, in some cases, in the same band used by legacy services, can cause interference that prevents the legacy service from fulfilling its mission.

Since FY 2010 the U.S. Coast Guard has engaged ITS under an IA to investigate effects of reallocation to accommodate the broadband radio service (BRS) on 2900–3100 band marine radars. The BRS is the next generation of personal communication services which will provide wideband Internet communications to mobile users.

Reallocation that leads to new commercial-Federal or Federal-Federal sharing scenarios can cause interference in three ways. First, reallocating services to nearby bands can introduce weak unwanted out-of-band or spurious signals into the legacy radio detection bandwidth. This interference cannot be mitigated by legacy receiver filtering. The reallocated service must mitigate the interference by reducing unwanted power and maintaining a minimum frequency offset and separation distance.

Second, reallocating services to nearby bands can cause legacy radio receivers not properly protected from strong signals outside the detection bandwidth to experience front end overload. This can cause gain compression, higher receiver noise levels, and intermodulation. This problem can be mitigated by legacy front end filtering. However when this is not feasible, the reallocated service must also mitigate the interference by reducing power and maintaining a minimum separation distance.

Third, reallocating services to the legacy radio band can cause co-channel interference. For example, reallocation could combine different radar services into the same band, or allocate communications links using spectrum sharing techniques into the radar band. Interference could occur if the sharing technique fails.

Analysis of the Marine Radar BRS Sharing Scenario

Figure 1 depicts the reallocation interference scenario. The BRS base stations are laid out in a grid on land. The larger ship is using a 2900–3100 band marine radar to detect the presence of the smaller ship between it and the shore. The BRS antenna is attached to a tower and is high enough to transmit the BRS signal into the radar antenna at significant distances.

Figure 2 shows the spectral relationships between the BRS signal and radar filters which can lead to interference in the radar system. Interference caused by overload can occur when the BRS signal is within the radar front end bandwidth. Interference caused by unwanted emissions can occur when the unwanted emissions are within the radar detection bandwidth.

There are two aspects to this problem. First, the marine radar community needs interference protection criteria (IPC) that can be used by regulatory agencies to determine maximum transmitted power levels and minimum frequency offsets and separation distances. Regulatory agencies of interest are the ITU, NTIA, and FCC. Second, the marine radar community needs to know how to test whether a marine radar can perform in the presence of other radio systems which satisfy the IPC. The testing methodology must be approved by test standards groups such as the United Nations/International Electrotechnical Council (UN/IEC).

In FY 2010 our work focused on examining prior work and assembling relevant models for our investigation. In FY 2011 we investigated the first potential threat—weak unwanted spurious signals from a communications link. In FY 2012 we investigated the second potential threat—radar front end overload

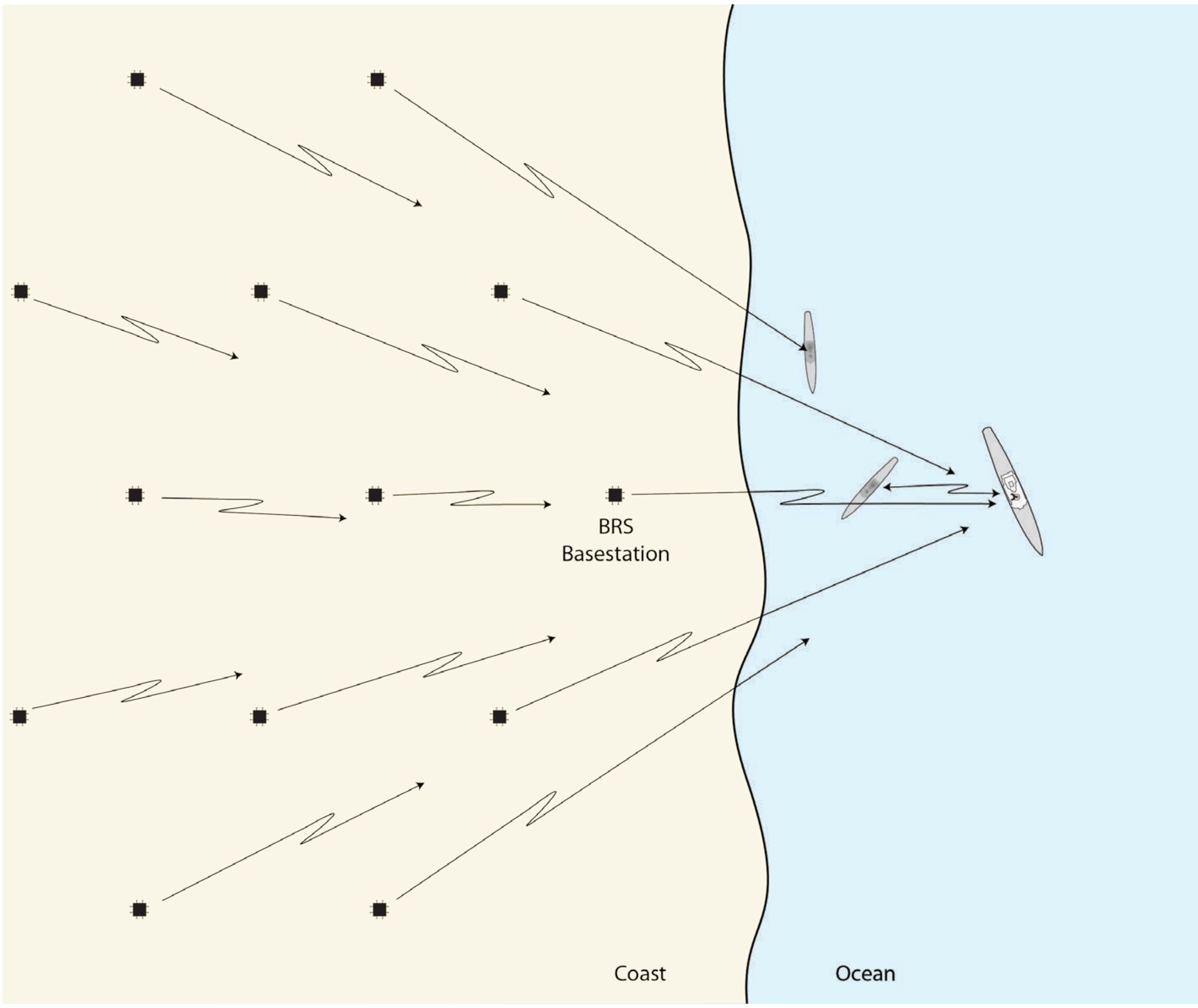

Figure 1. Interference scenario.

due to strong signals outside its detection bandwidth. In FY 2013 we focused on refining previous work and preparing final publications. The report series describing this work is in its final stages of publication. The three reports are entitled "Effect of Broadband Radio Service Reallocation on 2900–3100 Band Marine Radars" and subtitled "Background," "Base Station Unwanted Emissions," and "Front End Overload."

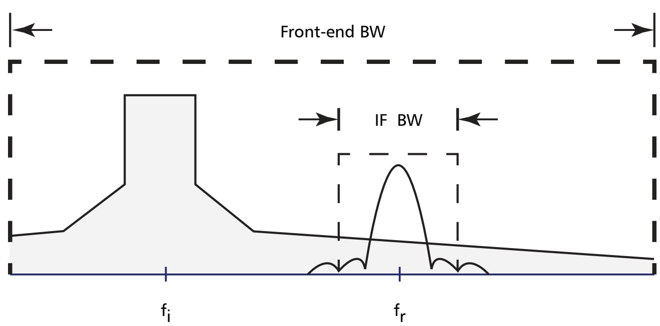

Figure 2. Spectral relationships between BRS signals and radar filters.

FY 2014 Work

All previous work focused on magnetron transmitter radar technology. Work in FY 2014 focused on comparing magnetron transmitter results to those that would be obtained with a solid-state radar. Solid state radars are attractive to mariners because of their reliability and ability to easily separate target returns from clutter returns caused by objects such as waves.

Magnetron transmitters switch the output of a high power magnetron oscillator on and off to create high power pulses. Solid state radars generate low power pulses and amplify them with solid state amplifiers. Solid state amplifiers cannot provide as much power as the magnetron oscillator. However this limitation is overcome by creating long pulses that can be compressed by the receiver and thereby achieve even higher signal to noise ratios than the magnetron radar achieves.

In addition to pulse decompression, the solid state receiver coherently integrates the received signal with a discrete Fourier transform—a process slightly more efficient than the non-coherent integration used in a magnetron radar receiver. Finally, lighter weight solid state transmitter circuitry is easier to mount on the antenna mounted at the tower top, which eliminates cable losses between the antenna and radar front-end where the first stage of amplification resides.

All these factors point to the solid state marine radar being able to detect targets at the same range and radar cross section with stronger signal to noise ratios than the magnetron radar. Consequently the solid state radar target detection is likely to be more robust than magnetron radars in the presence of spurious and out-of-band interference from BRS transmitters.

Solid state radar filter frequency responses are significantly different than those used in magnetron radars. This will impact frequency dependent rejection (FDR) and corresponding frequency offset IPC between the BRS transmitter and the marine radar center frequencies. Further work is needed to determine FDR between the solid state radar and the BRS base station.

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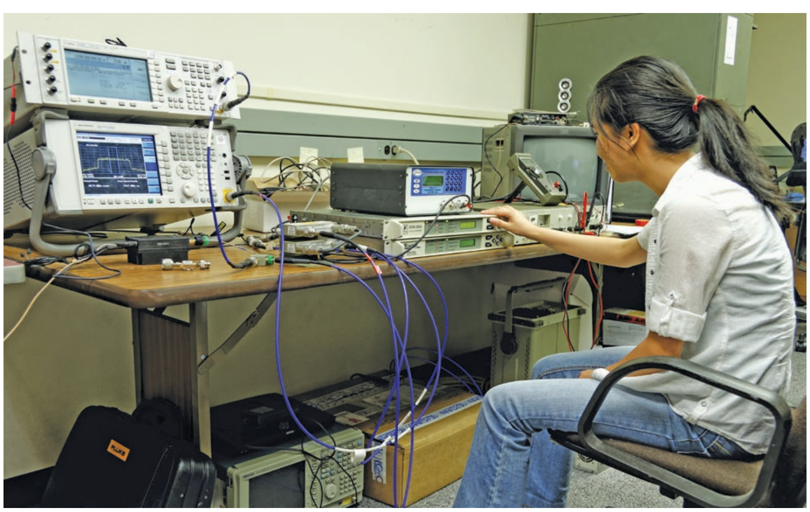
Analyses for Spectrum Sharing in Federal Bands

In FY 2014, ITS concluded a study of two systems affected by a proposed spectrum relocation of Federal broadband systems (entrants) to bands already in use by existing Federal systems (incumbents). The goal of ITS's research was to examine the interference potential between the incumbents and the proposed entrants. Based on the results of the study, ITS made recommendations to the affected agencies regarding the feasibility of maintaining seamless and mission critical communications in the potentially shared band.

In this project, ITS engineers used simulation and testing techniques to address the feasibility of successful spectrum sharing. These techniques are interrelated and each one reveals complementary information about the interference potential between systems. The comprehensive and detailed analytical evaluation that ITS provides forms a strong basis for simulating and testing interference interactions.



Engineer Linh Vu characterizes the performance of satellite modems in the presence of wideband interference in support of ITS's spectrum sharing studies. Photo by Tim Riley.

Initially, an engineering analysis of the potential interference environment requires that the characteristics of the incumbent and entrant systems in the shared band be adequately defined. The characteristics consist of the important parameters that define a given communication system. Parameters such as antenna patterns, modulation, transmit powers, and receiver sensitivity are used to accurately describe how the systems are deployed in, and react with, the interference environment.

During the discovery phase, laboratory and field testing are performed to fully verify the range of operations of each receiver and transmitter in an interference-free environment, and confirm system specifications that are relevant to interference-free transmission and reception (e.g., output power, sensitivity, signal-to-noise levels, isolation, processing gain, etc.). Operational scenarios of the systems under study are also parameterized to further refine the analysis.

It is important that the specific spectral characteristics of the transmitted signal, the electromagnetic limitations of the receiver, and an adequate description of the radio propagation environment be taken into account during the interference analysis. The radio propagation environment is typically represented by a mathematical model that describes dominant physical mechanisms that allow end-to-end communication. Years of expertise in the design and implementation of propagation models at ITS, and ITS's unique knowledge base, support fast and accurate predictions of the interference potential of a given scenario.

Related Publication: *N. DeMinco, T.J. Riley and C.J. Behm, "Electromagnetic Compatibility (EMC) Analysis Approach for Band Migration to Provide Spectrum for the President's Spectrum Initiative," IEEE International Symposium on Electromagnetic Compatibility (EMC), 2013, pp. 101–106, Aug. 2013. Available http://www.its.bldrdoc.gov/publications/2746.aspx.*

Applying an inappropriate propagation model for a given interference scenario could lead to inaccurate predictions. Decisions based on misapplied propagation predictions could result in efforts to reduce interference when none is present or to unexpected spectrum sharing conflicts because the field strength of the interfering signal is underestimated.

ITS has an extensive catalog of publicly available, and internationally adopted, frequency-dependent propagation models. Because the propagation models were developed in-house, ITS can assure project sponsors that the appropriate propagation model will be used for each scenario. These propagation models were used to characterize the shared propagation environment for the two systems under study in this case—satellite base stations and small portable devices—but they can also be used for many other communications scenarios.

Accurate characterization of communications systems will lead to more accurate determination of the interference threshold. This is accomplished through the calculation of specific signal-to-interference and interference-to-noise ratios based on the receiver's energy per bit to noise power spectral density ratio.

ITS engineers use simulations of the propagation channel, the communications systems, and usage patterns to help illuminate the complexities of an interference environment. Since the degree to which a system can be characterized analytically may be limited, simulation is used to supplement this information. Simulation can help in the development of mitigation techniques in scenarios where interference is found to be significant.

To explore how to mitigate against interference, simple simulations are performed using combinations of temporal, spatial, and spectral separations between the communications systems. All these mitigation techniques can be simulated to assure either that the services that share the band are unaffected or that the performance degradation is evident to all of those involved so appropriate error-correction methods can be applied. Simulation can also be used to simplify or replace very resource intensive measurements.

Testing is used to verify and validate the conclusions and the inevitable assumptions that are required to analyze and simulate systems with limited time and resources. Testing is also invaluable to assure the users of the shared spectrum that critical communication functions will not be interfered with and to identify the limitations in sharing a frequency band.

A satellite base station receiver antenna was mounted on the roof of the ITS laboratory for validation testing. Photo by Tim Riley.

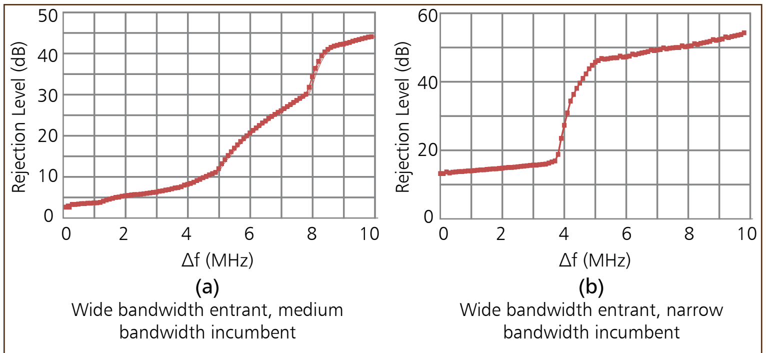


Figure 1

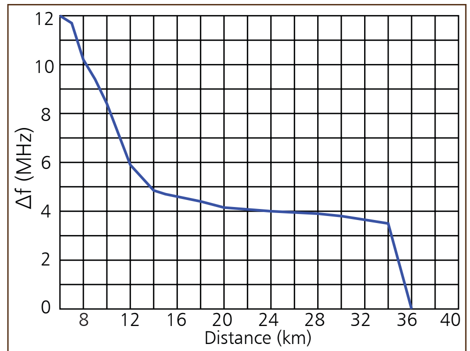


Figure 2

Figure 1. Frequency-dependent rejection versus frequency separation for a wide bandwidth entrant system and two types of incumbents. Figure 2. Frequency separation versus separation distance for a wide bandwidth entrant and a narrow bandwidth incumbent.

Figure 1 shows the performance of the target receiver for frequency offset versus receiver frequency dependent rejection. The figure represents scenarios where a wide bandwidth mobile Federal entrant system is interfering with a stationary Federal incumbent system. The incumbent system in Figure 1(a) is a medium bandwidth service; in Figure 1(b) it is a narrow bandwidth service. These types of plots graphically aid Federal spectrum managers to develop channel plans and/or establish geographic protection zones. Figure 1 indicates that the receiver will have less difficulty with interferers at spectral separations greater than 4 MHz. Figure 2 shows frequency separation versus separation distance between a wide bandwidth entrant and a narrow bandwidth incumbent. This graph shows that, given a fixed frequency separation of 4 MHz, a 20 to 34 km protection zone is needed to assure acceptable performance of the incumbent system.

ITS generalized the methods developed for this project and published the interference analysis in a conference paper delivered at the 2013 IEEE International Symposium on Electromagnetic Compatibility (EMC). An NTIA technical report describing this research in greater detail is being prepared for publication in FY 2015. This fulfills the important ITS mission objective of transferring technology to the public sector.

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Spectrum Sharing Innovation Test Bed Pilot Program

Objectives

- *Assess the effect of co-channel dynamic spectrum access device operations on the intelligibility of voice communications over government land mobile radio (LMR) systems.*
- *Confirm prior estimates of the interference range of DSA systems derived from Phase I laboratory tests.*
- *Determine the viability of DSA-based spectrum sharing in the 406–420 MHz band.*

Dynamic spectrum access may permit new radios to share spectrum with land mobile radio systems in the same band. But is this technology mature enough to ensure availability and preclude interference to mission critical public safety systems?

Background

In coordination with the FCC and other Federal agencies, NTIA established the Spectrum Sharing Innovation Test Bed pilot program to examine the feasibility of dynamic spectrum sharing between Federal and non-federal users as a means of improving spectrum efficiency and providing increased spectrum for commercial applications. This program provides an opportunity for Federal agencies to work cooperatively with researchers from industry and academia to investigate new technologies that might improve management of U.S. airwaves.

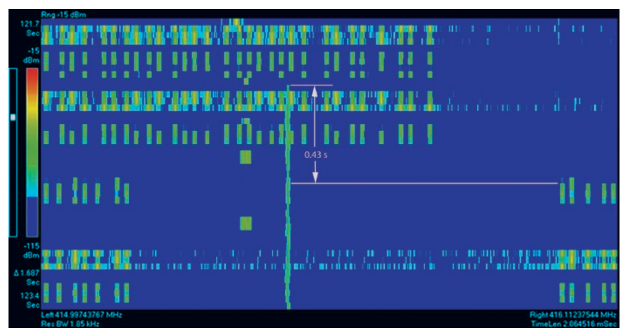
The program is evaluating the ability of dynamic spectrum access (DSA) devices that use spectrum sensing and/or geolocation techniques to share spectrum with land mobile radio (LMR) systems operating in the 410–420 MHz Federal band. DSA technology permits a transceiver to appraise its radio frequency environment using spectrum sensing and to opportunistically exploit vacant spectrum in time and frequency on a non-interference basis.

Program Design

The test bed program assesses the characteristics of several DSA devices under both lab and field conditions to determine the maturity of DSA technology and to inform the rulemaking process. The objective is to define key performance indicators for DSA devices that might permit a rulemaking and allow spectrum sharing without harmful interference to incumbent LMR systems.

The program is divided into two categories of testing. Phase I involves bench-top laboratory measurements of DSA radio characteristics such as transmitter emissions, sensor performance, and policy-based radio etiquettes. This is performed under controlled conditions at ITS's lab in Boulder. NTIA's Office of Spectrum Management (OSM) uses the lab measurement results to develop models that predict the interference potential of the devices. Key performance indicators measured in the lab suggest conditions in which DSA devices might operate without causing harmful interference to incumbent systems. Follow-on field testing performed in Phases II and III test the assumptions developed in Phase I through system-level field tests of DSA radios in live LMR environments.

DSA monitoring system deployed at a field location mimicking realistic LMR deployment conditions.



Waterfall display showing a DSA device's successful detection and avoidance of a land mobile radio signal within 0.43 seconds.

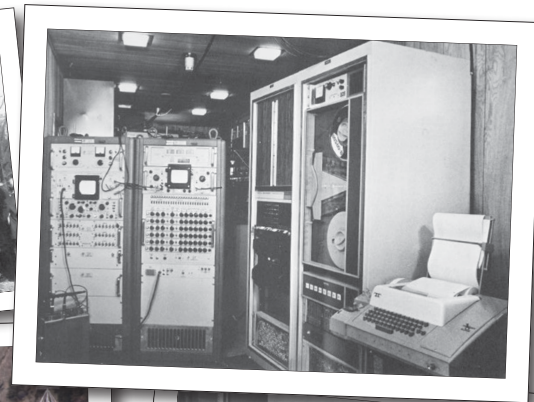
Testing is Completed on an RF Sensor

With Phase III field testing completed on two DSA devices the previous year, in FY 2014 the focus of the work shifted to a new device that was received. This was not a complete DSA transceiver but an RF sensor system with an advanced suite of detection capabilities which were of interest. Since the device lacked a transmitter, an appropriate subset of Phase I bench tests was selected for this device—namely, detection sensitivity tests using typical LMR signals and a noise signal. Testing was performed under both static and faded conditions.

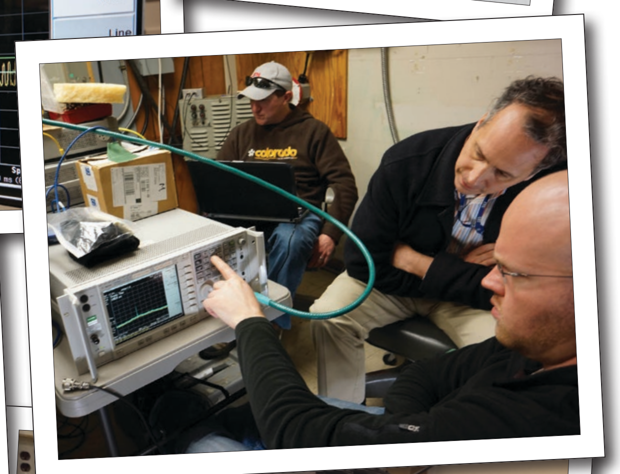
The sensor architecture was based on a commercial off-the-shelf RF sensor with customized software and a low-noise amplifier (LNA) front-end. Since the device had three different detection schemes, the battery of automated tests was repeated for each detector. Simulated Rayleigh faded signals at 5 and 60 mph were used. As expected, owing to the inclusion of an LNA, this device yielded better detection sensitivities than the previously evaluated DSA transceivers. The detectors performed best at detecting FM and P25 LMR waveforms, with detection results for noise-like waveforms yielding mixed results. Documentation of the test results was completed and delivered to NTIA/OSM, which is drafting the final report.

For more information contact Eric D. Nelson, (303) 497-7410, enelson@its.bldrdoc.gov.

The 1927 Bureau of Standards RF truck has been replaced over the years by increasingly sophisticated Radio Spectrum Measurement System mobile labs. Pictured are RSMS-1 (1973), RSMS-3 (1998), and RSMS-4 (2003). Measurement equipment and methods have also advanced, as shown in photos of ITS measurement instruments from the 1960s and 2014.






Radio Spectrum Measurements

The Table of Frequency Allocations provides only an indication of potential usage in each spectrum band. Analysis of actual assignments that identifies active and passive users and their spatial and temporal characteristics can provide greater understanding of a band's actual usage, but for a full understanding, spectrum measurements are also needed. Spectrum occupancy measurements provide information about the electromagnetic radiation actually present in a certain band at a particular location: how many signals, how strong they are, how often they occur, and on what wavelengths.

This quantitative information about actual usage is critical for validating the models and simulations used for planning and supporting spectrum management decisions regarding reallocation or sharing of spectrum to effectively and increase usage efficiency. It is simple to say that we need this information, but not simple to effect. Unless the spectrum measurement effort is carefully crafted on the basis of a sound understanding of the science, it may easily produce false spectrum occupancy results. An entire band may look occupied just because the detection threshold is not adapted to the requirements of the sub-band. On the other hand, bands that are used by low duty cycle or frequency hopping systems may look completely free because the scanning speed is too low or not enough samples are taken on each frequency.

Spectrum measurements also provide important information about the characteristics of the signals, both intended and unintended, present in a particular band. This information is critical to designing the technology to enable spectrum sharing in that band. Measurements document transmitter emissions for compliance assessment and interference analysis. Reliable measurements of the radio spectrum have informed propagation models, regulatory decisions, and telecommunications technology development since the first Department of Commerce spectrum measurements were taken in 1909.

Outputs

- *Measurements of patterns of radio spectrum usage*
- *Detailed band-by-band measurements of percentage occupancy*
- *Spectrum monitoring on a band-by-band basis*
- *Transmitter emission spectra*
- *Radio regulation compliance verification for transmitters*
- *Interference assessments and resolution*

ITS Radio Spectrum Measurements in FY 2014

Since its inception, ITS has developed and deployed state-of-the-art spectrum measurement systems. Outputs have included broadband spectrum surveys, measurements of emissions from individual transmitters, resolution of radio interference problems, and documentation of transmitter emission compliance with Federal standards such as the Radar Spectrum Emission Criteria (RSEC). The outputs from over five decades of such measurements, including NTIA Reports, ITU contributions, and hundreds of inputs to decision-makers in numerous Federal agencies and private sector entities, have had broad impacts on Federal and private sector spectrum planning and use.

In FY 2014, ITS performed a wide range of spectrum measurements while also continuing to develop next-generation measurement system hardware and software. ITS performed spectrum measurements on a number of radar transmitters, including two naval radars, a new model of tactical ground-based military air surveillance radar, and a major airborne military multi-mode radar. The naval radars were measured under ITS and OSM projects as part of a larger 3.5 GHz spectrum sharing investigation, the tactical radar was measured under an interagency agreement (IA), and the airborne radar was measured under a cooperative research and development agreement (CRADA). The tactical and airborne radars were measured for their compliance with the NTIA RSEC; demonstrated compliance with the RSEC brought these radars to what is called Stage IV (final-stage) spectrum certification, meaning that they can be deployed by their operating agencies on an effectively unlimited basis.

In FY 2014, ITS engineers also published three spectrum survey reports. Two of these presented broadband survey results for VHF through 10 GHz bands in large metropolitan areas: San Diego and Chicago. The third focused on activity in a single band, 3550–3650 MHz, in the San Diego area. These reports parsed spectrum usage in the surveyed bands in terms of percentage of time that frequencies were occupied and power levels of received signals on a frequency-by-frequency basis over long periods (weeks) of time. The 3550–3650 MHz band measurements were performed in a band that is being considered for future spectrum sharing under an FCC Notice of Proposed Rulemaking (NPRM) and Further NPRM; it showed levels and amounts of activity in this band due to incumbent radar systems in an area where many of them are routinely operated on ships offshore.

Other notable spectrum measurements performed in FY 2014 include examinations of new versions of time division duplexed (TDD) and frequency division duplexed (FDD) LTE transmitters designed to operate in a new band for spectrum sharing, near 3.5 GHz. The LTE signals were measured at manufacturers' research lab facilities with ITS suitcase measurement systems. The measurement dynamic ranges were limited due to the low amount of power available from the LTE transmitters. But the collected data was sufficient to show that these new types of 3.5 GHz LTE transmitters had much in common with other types of WiMAX transmitters previously measured by ITS.

ITS engineers continued spectrum measurement system development in hardware and software. They prototyped two new radiofrequency (RF) front end designs: a compact RF front end for wideband measurements in a single band or a limited set of bands, and an RF front end for dedicated monitoring in one or two bands at a time. The first unit, pictured here, is designed to be used with fifth-generation Radio Spectrum Measurement System (RSMS-5G) spectrum measurement software. The other unit was developed in collaboration with the Spectrum Monitoring Project described on page 20 and is designed for use with a new, dedicated spectrum monitor being built for future advanced spectrum sharing between radars and non-radar systems at 3.5 GHz. Both units are smaller and lighter-weight than existing RSMS RF front ends, albeit with more limited capabilities. Development also continued on software for measuring usage levels for broadband surveys.

Related Publications:

- *F.H. Sanders, J.E. Carroll, G.A. Sanders and L.S. Cohen, "Measurements of Selected Naval Radar Emissions for Electromagnetic Compatibility Analyses," NTIA Technical Report TR-15-510, Oct. 2014. Available http://www.its.bldrdoc.gov/publications/2781.aspx.*
- *G.A. Sanders, J.E. Carroll, F.H. Sanders and R.L. Sole, "Effects of Radar Interference on LTE (FDD) eNodeB and UE Receiver Performance in the 3.5 GHz Band," NTIA Technical Report TR-14-506, Jul. 2014. Available http://www.its.bldrdoc.gov/publications/2759.aspx.*
- *C.Hammerschmidt, "Broadband Spectrum Survey in the Chicago, Illinois Area," NTIA Technical Report TR-14-502, Apr. 2014. Available http://www.its.bldrdoc.gov/publications/2756.aspx.*
- *M.G. Cotton, and R.A. Dalke, "Spectrum Occupancy Measurements of the 3550-3650 MHz Maritime Radar Band Near San Diego, California," NTIA Technical Report TR-14-500, Jan. 2014. http://www.its.bldrdoc.gov/publications/2747.aspx.*
- *F.H. Sanders, J.E. Carroll, G.A. Sanders and R.L. Sole, "Effects of Radar Interference on LTE Base Station Receiver Performance," NTIA Technical Report TR-14-499, Dec. 2013. Available http://www.its.bldrdoc.gov/publications/2742.aspx.*

ITS compact RF front end containing noise diode calibration source, wide-range stepped RF attenuator, yttrium iron garnet (YIG) tunable microwave bandpass filter and low-noise amplifiers. Operates at frequencies up to 18 GHz. Photos by Frank Sanders.

For more information contact Frank Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov

National and International Standards Development

NTIA contributes to the development and application of national and international telecommunication standards by leading, participating in, and making technical contributions to various voluntary national and international telecommunication standards committees, such as the 3rd Generation Partnership Project (3GPP), International Telecommunication Union (ITU), and Alliance for Telecommunications Industry Solutions (ATIS). ITS provides technical expertise and guidance in the development of telecommunications standards to these standards bodies and, through interagency agreements, to other Federal agencies that have particular telecommunications concerns. ITS founded and continues to play a significant role in the Video Quality Expert Group (VQEG), which is presently focused on validation of new objective video quality metrics for standardization purposes. In FY 2014, NTIA staff held six Chair or Co-chair, one International Chair, and four U.S. Chair or Co-chair positions in these bodies, providing technical leadership that is trusted by commercial-sector and international participants.

In FY 2014, intense participation by ITS engineers in the 3GPP standards development process on behalf of the Public Safety Communications Research program and FirstNet resulted in Proximity Services and Group Communications requirements being included in the final agenda for 3GPP Release 12 and Mission Critical Push to Talk being included in the final agenda for 3GPP Release 13. These features are critical to ensuring that LTE can meet public safety's requirements and a prerequisite to allowing FirstNet to offer mission-critical voice (MCV) on the new Band Class 14 nationwide interoperable public safety communications network when these capabilities become available. Pursuing global commercial standardization of mission-critical public safety features is the first step in moving 15 million users in over 60,000 emergency response agencies nationwide away from the niche technology of the past—Land Mobile Radio (LMR)—to an advanced technology being embraced by the commercial marketplace.

ITS experts, working closely with policy experts from NTIA's Office of International Affairs, also provide technical expertise to the ITU, a treaty organization that provides a neutral platform for shaping global consensus on the standards that enable a seamless robust, and reliable, global communications system. The ITU holds the World Radiocommunication Conference (WRC) every two to three years to establish frequency allocations and regulatory procedures for the harmonious operation of global radiocommunication services. Global coordination of spectrum allocations ensures that services are not impaired by interference of competing signals and transmissions. ITU standards (called Recommendations) act as defining elements in the global infrastructure of information and communication technologies and play a critical role in advancing global interoperability and creating a level playing field in which companies can compete internationally. These are developed by consensus in Study Groups of public and private sector experts who provide input in the form of technical contributions.

Working with the U.S. ITU National Committees, ITS provides technical contributions and leadership to ITU-R (Radiocommunication Sector) and ITU-T (Telecommunication Standardization Sector) committees that develop technical standards of importance to U.S. industry and government. ITS also develops and coordinates approval of related U.S. voluntary consensus standards where appropriate. ITS recommendations are, and for decades have been, highly valued both nationally and internationally: a plurality of the technical recommendations of the ITU are based on research conducted at ITS, and key national quality-of-service standards developed under the American National Standards Institute (ANSI) accredited Committee T1 for video, audio, and digital data incorporate research results obtained at ITS.

ITU-R Standards Activities

Objectives

- *Develop and maintain internationally standardized radio propagation models for studies being conducted by the ITU-R*
- *Provide U.S. and international users of ITU-R Propagation Recommendations with expert advice on the contents and bases for these Recommendations*
- *Update the IF-77 propagation model to reflect advances in measuring propagation components*
- *Contribute to domestic and international working groups studying Earth-to-space and in-building communication links*

Background

The ITU-R is seen by many as the single most important worldwide telecommunications regulatory and standardization body. Entities such as government agencies, businesses, and academia use Recommendations developed by the ITU-R to study, plan, and develop radiocommunication systems. Within the ITU-R, Study Groups develop the technical bases for decisions taken at WRCs and develop Recommendations, Reports, and Handbooks on radiocommunication matters. ITS has long provided technical contributions and expert leadership to support U.S. interests in the ITU-R.

Study Group 3 (SG 3) of the ITU-R is responsible for Recommendations in the P series, which pertain to propagation issues. ITS, with its long technical history in propagation modeling, is well suited to support SG 3 work. In the 2014 meetings of the ITU-R SG 3 the U.S. delegation submitted 17 technical contributions on various engineering issues and subject areas. In particular, engineers ITS volunteered to lead the Correspondence Group on Building Entry Loss. This group is critical to LTE deployment across the world and represents millions if not billions of dollars in potential commercial development.

Other areas in which ITS contributes internationally recognized technical leadership are Spectrum Management (Study Group 1), Terrestrial Services (Study Group 5) and Integrated broadband cable networks and television and sound transmission (Study Group 9). ITS staff join over 4,000 specialists, from administrations, the telecommunications industry as a whole, and academic organizations throughout the world, to participate in the work of these Study Groups through smaller, specialist groups called Working Parties.

Internationally Standardized Propagation Models

Successful spectrum sharing requires careful planning to avoid interference between different users. To meet the objectives of spectrum flexibility and harmonization for the joint studies being conducted by the ITU-R, prudent spectrum management practice dictates that predicted harmful interference must be minimized both to and from the existing, incumbent services and the new (i.e., mobile) services. Radio propagation prediction models are powerful tools for building international consensus around the introduction of these new services.

Some international standards for propagation modeling are based on models developed by ITS from our extensive background in radio propagation. ITS continues to update all of its propagation models to reflect contemporary conditions and equipment. As well as presenting updates as contributions towards international standards, our work in this area includes ensuring that the best methods for accurate and realistic planning are available to both Federal and civilian users in the U.S. via IAs and CRADAs, respectively, as described in the section on Propagation Modeling on page 65.

When properly applied, propagation models provide accurate methods for evaluating the potential for interference arising from proposed spectrum reallocation and/or sharing scenarios. When these radio propagation prediction models are also ITU Recommendations, they are generally perceived as technically neutral and unbiased bases for multilateral coordination, regulation, and harmonization of spectrum.

JTG 4-5-6-7

In the 2012 World Radiocommunication Conference (WRC-12) the U.S. delegation successfully secured two agenda items for the 2015 World Radiocommunication Conference (WRC-15). WRC-15 Agenda Item 1.1 asks the ITU to consider allocation of additional spectrum to the mobile service on a primary basis to facilitate the development of terrestrial mobile broadband applications, and Agenda Item 1.2 proposes the use of the 694–790 MHz band by the mobile, except aeronautical mobile, service. A Joint Task Group of experts from four of the seven standing Study Groups (JTG 4-5-6-7) was established within the ITU-R as the responsible group for these two WRC-15 Agenda Items, to conduct the necessary sharing studies and to develop the necessary preparatory text. This ensures the opportunity for all stakeholders to participate during the sharing study work, and sets the international framework in motion to advance the U.S. Administration's Broadband Wireless Initiative at WRC-15. Owing to the importance of the work of JTG 4-5-6-7 and the very aggressive schedule for its completion, Working Party (WP) 3K has continued its work inter-sessionally via correspondence.

Earth-to-Air-to-Space Propagation Models

Different propagation models have been developed and standardized for different types of radio links under different conditions. For example, to accurately model transmission links for Earth to air, Earth to space, and air to space, the special conditions required to predict the transmission losses and interference levels from these specific applications must be included in the model. One candidate for sharing that falls into this category is the 1695 MHz band, which has both national and international allocations for space to Earth satellite transmission. Satellite systems can be vulnerable candidates for spectrum sharing: mistakes are costly to correct and might even be unfixable.

Unfortunately, there are only a few appropriate propagation models available for aeronautical and satellite wireless links. One of these is Recommendation ITU-R P.528, "Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF band," which gives a method for predicting basic transmission loss for aeronautical and satellite services. To accurately model transmission links for Earth to air, Earth to space, and air to space, the special conditions required to predict the transmission losses and interference levels from these specific applications must be included in the model. ITU-R P.528, which was developed from the

FY 2014 ITU-R Technical Contributions

ITS engineers prepared seven of the 17 U.S. technical contributions for the September 2014 block meetings of Working Parties 3J, 3K, 3L and 3M in Geneva, Switzerland. Of these seven, five were contributions to Working Party 3L:

- Document 3L/82: "Analysis of proposed "Over the MUF" loss calculation for Recommendation ITU-R P.533-12"
- Document 3L/83: "Comparison between ITU-R D1 database and ITU-R HF Prop Version 4.14.0.1"
- Document 3L/84: "Proposed draft changes to Recommendation ITU-R P.533-12 for clarification - Determination of "not otherwise included loss""
- Document 3L/85: "Comparison between ITU-R D1 Database and ITU-R HF Prop with absorption loss and E-layer screening modifications"
- Document 3L/86: "Procedure for selecting between the six methods for calculating the ground wave electric field strength"

Two of the seven were contributions to Working Party 3K:

- Document 3K/95: "Proposed revisions to Recommendation ITU-R P.528-3"
- Document 3K/96: "Preliminary draft new Report defining propagation model for Recommendation ITU-R P.528-3"

Additionally, an ITS engineer served as the International Chair of Working Party 3K. In this capacity, four liaison statements were drafted inter-sessionally: Documents 3K/80, 3K/81 (3M/127), 3K/84 (3M/128) and 3K/87 (3M/138), the last three of these being joint liaison statements with the Chairman of WP 3M. A Chairman's Report of the meeting of Working Party 3K (Document 3K/114) was also prepared.

ITS model IF-77, has been of particular interest in recent years because of its high altitude component. This high altitude component is critical for spectrum sharing studies among satellite services and between satellite services and terrestrial broadband services in bands proposed for sharing, such as the 1695 MHz band, which has both national and international allocations for space to Earth satellite transmission. In addition, propagation models with a high altitude component are needed to plan for the expanding role of unmanned vehicles and consequent spectrum required for communication and control of such vehicles.

The ITS-led correspondence group for the revision of Recommendation P.528 is has been developing and verifying a computational method for this Recommendation. Again, the basis for this work will be the ITS propagation model IF-77. Users could use this computational method to calculate interference levels with other systems and separation distances between Earth-based stations. ITS's work in both aeronautical and unmanned airborne systems is essential to studies to evaluate frequency sharing proposals, and provides important contributions to the expanded ITU SG 3 investigations into all airborne platforms (Question ITU-R 233/3). The calculations based on the future computational method for P.528 and prediction method(s) likely to come out of the SG 3 investigations for airborne platforms will also be important in planning both satellite and aeronautical systems.

For more information contact Paul M. McKenna, (303) 497-3474, pmckenna@its.bldrdoc.gov

ITU-T and Related Standards Activities

Objectives

- *Promote QoS/QoE standards through leadership roles in ITU-T Study Group 9 and the Video Quality Experts Group*
- *Develop and present technical contributions with U.S. standards proposals and ITS research results*
- *Work within the ITU-T to improve working methods by helping to revise key Recommendations and Resolutions*

Overview

The Institute has a long history of leadership, technical contributions, and advocacy of U.S. Government and industry proposals in the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) and related U.S. standards organizations. In addition to the ITU-T, ITS experts provide input to the Alliance for Telecommunications Industry Solutions (ATIS) and the Society of Cable Telecommunications Engineers (SCTE), both North American partners for international SDOs.

The Institute's long-term goal in ITU-T, ATIS, and SCTE is to motivate the standardization of user-oriented, technology-independent measures of telecommunication service quality (QoS/QoE), and to relate those measures to the technology-specific performance metrics and mechanisms providers use to provision and operate networks. This work promotes fair competition and technology innovation in the telecommunications industry, facilitates inter-working among independently-operated networks and dissimilar technologies, and helps users define their telecommunication needs and select products and services to best meet them. This facilitates the optimization and efficient use of spectrum and bandwidth resources.

ITU-T Study Group 9

ITU-T SG 9 (Broadband cable and TV) carries out studies on the use of telecommunication systems for broadcasting of television and sound programs and the use of cable television networks to provide interactive video services, telephone, and data services, including Internet access. Among the Recommendations standardized by ITU-T SG 9 are those defining video and multimedia quality assessment and those supporting emergency telecommunications over broadband cable networks. SG 9 also develops Recommendations on digital transmission systems, digital rights management, and program insertion specifications, all for cable television systems.

Arthur Webster of ITS (second from left) Co-chaired the Joint Plenary Session of ITU-T SG 9 and SG 12 at ITU Headquarters in Geneva, Switzerland in December 2013. Left to right: Stefano Polidori (ITU-T SG 9 Advisor), Arthur Webster (SG 9 Chair), Kwame Baah-Acheamfuor (SG 12 Chair), Hiroshi Ota (SG 12 Advisor).

In FY 2014, ITS staff members held several prestigious leadership roles in the ITU-T, including International Chair of SG 9, Head of the U.S. Delegation to SG 9, and Co-chair of the ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA) and the Intersector Rapporteur Group on Audiovisual Quality Assessment (IRG-AVQA). ITS staff also served as SG 9 representative for Audiovisual Media Accessibility (AVA), Associate Rapporteur for Questions 2/9 (Measurement and control of the end-to-end quality of service (QoS) for advanced television technologies) and 12/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9), and SG 9 contact for Electronic Working Methods.

VQEG

An ITS staff member co-founded the Video Quality Experts Group (VQEG) and has co-chaired it since 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics (VQM). The group's reports strongly impact the standardization of VQMs in both ITU-T and ITU-R. VQEG works largely via several e-mail reflectors, publicly accessible at http://www.VQEG.org. During FY 2014, the number of participants subscribed to the main reflector reached over 500. VQEG produces independent validation data, which the U.S. considers to be a key prerequisite for standardizing a VQM. Thus, VQEG acts as a cooperative technical advisory committee that facilitates standardization efforts in ITU-T SG 9, SG 12 (Performance and Quality of Service (QoS)), and ITU-R Working Party (WP) 6C (Broadcasting Services—Programme Production and Quality Assessment) to develop objective, computer implementable, perception-based video and multimedia quality metrics that emulate the human visual system.

ITS staff members provide key leadership and technical contributions to VQEG. Arthur Webster co-chaired VQEG and chaired the two meetings that occurred in FY 2014. Margaret Pinson co-chaired VQEG's audiovisual high-definition television (AVHD) and Independent Laboratory Group (ILG) groups and spearheaded the final analyses and documentation for the hybrid effort to validate objective measurements of video quality. ITS has been very active in developing the Hybrid Perceptional-Bit-Stream test plan and organizing the test. Through the combined efforts of several ITS projects, the Institute provided key video source material that comprises most of the validation sequences used in the VQEG's current testing efforts. ITS is spearheading new ITU-T work on audiovisual quality assessment and Internet video quality assessment through its leadership in VQEG and ITU-T SG 9.

The Video Quality Experts Group January 2014 meeting was hosted by ITS at the Department of Commerce Boulder Laboratories. Photo by Arthur Webster.

IRG-AVQA

In related work, ITS leads the ITU-T's Intersector Rapporteur Group on Audiovisual Quality Assessment (IRG-AVQA). This group supersedes the JRG-MMQA and is a cross-cutting ITU standards body that unites the video quality expertise of SG 9 and SG 12 in the ITU-T with the quality experts in the ITU-R SG 6 in an effort to develop objective, perception-based metrics for combined audio and video signals in mobile, broadcast, cable, and PC environments. The IRG-AVQA meets concurrently with VQEG and has additional sessions co-located with Study Group meetings. The IRG-AVQA provides an official mechanism for coordinating VQEG activities with ITU-T SG 9, ITU-T SG 12, and ITU-R SG 6.

At the 2012 Telecommunications Standardization Assembly (WTSA-12), a new mechanism for facilitating technical work across the ITU-T and ITU-R Sectors was approved. In early FY 2014, the JRG-MMQA was replaced by the IRG-AVQA. This expands both the scope and the reach of this joint ITU work by expanding the technical terms of reference and by including the ITU-R SG 6 in the first official Intersector Rapporteur Group in the history of the ITU. During FY 2014 SG 9 became party to three Intersector Rapporteur Groups.

Preparation for U.S. Participation in ITU World Conferences

In addition to direct participation in the technical committees discussed above, an ITS engineer participated in the State Department's U.S. preparatory process for the Telecommunication Standardization Advisory Group (TSAG). Arthur Webster attended TSAG and the ITU-T Review Committee (REVCOM) on the U.S. Delegation and presented reports on SG 9.

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Public Safety Communications Interoperability

The Government's interest in ensuring the availability of wireless communication for the safety of the public has been acknowledged since the earliest days of the 20th century. The first two-way transmission of wireless telegraphy across the Atlantic took place in 1906; three years later, a liner involved in a collision off Nantucket Island sent the first distress call, leading to the rescue of over a thousand people. After the sinking of the Titanic, when distress calls went unanswered for four hours because the closest radio operators were off-shift, the Wireless Ship Act of 1912 required that all large ships have 24 hour radio communication capability. That act also delegated to the Department of Commerce the authority to enforce wireless communication laws, treaties, and conventions, and to regulate radio communication by issuing licenses to operate in order to prevent or minimize interference.

Since that time, the radio laboratories of the DoC have worked hand in hand with other government agencies at all levels to improve public safety communications—from radio signaling for military operations in World War I to the first radio beacons for airway safety in the 1920s to World War II and the birth of radar to the advent of digital radio in the 1970s and 1980s to the present-day work with the First Responders Network Authority (FirstNet)—the body mandated to establish a nationwide, interoperable public safety broadband network by legislation passed in 2012, 100 years after the Wireless Ship Act.

ITS has worked with the NIST Communications Technology Laboratory (NIST/CTL) Public Safety Division and its predecessors for decades to conduct research and contribute to standardization efforts to assist fire, emergency medical, and law enforcement agencies to select and procure communications equipment that meets their needs. Since FY 2003, this work has been carried out through the Public Safety Communications Research (PSCR) program (www.pscr.gov), a joint effort that leverages the capabilities of NIST/CTL and ITS through collaborative research projects.

PSCR is one of the largest sponsored programs at the Institute. The program conducts broad-based technical efforts aimed at facilitating communications interoperability and information sharing within the public safety community. The sponsors of the program's research include the Department of Homeland Security (DHS) Office for Interoperability and Compatibility (OIC), the DHS Office for Emergency Communications (OEC), and FirstNet. PSCR projects are planned and performed with coordination among local, state, tribal, and Federal practitioners. Technical thrusts within the program include public safety broadband requirements and standards, the PSCR Broadband Demonstration Network, and public safety broadband research.

Public Safety Broadband Requirements and Standards

Objectives

- *Identification of public safety broadband communications requirements*
- *Representation of the First Responder Network Authority in standards development*

Overview

In 2010 the FCC published the National Broadband Plan, which outlines how broadband spectrum will be utilized in the future. The Plan also proposed the development and implementation of a nationwide interoperable public safety broadband communications network. In order to assure that the nationwide network would be interoperable across agencies, jurisdictions, and regardless of manufacturer, PSCR actively participated in the requirements gathering and standards development process on behalf of public safety. Following enactment of the Middle Class Tax Relief Act of 2012 and the creation of FirstNet, the PSCR standards team now directly represents FirstNet, and thus all public safety in the United States, in all broadband standards development. Coordinated implementation of a public safety broadband network under a single network operator—FirstNet—presents a unique opportunity for public safety to define their requirements before deployment and to potentially preemptively eliminate the interoperability problems that have plagued public safety in land mobile radio.

Activities

PSCR has been active in the requirements gathering and standards development process for public safety broadband communications since its inception in 2003. PSCR actively participated in the Telecommunications Industry Association (TIA) standards process for land mobile radio and has long-standing relationships with many public safety organizations that focus on defining requirements for public safety communications. PSCR is uniquely positioned to represent public safety as new broadband technologies are tested in PSCR's Demonstration Network and as the nationwide network is built out.

- PSCR led the creation of the SAFECOM Statement of Requirements in 2004, which was a spectrum and technology agnostic perspective of advanced public safety communications
- PSCR led the National Public Safety Telecommunications Council's (NPSTC) Broadband Working Group to develop a 700 MHz Broadband Statement of Requirements in 2007
- PSCR led the NPSTC Broadband Task Force Technology Working Group, which addressed interoperability issues and delivered its report and recommendations in August 2009
- PSCR led the NPSTC Broadband Working Group in the creation of the qualitative Mission Critical Voice Requirements document in 2011
- PSCR led the NPSTC Broadband Working Group in the creation of the Local Control and Priority & Quality of Service Requirements documents in 2012
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Public Safety Launch Requirements to the FirstNet Board in 2012
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Mission Critical Push To Talk over LTE Requirements to the FirstNet Board in 2013
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Definition of Public Safety Grade Systems and Facilities to the FirstNet Board in 2014
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Public Safety Console for LTE Requirements to the FirstNet Board in 2014

In its standards development efforts, PSCR also represents FirstNet as a member of the organizations that are collectively responsible for developing the standards for the LTE technology selected by public safety for 700 MHz broadband—the 3rd Generation Partnership Project (3GPP, a collaboration among six telecommunications standards bodies to produce globally-applicable cellular system specifications); the Alliance for Telecommunications Industry Solutions (ATIS, the founding North American Organizational Partner of 3GPP); the Open Mobile Alliance (OMA, a standards body which develops open standards for the mobile phone industry); and the GSM Association (GSMA, an international association of mobile operators and related companies that supports GSM mobile telephone standardization).

As a result of PSCR's involvement, public safety was identified as the top priority in 3GPP for Release 12. PSCR currently represents FirstNet in ensuring Release 12 LTE products contain two critical features for public safety: efficient group communications capabilities and direct mode capability. Additionally, PSCR is representing FirstNet in 3GPP to ensure that Release 13 LTE products have a mission critical push to talk over LTE capability, and is working with DHS OIC for the standardization of video for public safety over LTE in Release 14.

As part of its requirements and standards work, PSCR is coordinating with public safety organizations in the United Kingdom, continental Europe, Canada, and Australia as they begin to develop public safety broadband efforts for their first responders.

Principal Relevant Requirements and Standards Documents

- SAFECOM Statement of Requirements (SoR) for Public Safety Communications Interoperability (2006–2008)
- NPSTC Public Safety 700 MHz Broadband Statement of Requirements (SoR) (2007)
- NPSTC Broadband Task Force Requirements
- NPSTC Mission Critical Voice Communications Requirements for Public Safety Functional Description (2011)
- NPSTC LC21 "Local Control in the Nationwide Public Safety Broadband Network," Rev. F, March 19, 2012
- NPSTC "Priority and QoS in the Nationwide Public Safety Broadband Network," Rev 1.0, April 17, 2012
- NPSTC Public Safety Broadband High-Level Launch Requirements, Statement of Requirements for FirstNet Consideration (December 7, 2012)
- NPSTC Public Safety Broadband Push-to-Talk over Long Term Evolution Requirements A NPSTC Public Safety Communications Report (July 18, 2013)
- 3GPP TR22.803 Feasibility study for Proximity Services (ProSe) (Release 12) V12.2.0 (2013-06)
- 3GPP TS22.278 Service requirements for the Evolved Packet System (EPS) (Release 12) V12.4.0 (2013-09)
- 3GPP TS22.115 Service aspects; Charging and billing (Release 12) V12.2.0 (2013-09)
- 3GPP TR23.703 Study on architecture enhancements to support Proximity based services (ProSe); (Release 12) V12.0.0 (2014-02)
- 3GPP TS23.303 Proximity based services (ProSe); Stage 2 (Release 12) V12.0.0 (2014-02)
- 3GPP TS22.468 Group Communications System Enablers for LTE (GCSE_LTE) (Release 12) V12.0.0 (2013-06)
- 3GPP TS23.768 Study on architecture enhancements to support Group Communication System Enablers for LTE (GCSE_LTE) V12.0.0 (2014-02)
- 3GPP TS23.468 Group Communications System Enablers for LTE (GCSE_LTE); Stage 2 (Release 12) V12.0.0 (2014-02)
- 3GPP TR36.843 Study on LTE Device to Device Proximity Services; Radio Aspects (Release 12) V12.0.1 (2014-03)
- 3GPP TR36.868 Study on group communication for E-UTRA (Release 12) V12.0.0 (2014-03)
- 3GPP TR 33.833 Study on security issues to support Proximity Services (Release 12) V0.4.0 (2014-02)
- 3GPP TR 33.888 Study on security issues to support Group Communication System Enablers for LTE (GCSE_LTE) (Release 12) V0.2.0 (2014-01)
- 3GPP TS 33.246 Security of Multimedia Broadcast/Multicast Service (MBMS) (Release 12) V12.1.0 (2014-09) (See Annex N)
- 3GPP TS 33.107 3G security; Lawful interception architecture and functions (Release 12) V12.8.0 (2014-09) (See clause 16 and 17)
- 3GPP TR 36.877 LTE Device to Device Proximity Services; User Equipment (UE) radio transmission and reception (Release 12) V0.0.4 (2014-08)
- 3GPP TS 36.101 Evolved Universal Terrestrial Radio Access (E-UTRA) User Equipment (UE) radio transmission and reception (Release 12) V12.5.0 (2014-09) (Changes to address D2D)

Value to Public Safety

Broadband technology presents a significant opportunity for public safety agencies to use a nationwide interoperable communications network that meets the unique needs of first responders and is deployed by a single network operator (FirstNet). There are as many as five million public safety users in the country. The newly available 700 MHz spectrum will let public safety adopt broadband technologies that support high-speed data transmission across long distances, creating access to video, mapping, GPS applications, and more. It is crucial that public safety's requirements be incorporated into standards so that Federal grant dollars and taxpayer dollars are spent only on equipment that is interoperable and allows first responders to better carry out their mission of protecting lives and property.

PSCR Broadband Demonstration Network

Objectives

- *Technical contributions to the public safety community specific to Long Term Evolution (LTE) technology*
- *Technical contributions and support to the First Responder Network Authority (FirstNet)*
- *Cooperative research and development agreements with public safety broadband vendors*

Overview

Public safety land mobile radio (LMR) networks have traditionally been built by individual localities or on a statewide basis. Stove-piped proprietary systems and non-contiguous spectrum assignments have long impeded effective cross agency/jurisdiction public safety LMR communications. To avoid similar issues with new broadband technology, Congress made spectrum in the newly cleared 700 MHz frequency band available to public safety for a unified nationwide public safety broadband system. The FCC and public safety leadership are working to develop baseline requirements for interoperability on this system.

PSCR leads this effort, tailoring it to the unique operational and technical requirements specific to broadband communications for public safety. Deploying new cellular technologies nationwide will be far more complex than building local or even regional networks, and require an unprecedented level of coordination. The PSCR Broadband Demonstration Network, established in FY 2010, facilitates accelerated development of testing for emerging LTE broadband equipment specific to public safety. It is an independent, vendor-neutral venue where public safety agencies can test equipment and identify interoperability issues prior to building or altering their networks.

Title VI—Public Safety Communications and Electromagnetic Spectrum Auctions of the Middle Class Tax Relief and Job Creation Act of 2012, enacted as Public Law 112-96 on February 22, 2012, created the First Responder Network Authority (FirstNet). FirstNet is tasked with establishing a nationwide public safety broadband network (NPSBN). This legislation also reallocated the D Block spectrum to public safety and created funding mechanisms for the network via spectrum auctions. The PSCR Broadband Demonstration Network will be leveraged for the research, development, and testing aspects in support of FirstNet's vision for the NPSBN. As part of its role in assisting FirstNet activities to build out the NPSBN, the PSCR Broadband Demonstration Network will also support technical contributions to 3GPP.

Goals of the Demonstration Network

National telecommunications companies maintain sophisticated test networks and dedicated laboratories to ensure that selected equipment meets their specifications and to identify interoperability issues prior to building their networks or adding new features, hardware, or software. The Public Safety Broadband Demonstration Network was established at the U.S. Department of Commerce Boulder Laboratories to provide an equivalent Government lab facility in the U.S. where the fragmented, resource-constrained community of public safety agencies could test and demonstrate public safety 700 MHz broadband networks and applications. This over-the-air broadband demonstration network and laboratory, operating in the public safety broadband spectrum (LTE Band Class 14), leverages the expertise of the PSCR staff and the unique assets of the Boulder Laboratories—specifically, the Table Mountain Field Site and Radio Quiet Zone and the Green Mountain Mesa Test Site.

The Demonstration Network is made available through CRADAs for manufacturers and carriers to test the deployment of LTE systems in a multi-vendor environment. It serves as an educational site for public safety by allowing interested agencies to observe these systems and execute specific test cases that are unique to their operational environment. The PSCR Broadband Demonstration Network's goals are to:

- Assess the defined open interfaces associated with LTE that will ensure interoperability for the public safety broadband system.
- Demonstrate broadband air-interface and core network capabilities to provide proof of concepts, improve quality of future systems, and create new technology and requirement benchmarks.
- Evaluate broadcast capabilities for wide-area simultaneous data delivery.
- Assess interoperability concepts with existing LMR, cellular, and broadband technology, leveraging several past PSCR projects.
- Explore roaming functionality with LTE and non-LTE systems, including how quality of service, billing, priority, preemption, and applications work when roaming.
- Validate key public safety functionalities and requirements, and gather public-safety specific information to influence the LTE standards process.


The PSCR Broadband Demonstration Network has three stationary eNodeB sites: the one shown here at the Table Mountain Field Site and Radio Quiet Zone, one at the Green Mountain Mesa Field Site, and one in the ITS Public Safety Radio Lab. The cell on wheels (right) can be used as a mobile fourth node in the network.

For more information about Public Safety Broadband Requirements and Standards and the PSCR Demonstration Network contact Andrew Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov.

Public Safety Broadband Research

Public safety broadband users have unique needs compared to users of civilian cellular networks. Civilian broadband networks are primarily constrained by capacity—the need to serve a relatively well concentrated population of customers using cellular base stations with a finite user capacity. Public safety networks, by contrast, typically serve a small number of highly mobile users but must provide service anywhere—incidents are obviously not constrained to occur only within areas of high population density. Thus, the public safety broadband network must be designed for coverage first, with capacity as a secondary consideration.

Commercial networks are typically designed for population centers like cities or areas of high transient population density like highways; for this application, the proper design rule is to increase the number of base stations until the capacity demands are met, with the assurance that all of the users will contribute to the capital equipment and operational costs that result. Although usage fees are contemplated for the National Public Safety Broadband Network (NPSBN), the bulk of the cost for implementation of this network must be covered by money already furnished by Congress in the Middle Class Tax Relief Act of 2012. Given the greater size of the coverage area and the smaller number of fee paying users, it is highly likely that the NPSBN will need to operate with lower base station densities than current civilian LTE networks.

In addition to different requirements for coverage, public safety users have unique concerns about quality and network management. Signal degradation that is a nuisance to a civilian user may be life-threatening in a public safety emergency. During a large-scale emergency, public safety networks must allow first responders from multiple services and jurisdictions to communicate, while giving the incident commander control over resource prioritization.

LTE has been chosen by the public safety community as the most promising technology to assure public safety broadband transmissions are both robust and efficient. The Public Safety Broadband Research program at ITS explores ways to optimize LTE for the operation of a public safety network; projects are designed to investigate or help mitigate the effects of one or more of the identified constraints. In the process, the program is developing new tools for active network testing which will be more widely applicable to inform design decisions for any high-speed wireless data system. The results of this research support and inform the requirements gathering and standards development effort that targets inclusion of public safety requirements in commercial standards so that public safety agencies can benefit from the competitive commercial market in cost-effectively acquiring communications equipment.

In FY 2014, PSCR research programs focussed on strategies for extending LTE coverage both over large geographic areas and into buildings in urban areas, on testing a wide variety of scenarios to explore the capabilities and relationships of the LTE network architecture, and on developing methods to identify digital speech and audio coders best suited for mission-critical voice communications over an LTE network.

Extended Cell Testing

Objectives

- *Deploy single sector Band Class 14 LTE system*
- *Utilize standards-based advanced LTE features to extend the cell radius up to 62 miles*
- *Test and evaluate coverage and performance of extended cell*

Overview

Public safety organizations are beginning to deploy Band Class 14 LTE networks throughout the country. This effort is being directed by FirstNet as part of its mission to deploy a nationwide public safety broadband network (NPSBN). The Public Safety Communications Research (PSCR) program is testing and evaluating Band Class 14 LTE to support public safety's requirement to provide nationwide coverage. Public safety LTE operates on 10 MHz channels centered at 763 MHz on the downlink and 793 MHz on the uplink. This spectrum provides excellent propagation characteristics such as the capability to propagate over larger geographic areas with less infrastructure relative to higher bands. To provide service to rural areas, a potential solution is to increase the size of each cell beyond the typical LTE cell radius of 9.6–13 km (6–8 miles). An extended cell is capable of providing coverage to rural areas, where user density is lower, and by using a smaller number of towers, deployment costs can be reduced.

Extended Cell Implementation

To increase the cell radius beyond the typical range, two modifications to the eNodeB side of the link were implemented. First, the coverage area was increased by deploying the eNodeB and antenna at a greater height. Second the LTE Physical Random Access Channel (PRACH) preamble format was modified. The LTE 3GPP standards specify four preamble formats to accommodate longer round trip propagation delay in large cells. The ones of interest for extended cell are PRACH preamble format 1, which supports a cell radius of up to 77 km (48 miles), and format 3, which supports a radius up to 100 km (62 miles). On the user equipment end of the link, another advantageous technique involved the use of directional antennas.

PSCR deployed a single sector Band Class 14 LTE system on a 1000 foot NOAA tower in Erie, CO, shown in Figure 1. The project consists of two phases; the first phase was completed and tested over a drive test route in 2013. The second was in development in FY 2014 and will be tested starting in 2015. In Phase I, the eNodeB radio head and antenna were deployed at a tower height of 85 meters (280 feet) using PRACH preamble format 1, with the antenna pointing at a 90 degree azimuth. A series of mobile measurements were conducted over a test route that went out to 77 km (48 miles) directly east of the antenna. Phase II is currently being deployed at an antenna height of 280 meters (920 feet) using PRACH preamble format 3.

Measurements

Measurements were conducted using an LTE UE with external antenna ports. The currently available Band Class 14 UEs are capable of transmitting 23 dB (200 mW) power. At the UE, two types of antennas were used: a rooftop magnetic mounted antenna and a directional antenna. Using the drive test vehicle

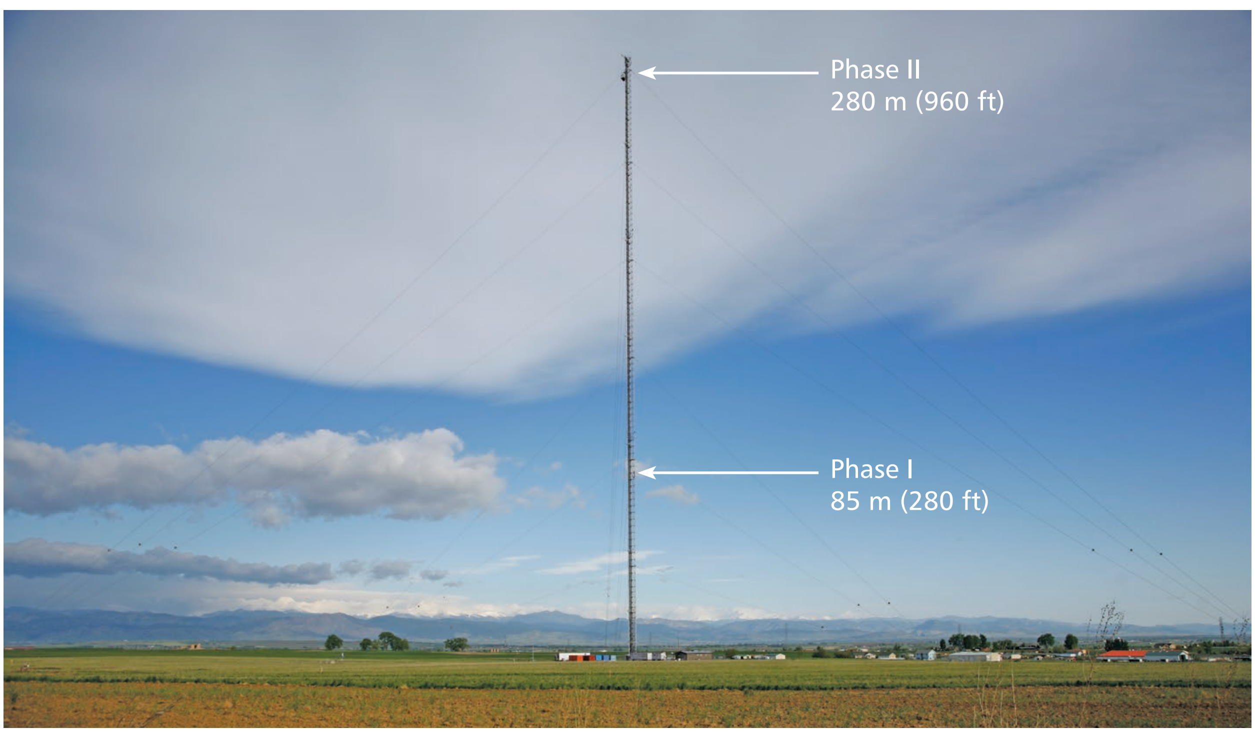

Figure 1. NOAA tower used for LTE extended cell testing. Photo by Ron Carey.

PSCR mobile measurement vehicle. Photo by Chris Redding.

shown in Figure 2, a series of uplink and downlink throughput measurements were conducted while driving and at static locations. Key testing objectives for the measurements include determination of the maximum cell radius at which the system is capable of operating and performance of the network at cell edge. The measured results will be compared with modeled data for high gain and omni-directional antenna performance, cell edge performance, and multiple UE performance. Measurement results were presented at the 2014 Public Safety Broadband Stakeholder Conference and at the APCO International 2014 Annual Conference & Expo.

Future Plans

Plans are in place to continue Phase II of the project which will extend cell coverage up to 62 miles. Test results will be presented at the 2015 Public Safety Broadband Stakeholder Conference.

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In-Building Coverage

Objectives

- *Explore multiple alternatives to improve in-building LTE coverage*
- *Conduct tests and measurements to assess efficacy of each alternative*

Background

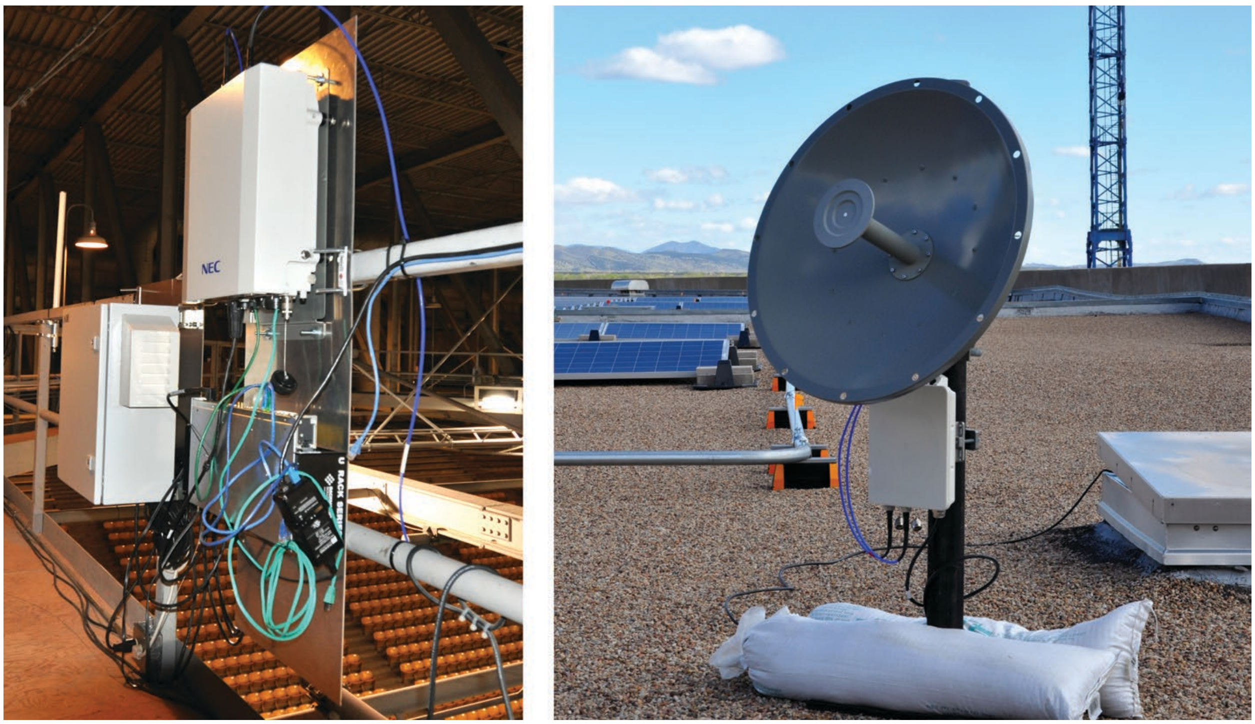
The ability for first responders to communicate within and into buildings during emergency scenarios is of paramount importance. Modern commercial and public buildings significantly attenuate radio-frequency signals and make communications difficult for high-performance Band Class 14 LTE systems. One contributor is the widespread use of low-emissivity glass (low-E) which can reduce received signal power levels by a factor of a hundred or more. Other commonly used building materials that significantly reduce radio signal levels are concrete and steel.

Tests and Measurements

In order to study and explore this important problem, PSCR engineers collaborated with researchers from the University of Colorado, whose Boulder campus is well within the coverage area of the PSCR Band Class 14 network and contains a rich variety of building types. After extensive research, two structures were identified for study: 1) the Discovery Learning Center (DLC) and 2) the Coors events center (CEC). These structures are similar to those that might be encountered in a public safety emergency scenario.

A comprehensive series of LTE in-building tests were carried out in these buildings during the period of July 2013 to May 2014. The PSCR macro network coverage was used as a baseline to study methods for improving indoor coverage. We investigated three approaches for coverage improvement: 1) a cell on wheels (COW) placed in close proximity to a building, 2) a small cell and tripod-mounted antennas placed inside a building, and 3) a small cell feeding a distributed antenna system (DAS) installed in a section of a building. The test results indicated that the PSCR macro network did not provide complete coverage of either the Discovery Learning Center or the Coors Events Center. A significant improvement was seen in indoor coverage and system performance when we used the three coverage improvement options either individually or in combination. The results of these tests highlight the fact that the PSCR macro network does not provide complete indoor coverage in these buildings and that some form of in-building support is needed to achieve peak network performance.

The results of this study are currently being incorporated into an NTIA technical report that will be published in 2015.



One of the three approaches to improve indoor coverage tested by ITS researchers was to place a small cell feeding a pair of COTS antennas (approach #2) on the catwalk high above the stadium in the Coors Events Center (left). Microwave backhaul back to the PSCR lab was implemented using the dish/transceiver system which was deployed on the roof of the Coors Events Center (right). Photos by John Ewan.

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Next Generation Network Wireless Priority Services Testing and Evaluation

Objectives

- *Investigate Next Generation Network Priority Services interactions in a commercial LTE network*
- *Validate proposed changes to commercial LTE networks to ensure that Wireless Priority Services perform as expected*

Overview

Call completion and quality of experience are more critical for personnel responding to National Security and Emergency Preparedness (NS/EP) events than for the average commercial wireless user. NS/EP users are often the "eyes and ears" on the ground. Their calls and data must reach their intended destination and meet minimum intelligibility standards even when significant portions of the commercial communications network are damaged or overloaded. System planners and architects use priority mechanisms to improve the overall communications experience of NS/EP users. With the advent of fourth generation (4G) mobile wireless, or LTE, a new suite of priority mechanisms is available to NS/EP users as well as system planners, network architects, and equipment vendors. But with these new priority mechanisms comes the challenge of ensuring that the existing systems that NS/EP users have come to rely on, such as Wireless Priority Services (WPS), continue to work as they do now in 2G/3G wireless systems.

Next Generation Priority Services (NGN-PS)

NGN-PS mechanisms can be grouped into three general categories: admission, allocation, and quality of experience. Admission mechanisms affect the way a user equipment device (UE), such as a smartphone, gains access to the network via the eNodeB (eNB). Allocation mechanisms affect the way bearers are assigned to UEs. Decisions about the kind of bearer to assign and whether or not bearer establishment requests are refused fall under the Allocation and Retention Policy (ARP). Mechanisms relating to quality of experience (QoE) can define things like which packet data network (PDN) delivers higher layer traffic, e.g. RTP, UDP, TCP/IP, etc.—also known as the Access Point Name (APN). QoE mechanisms can also affect the amount of bandwidth one receives and the maximum and guaranteed bit rates at the UE or APN.

Wireless Priority Services

The Department of Homeland Security's Office of Emergency Communication (DHS-OEC) administers both the Government Emergency Telecommunications Service (GETS) and Wireless Priority Service (WPS) programs. Both programs offer their users an alternative method for call completion when either the Public Switched Telephone Network (PSTN) or a commercial wireless network is congested and the probability of completing a normal call is reduced. WPS and GETS are funded by DHS-OEC and implemented via contracts with the major wireline and wireless carriers. Since WPS has not yet been implemented in 4G, it remains to be seen how and how well it will be executed by the mobile network operators (MNOs). MNOs may use a mix of NGN-PS mechanisms to deliver the WPS functionality that users of 2G and 3G wireless have come to rely on. A carrier's design is first shared with members of both the DHS-OEC and PSCR teams through Technical Exchange Meetings during which proprietary details of the carrier's proposed deployment are presented and, ultimately, a decision is made as to whether the proposed design will satisfy DHS-OEC's initial requirements. After the meetings, PSCR team members recreate a carrier's design in the lab to test it for unforeseen interactions that might negatively affect call completion or quality.

Test Bed Architecture and Design

The study of NGN-PS mechanisms and interactions focuses on the end-user experience and the higher-level protocol traffic that goes with it when NS/EP users send and receive voice, video, and data. The simulated network must incorporate past revisions of 3GPP standards as well as forward-looking features that have not yet made it into released standards. Voice over LTE (VoLTE) applications must be studied. Both commercial and public safety band class eNBs and UEs are used in the test bed, and the ability to load any isolated network element found in a commercial Evolved Packet System (EPS) is also required. In other words, the project team must construct the Swiss Army Knife of test beds—a network that can handle a wide variety of testing tasks and scenarios. Figure 1 shows a conceptual view of this network.

Each test starts with an application. In the network illustrated in Figure 1, application-level traffic protocols originate from a wide variety of sources. Media endpoints are used to originate and terminate voice/video calls, initiate and serve files, and enable voice and video conferencing via Internet browsers using Web-based Real Time Communications (WebRTC); Figure 2 shows a screen capture from a live WebRTC call. Traffic and load generators inject or receive traffic at various points in the network; a wide variety of commercial and public safety UEs are also used to generate realistic traffic on the network. The last, and arguably most important, piece of the test bed is the portion that can simulate an EPS and replicate LTE interfaces into and out of the device under test (DUT). PSCR recently acquired a testing system capable of simulating both an entire EPS and the network surrounding a single network element in the Evolved Packet Core (EPC). The first scenario is commonly referred to as "back to back" testing. In this mode, the test device simulates everything from, for example, a Web browsing session on a UE, through the eNB and EPC to an APN and, ultimately, a server in some distant Packet Data Network (PDN), e.g. the Internet or a public safety "app store." In the second case, the test device provides the traffic to and from the DUT via standardized LTE interfaces. The DUT can be a single network element, a group of entities, or another vendor's entire EPC. The inherent flexibility in the test bed architecture allows us to very cost effectively test the maximum number of scenarios and configurations.

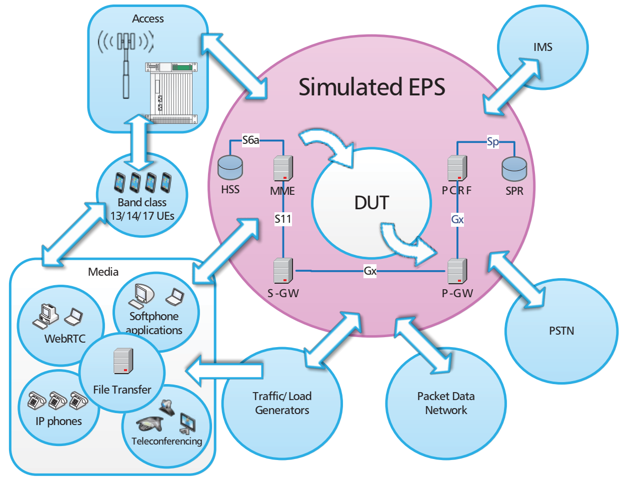

Figure 1. A schematic of the PSCR NGN-PS test bed capabilities and relationships. At the heart of the test bed is an LTE network simulator that can simulate an entire EPC as well as isolating specific network elements. The rest of the network provides realistic inputs and outputs to the DUT.

Testing Methodology

Construction began in FY 2014 on an NGN-PS test bed engineered to support the widest possible set of testing scenarios. Testing occurs in three main phases: back to back, mixed simulations, and load generation. In the first phase, the team will use the EPC simulation hardware/software platform to simulate all parts of an LTE EPS, e.g. hundreds of UEs running standard voice/data applications, multiple eNBs and subsystems, and application servers for voice and data on the other side of an APN in a 3GPP Release 9 or 10 configuration. A set of LTE attach procedure tests derived from OEC's two Government Industry Requirements documents will be tested. The primary goal of this phase is to learn the NGN-PS mechanisms and start looking at their interactions in a controlled, self-contained system.

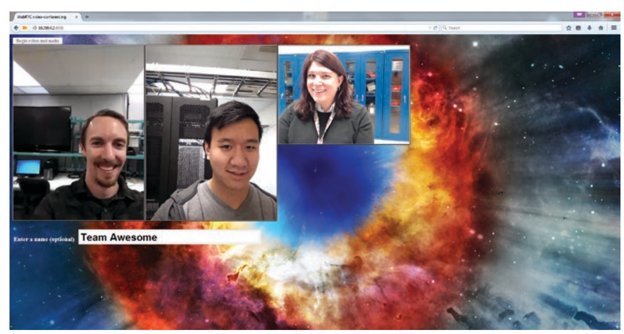

Figure 2. This WebRTC session is an example of a One2Many call (similar to videoconferencing, but using a web browser instead of a single-purpose application). ITS engineer Anna Paulson (right) initiated the session from a desktop browser, while Joe Parks (left) and Anton Nguyen-Vu (center) are connected to the session using web browsers on smartphones over the PSCR LTE demonstration network.

Future Work

The next phase of testing will use a software-only virtual EPC (vEPC) running on a virtual machine that simulates a commercial EPC receiving traffic through LTE standard interfaces for tests designed to further investigate preemption. Finally, all of the testing tasks will be performed on a network which closely resembles a commercial implementation. In this phase, the team will leverage the test bed resources to generate load on commercial equipment already present in the PSCR Broadband Demonstration Network.

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Speech Intelligibility Testing

Objectives

- *Develop efficient and reliable methods to estimate speech intelligibility of LTE voice communications*
- *Publish test methods and results to transfer the technology to the public safety community*

Background

Over the past several years PSCR staff have conducted extensive speech intelligibility testing operations. These tests have been based on the standardized, controlled, testing paradigm called the Modified Rhyme Test (MRT). Test results have shed light on how different factors in communication scenarios contribute to, or detract from, speech communications. Background noise is a particularly important factor, as public safety practitioners often must work in extreme noise environments. Test results identifying and quantifying relationships between background noise conditions, digital speech coders, and speech intelligibility are now available in three major NTIA technical reports. These reports have generated significant interest across the public safety stakeholder community. Indeed, it is essential that public safety practitioners be able to call for help, to warn others, and to communicate clearly when their lives are in danger.

More recently, PSCR staff have developed an automated version of the MRT called Articulation-Index Band Correlation MRT (ABC-MRT). This newer tool is a digital signal processing (DSP) algorithm that runs on ordinary desktop or laptop computers. As such it provides quick, repeatable estimates of MRT scores without the time and expense required by laboratory testing with human subjects. PSCR staff used this new tool for preliminary evaluation of multiple configurations of a proposed P25-LTE interconnection solution and it did provide useful, concrete feedback in a very timely fashion.

The PSCR is now equipped to move forward with a broader, more efficient round of speech intelligibility testing. The key idea is that ABC-MRT can be used to quickly and efficiently gain preliminary, coarse, speech intelligibly results for a very wide range of background noise conditions and digital speech coders. This first stage can then guide the selection of a smaller, more practical set of conditions to evaluate more fully and precisely using the actual MRT test protocol.

With this next round of testing PSCR seeks to identify which digital speech and audio coders might be best-suited for mission-critical voice communications over an LTE infrastructure. There is a broad field of candidates and the PSCR holds a unique combination of experience and tools to efficiently address this issue and provide critical guidance as public safety moves toward more and more reliance on a broadband, LTE-based network.

Related Publications:

DJ Atkinson and A. Catellier, "Intelligibility of Selected Radio Systems in the Presence of Fireground Noise: Test Plan and Results," NTIA Technical Report TR-08-453, Jun. 2008. Available http://www.its.bldrdoc.gov/publications/2490.aspx.

DJ Atkinson, S.D. Voran, and A.A. Catellier, "Intelligibility of the Adaptive Multi-Rate Speech Coder in Emergency-Response Environments," NTIA Technical Report TR-13-493, Dec. 2012. Available http://www.its.bldrdoc.gov/publications/2693.aspx.

DJ Atkinson and A. Catellier, "Intelligibility of Analog FM and Updated P25 Radio Systems in the Presence of Fireground Noise: Test Plan and Results," NTIA Technical Report TR-13-495, May 2013. Available http://www.its.bldrdoc.gov/publications/2720.aspx.

For more information contact Stephen D. Voran, (303) 497-3839, svoran@its.bldrdoc.gov

Improving Telecommunications Network Performance

End-to-end performance of a telecommunications network is influenced by both the characteristics of the radio wave and the characteristics of the equipment used to transmit and receive it, including the software that controls the equipment. The ultimate arbiter of the performance of a telecommunications network for inter-human communication is the end user, the listener or viewer of the audio or video signal transmitted over that network. The ITS Audio and Video Quality Research programs perform research to assist in developing and standardizing methods for assessing and improving the quality of delivered transmissions. These programs, which are both long-standing and internationally renowned, conduct research and development leading to publication, implementation, and standardization of perception-based tools for assessment and optimization of video and audio communication systems. The goal of these NTIA-funded programs is to develop tools to monitor and optimize the quality of audio and video information on communication channels, especially in light of bandwidth constraints and time-varying channel quality. Their work provides important information for network and equipment designers as well as reliable technical input to standards bodies.

Great strides have been made in recent years towards developing automated tools for assessing audio and video quality, but subjective testing is still a very important tool for assessing the success of emerging audio and video encoding and transmission technologies. ITS continues to conduct subjective testing for validation of automated tools as well as for other purposes. In recent years, new research has been performed to develop methods for subjective testing involving a much broader variety of platforms and use case scenarios. Another area of investigation is subjective usability testing. This area includes speech intelligibility testing for public safety communications and testing the readability of video transmission of sign language.

Audio Quality Research

Objectives

- *Tools that accurately quantify speech quality and speech intelligibility*
- *Improved speech quality in wireless voice services*
- *More consistent performance of voice services through greater robustness to transmission channel impairments*

Background

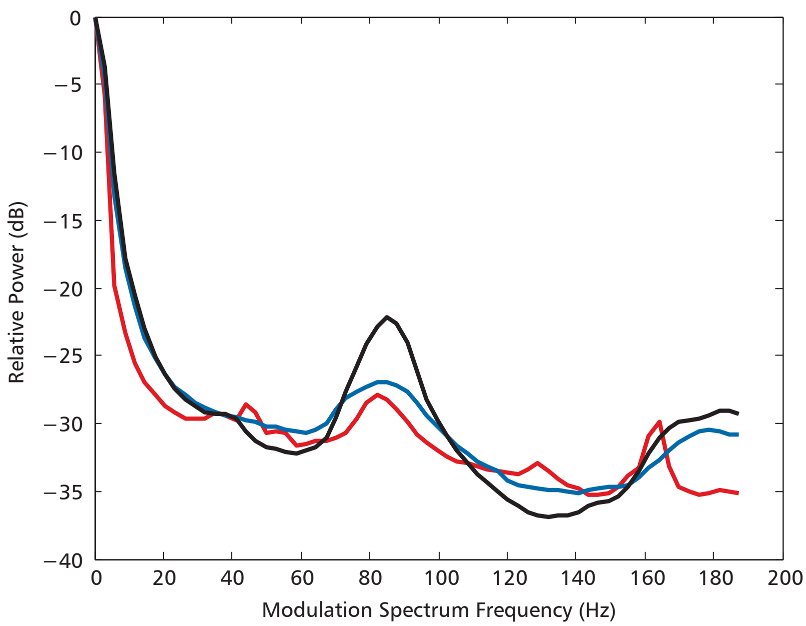
Variations in transmission channels reduce speech quality, and can also reduce the intelligibility of speech. To mitigate these quality and intelligibility reductions, digital speech coding, transmission, and decoding algorithms must be maximally robust to channel variations. User experiences can be further enhanced if the algorithms are able to adapt with respect to different signal classes, background noise environments, speech bandwidths, quality levels, or coding rates. Such adaptive nature allows telecommunications speech transmission that is well-matched to channel conditions even though those conditions are continually evolving. This in turn maximizes the user experience associated with the telecommunications speech service. The ITS Audio Quality Research program supports the industry-wide effort towards robustness and adaptability. The program identifies, develops, and characterizes algorithm innovations in the areas of robustness and adaptability. In addition, the program seeks to improve tools and techniques for characterizing speech quality and speech intelligibility, both through subjective testing and by means of signal processing algorithms.

Objective Estimation of Speech Intelligibility:

One way to evaluate speech intelligibility is rhyme testing, and a specific, popular test is the Modified Rhyme Test (MRT). In the MRT a trial consists of the presentation of one word in a carrier phrase—for example "Please select the word kit." Listeners then use a graphical interface to indicate which of six rhyming options was heard—in this case those options are "kit," "bit", "fit," "hit," "wit," and "sit." Thus the MRT asks listeners to perform a specific speech recognition task and the rate of correct word identification leads to a measure of speech intelligibility.

In FY 2014 program staff continued with development and refinement of the Articulation-index Band Correlation MRT (ABC-MRT). This objective estimator of speech intelligibility was previously developed by program staff to mimic the MRT, but without the time, cost, and variability associated with human listeners. ABC-MRT is a signal processing algorithm that forms novel time-frequency representations of speech signals and then performs temporal correlations between the sent and received speech representations in each individual Articulation-index Band. These correlations are then further processed to arrive at an estimated MRT score.

Recent extensions include a detailed and specific analysis of the modulation spectrum of the received speech. The figure shows example modulation spectra in articulation index band number five for three cases: original speech (black), digitally coded speech (blue), and speech with very high background noise level (red). The deviations are clearly apparent but they are not simple to characterize. However, when multiple representations of this type are carefully processed and properly interpreted within the MRT context, the results can be used to directly estimate the MRT scores—no reference to the sent speech is required. This extension provides considerable practical advantages when the algorithm is implemented in field testing applications.



Example modulation spectra for original (black), digitally coded (blue) and noisy (red) speech.

Quantifying Performance of Objective Estimators:

Objective estimators of speech intelligibility, audio quality, or video quality are useful and efficient surrogates for subjective testing. One open issue is how to best characterize the performance of these estimators. Given a choice of estimators, which one will be most useful? Given that an estimator has been selected, how much confidence should we place in its readings? Statistical measures such as correlation, root-mean-squared error, or classification error rates provide some guidance, but that guidance is somewhat abstract.

In FY 2014 program staff developed two new schemas with very direct and practical interpretations. The first assesses estimators in terms of equivalent subjective test size. For example, a good estimator behaves similar to a subjective test with one or two subjects while a very good estimator is roughly equivalent to a subjective test with four subjects. The second approach compares objective estimators to individual subjects in a test. For example, a very good estimator can perform similar to the best subject in a test while a less desirable estimator behaves much like an average subject. These new approaches should allow for more concrete understandings of what is gained or sacrificed when one uses objective estimators to augment or to replace subjective tests.

Performance of Speech Enhancement Algorithms:

An Ideal Binary Mask (IDBM) is a two-level time-frequency pattern that can be used to separate desired speech from undesired background noises in order to enhance the speech and make it more intelligible. The technique is quite powerful, but it hinges on proper estimation of the IDBM and that step can be extremely challenging. While industry works to improve IDBM estimation algorithms, program staff have been working to characterize the relationship between an IDBM and estimates of that IDBM. The existing approach of simply reporting classification error rates is mathematically sound, but the relationship to speech intelligibility is limited at best. In FY 2014 program staff showed that novel but relatively simple mathematical processing of IDBMs and their corresponding estimates can quantify the resulting speech intelligibility with much better reliability than existing methods.

Additional FY 2014 Activities

Throughout FY 2014, program staff performed speech and audio quality testing using both objective and subjective techniques, supporting this and other ITS programs. Laboratory facilities were upgraded and staff continued to draft technical documents detailing research results. Staff also served in numerous peer reviewer and associate editor capacities for the technical paper publication process in support of the international speech and audio research community. Program publications, technical information, and other program results are available at http://www.its.bldrdoc.gov/audio.

For more information contact Stephen D. Voran, (303) 497-3839, svoran@its.bldrdoc.gov

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Video Quality Research

Objectives

Develop and disseminate knowledge, techniques, and tools that will:

- *Enable subjective video quality testing of new technologies*
- *Allow industry to develop improved video systems*
- *Encourage the development of international standards related to video quality issues*

Background

Video is a booming industry: content is embedded on many Web sites, delivered over the Internet, streamed to mobile devices, delivered on-demand, and used for real time monitoring in increasingly diverse applications. Cisco statistics indicate that video was 55% of total mobile traffic by the end of 2014, and predicts that nearly 75% of the world's mobile data traffic will be video by 2019.[1]

The work of the Video Quality Research program emphasizes international issues and technology transfer, because U.S. industry benefits from the availability of new algorithms and products to support increased quality and efficiency of video transmission through wired and wireless services.

The success or failure of a video service depends on the delivered quality of experience (QoE). Video quality is an important factor within QoE. The available video quality continues to be limited by constraints on the network bandwidth and receiver's speed and memory.

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1. "Cisco visual networking index: global mobile data traffic forecast update, 2014-2019," Feb. 3, 2015. Accessed http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html March 2, 2015.

There are two ways to measure video quality:

- Subjective video quality tests
- Use a computer algorithm

Asking a person's opinion of video—also known as subjective testing—is by far the most accurate way to measure video quality, though the cost and the time required are often a problem. For example, industry needs rapid feedback while fine tuning a new product, but subjective testing is a lengthy and expensive process. An objective video quality model is a computer algorithm that attempts to predict human perception of video quality by trying to imitate human perception, object recognition, and judgment. Though this method is faster and less costly than subjective testing, it is difficult to do well.

Subjective Testing

In January 2014, ITS efforts led to the approval of a new ITU Recommendation, ITU-T Rec. P.913, "Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment." P.913 includes improved techniques for subjective testing developed over the past decades; reduces costs by eliminating unnecessary constraints; and describes new techniques for subjective testing of mobile devices in public environments. P.913 represents the fruition of years of research effort by ITS, including collaborative efforts within the open forum of the Video Quality Experts Group (VQEG).

ITU-T Rec. P.913 (2014) describes how to perform subjective tests in noisy environments. The impact of a distracting, public environment is important when evaluating the audio or video quality of mobile devices.

As a complementary effort, ITS made available subjective test software that allows researchers to conduct subjective tests on multiple devices. The system leverages modern Web technologies and infrastructure to deliver test stimuli to typical mobile devices and personal computers. Devices with a modern web browser may be tested wherever a network connection is available. This unique capability allows for diverse and interesting subjective test plans.

Continued investigations into improved understanding of subjective testing focus on modeling subject behavior and improved experiment design. The results of this research led to a model of subject rating behavior based on subject bias and subject error. Bias acts like a random variable within ratings, and so should be removed from most analyses. This allows improved accuracy without added cost. The related publication won the best paper award at the Fifth International Workshop on Quality of Multimedia Experience (QoMEX 2014).

Reliable Objective Video Quality Models

ITS developed objective Video Quality Models (VQM) from 1988 to 2011. ITS's VQM software offers an inexpensive alternative to subjective tests. The VQM software can be downloaded royalty-free for commercial or non-commercial use from www.its.bldrdoc.gov/vqm. In FY 2014, 685 people downloaded the VQM software.

Since 2011, ITS ceased objective model development and now focuses its efforts on validating the performance of models developed by other organizations. Margaret Pinson is Co-chair of the Video Quality

Experts Group (VQEG, www.vqeg.org) and Associate Rapporteur of the ITU-T Study Group 9, Questions 2 and 12. In these roles, she has helped progress the validation of hybrid perceptual bit-stream models. These hybrid models examine both the network performance and the decoded video, to produce an accurate quality estimation that is suitable for real time deployment in most modern video systems. This validation effort led to the approval of ITU-T Rec. J.343, "Hybrid perceptual bitstream video quality assessment" and six supporting Recommendations (J.343.1 through J.343.6) that identify specific hybrid models suited to different purposes.

Leadership

VQEG determines whether objective video quality models are accurate enough for industry to trust. ITS helped establish VQEG in 1997 and continues to participate in VQEG by:

- Co-chairing VQEG meetings
- Providing independent oversight to promote fairness and accuracy
- Analyzing data from VQEG sponsored subjective tests
- Writing subjective test plans and reports

In FY 2014, VQEG began an eLetter to provide a forum for presenting up-to-date technical advances on video quality related topics. Each issue of the VQEG eLetter features a collection of papers authored by well-known researchers. ITS supports the VQEG eLetter publication by providing editors, editing, and distribution support.

More information can be found on the Video Quality Research home page at http://www.its.bldrdoc.gov/n3/video.

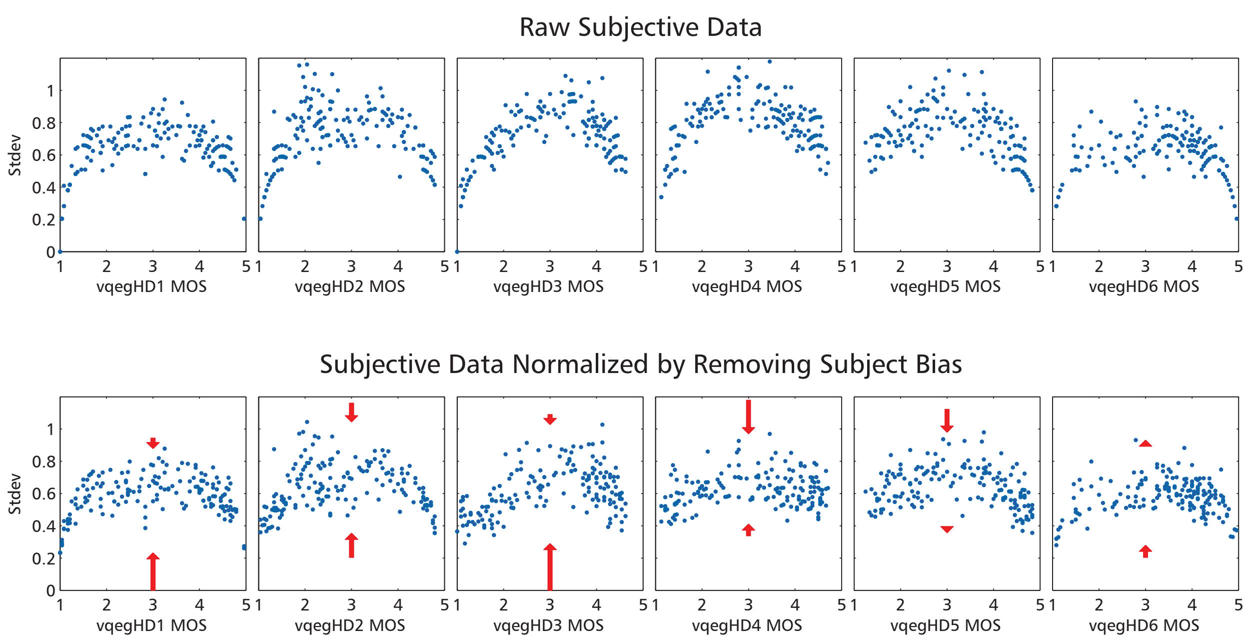
Related Publications:

Lucjan Janowski and Margaret H. Pinson, "Subject Bias: Introducing a Theoretical User Model," Fifth International Workshop on Quality of Multimedia Experience (QoMEX 2014), Singapore, 18-20 September 2014. Available http://www.its.bldrdoc.gov/publications/2774.aspx.

Margaret H. Pinson and Lucjan Janowski, "AGH/NTIA: A Video Quality Subjective Test with Repeated Sequences," NTIA Technical Memo TM-14-505, June 2014. Available http://www.its.bldrdoc.gov/publications/2758.aspx.

Andrew A. Catellier and Luke Connors, "Web-Enabled Subjective Test (WEST) Research Tools Manual," NTIA Handbook HB-14-501, January 2014. Available http://www.its.bldrdoc.gov/publications/2748.aspx.

Margaret Pinson and Naeem Ram, Eds., VQEG eLetter: Volume 1, Issue 1, March 2014. Available http://www.its.bldrdoc.gov/publications/2751.aspx.



These scatter plots show the impact of removing subject bias from the six VQEG HDTV datasets. Note that mean opinion score (MOS) does not change when subject bias is removed. Long red arrows indicate a large change in the minimum or maximum standard deviation of scores. Short red arrows indicate a small change.

Consumer Digital Video Library

Objective

- *Disseminate high quality, uncompressed video sequences to encourage novel research and development on future video technologies*

Background

Finding—and getting rights to use—relevant test video is an obstacle to some interesting research topics. The Consumer Digital Video Library Web site (CDVL, www.cdvl.org) was created to address this problem. ITS developed, hosts, and supports the CDVL Web site.

The CDVL makes high quality, uncompressed video clips available for download, free. Clips hosted on CDVL are ideal for use by the education, research, and product development communities. CDVL content allows academia and industry to:

- Develop new products
- Choose video equipment
- Improve video coding algorithms
- Optimize video system performance
- Train objective video quality models
- Conduct subjective video quality tests

In FY 2013, ITS made available broadcast quality stereoscopic television (3DTV) sequences. These video sequences encourage research into issues that have thwarted acceptance of 3DTV in the home. 3DTV filming requires the expertise of a professional stereographer and filming crew. 3DTV footage is typically only produced by major studios, which have licensing issues that prevent redistribution for R&D purposes. Inexpert production typically yields footage with technical problems that cause visual discomfort. Thus, the ITS 3DTV footage is a particularly rare and valuable resource.

In 2014, 226 people downloaded video from CDVL. The research impact can be seen in the 34 IEEE publications (2008–2014) that reference the CDVL Web site.

This figure shows samples frames from the 3DTV videos available on the Consumer Digital Video Library. These frames are presented in side-by-side format, meaning that the two video streams are subsampled by two horizontally and packed into a high definition television (HDTV) stream.

For more information about Video Quality research or the Consumer Digital Video Library contact Margaret Pinson (303) 497-3579, mpinson@its.bldrdoc.gov

Propagation Modeling

Radio propagation models are mathematical algorithms that predict the behavior of radio waves. Some of the earliest efforts of the NBS Radio Section (ITS's early 20th century ancestor) were aimed at predicting the distance that radio waves could travel under specified conditions, and the search for better methods of prediction has continued uninterrupted since. The behavior of radio waves is determined not only by their frequency, amplitude, and polarization, but also by their interaction with the environment through which they travel, through phenomena such as reflection, refraction, diffraction, absorption, and scattering. Radio receiver sensitivity, radio noise, and interference from both natural and man-made sources must also be taken into account.

Many radio propagation models are empirical/statistical, predicting the most likely behavior of a radio link under specified conditions based on large amounts of measured data. As computing equipment has become more powerful, more data and more parameters can be included in the calculation, and prediction becomes correspondingly more accurate. Methods to predict the propagation of radio waves in ionized and non-ionized media are standardized internationally by the ITU. (See page 42 for a description of ITS activities to advance international propagation modeling standards in FY 2014.) At the core of some of those are propagation prediction models first developed by CRPL/ITS in the mid to late 20th century.

ITS's immediate predecessor, the Central Radio Propagation Laboratory (CRPL), began developing computer programs for radio propagation prediction in the 1950s. Two of the most well-known and widely-used propagation models published by CRPL and eventually computerized by ITS are the Longley-Rice or Irregular Terrain Model (ITM) and the IF-77 or Gierhart-Johnson model. ITS continues to refine and expand computerized propagation prediction methods as the technology advances.

Different propagation models are used to predict radio link behavior at different frequencies, antenna heights, antenna characteristics, and the distances. The accuracy of a propagation prediction depends not only on the reliability of the model itself, but also on the suitability of the model for use in the particular case. ITS propagation modeling software has been programmed to include the capacity to perform propagation analysis using many different propagation models.

ITS expertise in propagation modeling and scenario analysis using different propagation models supports other work performed at ITS as well as policy development by ITS's sister office in NTIA, the Office of Spectrum Management. Other agencies also frequently consult ITS for assistance in propagation modeling for planning telecommunications systems.

FY 2014 Propagation Modeling Research

Small Cell Communications Networks

In December of 2012, the FCC issued a Notice of Proposed Rulemaking (NPRM) that proposed a new Citizens Broadband Service in the 3550–3650 MHz (3.5 GHz). The proposal called for an innovative new framework to facilitate rapid broadband deployment while protecting existing incumbent users of the band. NTIA had identified the 3.5 GHz band as a potential "fast track" band because unlicensed WiMAX equipment has already been developed and deployed in this band, Federal operations in the band are geographically limited, and the band has already been allocated for fixed services in other parts of the world.

As the FCC NPRM pointed out, the 3.5 GHz band has some unique characteristics that can be seen as both advantages and disadvantages from a radio propagation perspective. Signals propagating at 3.5 GHz decay faster and penetrate buildings less well than those transmitted in lower frequency bands. These same characteristics, however, make the band an excellent candidate for small cell communications architecture. The FCC concluded that "the band's characteristics make it well-suited to spectrum sharing, particularly geographic sharing. The limited propagation—especially in combination with low-power operation—should allow disparate radio systems to operate in closer proximity than lower frequency bands. This feature of the band should enable greater sharing opportunities with incumbent systems (such as radars and satellite communications networks) with appropriate geographic separation and other mitigation techniques such as resilient and flexible technologies. It also raises the possibility of greater sharing between disparate commercial systems in the band."[1]

A multi-agency Joint Working Group that included experts from NTIA, the FCC, and agencies with incumbent systems in the 3.5 GHz band began to explore how to apply known propagation prediction methods to planning under the proposed sharing scenario. To accurately predict interference in a communications network deployment relying on small cell infrastructure in heavy traffic areas, propagation models would need to account for radio propagation in man-made and naturally cluttered environments, as well as other impediments to propagation such as terrain obstructions.

Several possible alternative models were considered and a plan of work was drawn up that proposed a new extended Hata model. The frequency range of the Hata (1980) model was extended in frequency and distance; frequencies from 1,500 to 3,000 MHz were included based on Hata's original path loss exponent method for path distances less than approximately 20 km and on a different method for longer distances. Other site-specific corrections that depend on the details of the terrain profile between the transmitters and receivers were also implemented, as well as corrections to account for urban or suburban environments.

When modeling the propagation effects of small cell communications networks, a concern is how the radio environment might be affected by the aggregate impact of transmission from multiple cells. To attempt to understand how an environment of multiple transmissions from a grid of small cells would impact the results of predictions using this newly extended model, the results were compared to the predictions using ITM and the larger median loss value was used as the basis for Monte Carlo studies of the aggregate interfering power.

For more information contact Paul M. McKenna, (303) 497-3474, pmckenna@its.bldrdoc.gov

Comparison between Models and Measurements

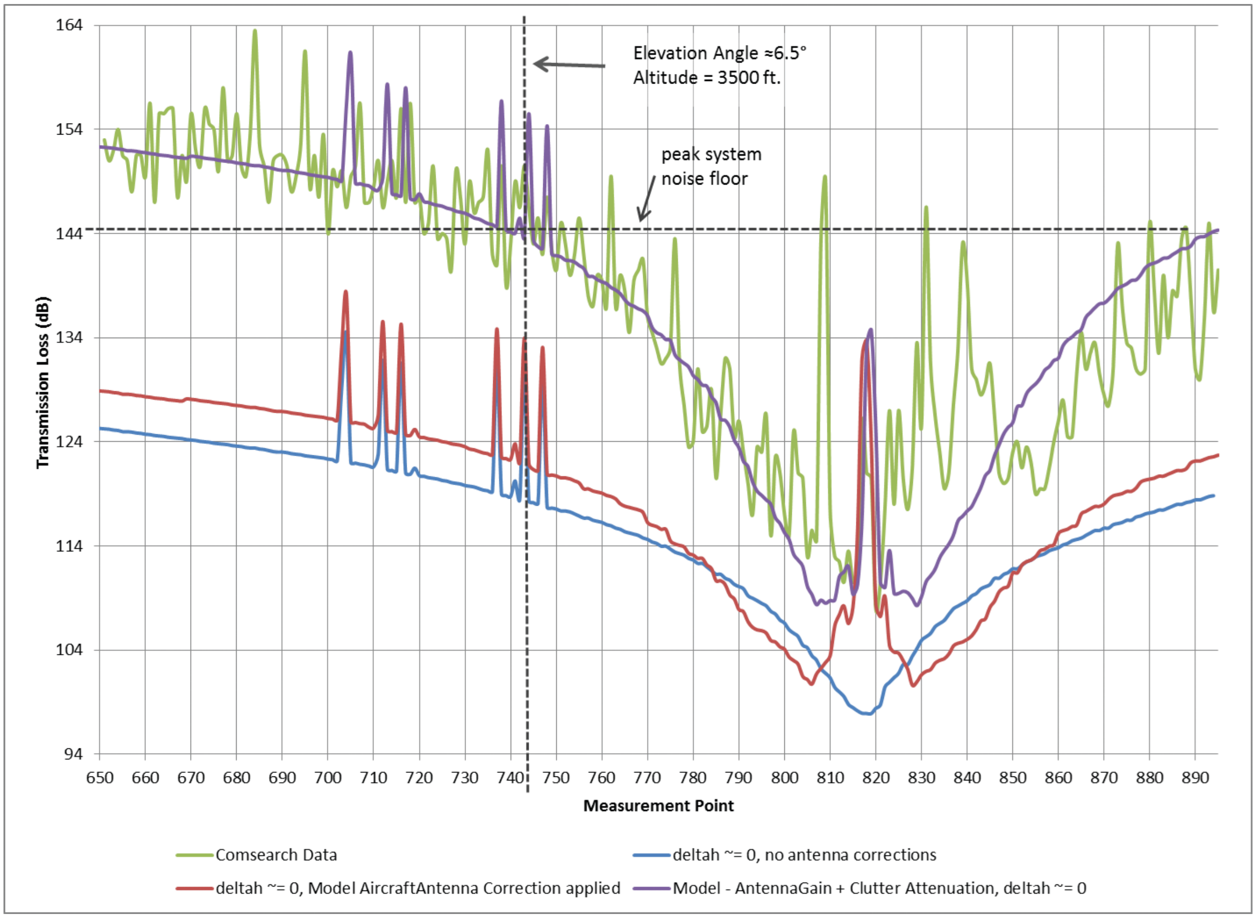
In 2013, Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 5 (WG-5), performed a spectrum sharing study between Federal airborne systems and commercial LTE systems proposed for operation in the 1755–1780 MHz band. The propagation model used omitted terrain effects and attenuation due to vegetation or buildings (clutter). This yielded a sharing scenario with large protection/coordination distances where commercial wireless systems would not be permitted to operate to protect Department of Defense (DoD) systems. This finding motivated the commercial wireless carriers to perform measurements of the aggregate power from multiple user equipment devices in several heavily loaded commercial mobile bands using a receiving system on a small aircraft. The carriers also placed a continuous-wave (CW) transmitter in a cluttered environment to assess the effects of clutter as the aircraft flew in several arcs around the Washington, D.C./Norfolk, VA, areas.

The aircraft measurements were made by ComSearch Government Systems on behalf of T-Mobile USA, Inc, AT&T, Inc., and Verizon Wireless, using the RFEye spectrum sensor. ITS was asked by the wireless carriers to compare the measurements with predictions using ITS's IF-77 air-to-ground propagation model. The IF-77 model included terrain elevation data in the vicinity of Patuxent River Naval Air Station where the aircraft measurements were made. A terrain database of 3 arc-second data was used as well as surface reflection multipath corrections.

1. Federal Communications Commission, "Enabling Innovative Small Cell Use In 3.5 GHZ Band NPRM & Order," Notice of Proposed Rulemaking, GN Docket No. 12-354, FCC 12-148, (Adopted December 12, 2012, Released December 12, 2012)

Initially, the IF-77 propagation model showed a large discrepancy between the measured and modeled data. The measured data is shown by the green trace in the figure and the modeled data is shown by the blue trace in the figure. In an effort to resolve the discrepancy between measured and modeled data, ITS engineers also included corrections for the antenna gain pattern both for the omnidirectional transmit antenna on the ground and for the antenna centered on the underbelly of the aircraft. This data is shown by the red trace. After further consideration, we decided to use the International Telecommunications Union (ITU-R) P.833 Recommendation for modeling clutter losses where one terminal is outside the clutter region and the other is inside the clutter region and clutter losses are vegetative in nature. We chose this model because it approximated to a high degree the densely foliated region of interest. The application of this model resulted in the purple trace shown in the figure. This analysis demonstrated that the inclusion of terrain, antenna gain patterns, and clutter in the propagation models yields good agreement with measurements.

The results of the study were included in an FCC Ex-Parte Briefing (GN Docket No. 13-185) on February 28, 2014. This work also led to follow-on discussions between the DoD and the wireless carrier consortium in which ITS represented the wireless carriers in pre-auction meetings to reduce protection/coordination distances.



Comparison between measured aircraft data and the ITM model, the ITM model with corrections for antenna pattern gain, and the ITM model with corrections for both antenna pattern gain and the ITU-R P.833 clutter-loss model.

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Web-based Propagation Prediction Applications

Government operations, including those for public safety and national security, depend critically on the ability to successfully predict propagation in a variety of environments and conditions. Advanced propagation prediction models that can successfully integrate geographic data and display coverage predictions are important tools for accurately predicting the performance of communication systems. Ideally, these models should be easy for non-specialists to access and use for operational and financial planning purposes. They should also be detailed and accurate enough for specialists to use in deployment.

Previous propagation modeling programs that ITS made available for government users required that users have a concrete understanding of radio propagation and prediction concepts to be able to use them. More recently, many of these models were ported to new programs that operate in a Windows® environment and integrate with the proprietary Esri™ Geographic Information System (GIS) program most commonly used by our sponsor agencies. This implementation required users to have licensed commercial software installed and some expertise in the use of that software.

ITS now disseminates software applications that reduce dependency on licensed software applications for end users, allowing them to access the models through a Web interface. Designing a web-based tool is consistent with the Federal Digital Government goals of making existing high-value data and content available through Web APIs and using a shared platform approach to developing and delivering digital services to lower costs and reduce duplication.

Propagation Modeling Website

Objectives

- *Allow users to perform propagation prediction studies for High Frequency (HF) and Very High Frequency (VHF) applications using custom-tailored Propagation Modeling Website (PMW) software through a browser interface*
- *Enable compositing thousands of transmitter analyses to predict regional wireless network coverage for system planning and interference detection for national security and public safety*

Overview

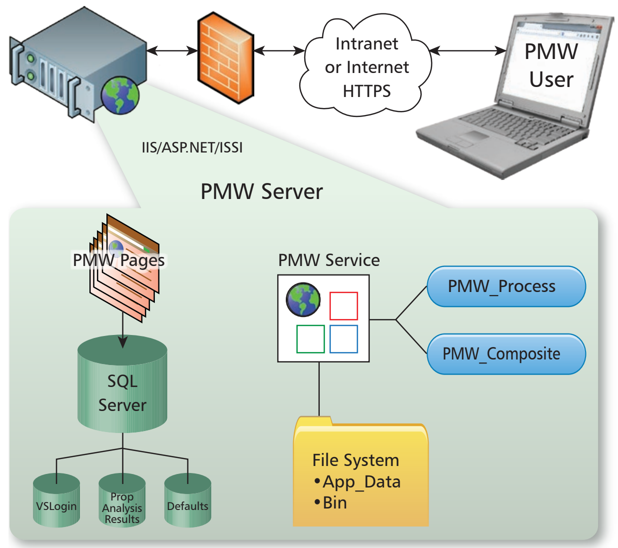
Accurate propagation modeling is an essential component of wireless communications planning, and accurate geographic information is a critical input for accurate modeling. To assist other agencies in the design of effective wireless systems, ITS has developed propagation modeling Web site tools that use commercial GIS to both acquire geographic data and display geographic coverage areas. The Propagation Modeling Website (PMW) is a web-based GIS propagation modeling tool, customized to meet the propagation prediction needs of the Department of Defense (DoD) and Department of Commerce (DoC)/National Weather Service (NWS) sponsors. PMW is presently available only to Federal government agencies. The PMW covers radio frequencies from 1 MHz to 20 GHz.

The PMW project builds on over 50 years of ITS expertise in evaluating and analyzing propagation models. Over the last seven years, ITS has been developing the newest generation of propagation prediction tools, the PMW web-based GIS solutions. The PMW provides intranet users with web-accessible propagation models, a central imagery/data storage facility, and a central database location to store all propagation analyses, using just one set of licensed software, as illustrated in the diagram of the PMW architecture. The system enjoys streamlined maintenance, operation, and upgrades for ease of deployment, and ITS has a support system in place to deliver end-user support, upgrades, and enhancements.

Work on the Propagation Modeling Website (PMW) software is sponsored by several DoD agencies and NOAA's National Weather Service (NWS).

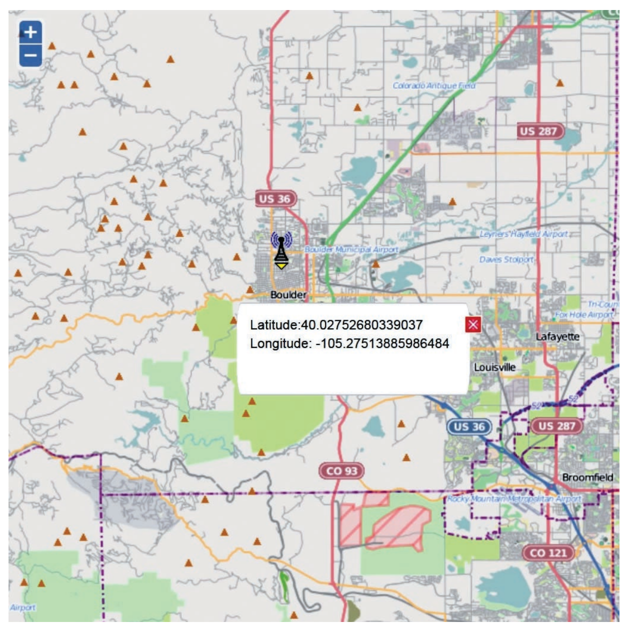
PMW Capabilities

PMW presently includes the capacity to perform propagation analysis using any of the following propagation models: TIREM 3.15; Longley-Rice 1.22; COST 231 Extended Okumura-Hata; Undisturbed Field/Mobile-to-Mobile; and ICEPAC. Development to incorporate low frequency/medium frequency (LF/MF, 30 KHz to 3 MHz), ICEWave, and ITURHFProp (3 to 30 MHz) models is currently underway. Users can simultaneously run a batch of transmitters, specified in an Excel® transmitter file. Propagation analyses, using all five of the currently available models, can be performed in either single or batch-transmitter mode using a separate thread for each analysis.



Overview diagram of the PMW architecture.

In single analysis mode, users can geographically select a transmitter from an embedded interactive map display. In batch mode, users can load an Excel® transmitter file and plot the desired transmitters on the map prior to running the analysis. This functionality was developed using open source products OpenStreetMap© and OpenLayers©. The PMW is delivered with five zoom levels for the map; level 5 translates roughly to a scale of 4,888 meters per pixel. Additional zoom levels can be added, up to level 12—a scale of 76 meters per pixel. OpenStreetMap provides 20 zoom levels to achieve a scale of 0.298 meters, but rendering each tile for 20 zoom levels would require 54 terabytes of storage. The geographic data is packaged and shipped with the software because many PMW users operate in a secure environment and cannot connect to the Internet to dynamically update the data.



Web map zoomed to level 12.

Users can export analyses for use with Esri's ArcGIS® Desktop application or any other GIS application that accepts GIS shape or Esri layer files. Because the PMW is modular in design, ITS engineers can enhance the PMW software to incorporate the specific needs of different sponsors.

The PMW incorporates a parallel-threaded design that offers enhanced speed for running analyses. Depending on the user's hardware capabilities, the software can use parallel threading to decrease propagation analysis time proportionally to the number of computer cores. All models take advantage of this feature except the ICEPAC model, which contains legacy code that cannot easily run in parallel. The PMW also provides the ability to create analysis composites for thousands of transmitters and export data analyses to Google Earth® (KML/KMZ) for all models except the ICEPAC model, which typically produces analyses that cover the globe.

For TIREM, Longley-Rice, and ICEPAC models, users can choose from antenna pattern data included with the software to run an analysis or upload their own files to the site. TIREM and Longley-Rice propagation models use SRTM1, SRTM2, DTED1, DTED2, GLOBE, or user-selected terrain files.

The PMW contains a Windows® service module, which reads XML propagation model files created by the Web site and runs each XML process according to priority and availability of system resources. This service monitors and communicates the status of all processes back to the PMW Web site for users to monitor system progress.

Over the next several years, as the PMW continues to mature, current and future sponsors may choose to incorporate several software enhancements, including interference studies, the ability to plot completed analyses in the Web map, additional input parameters like signal-to-noise ratio (SNR), composites for sectors of a cell tower, new terrain formats (HRTe, LiDAR, IFSAR, etc.), path profile, output reports, point-to-point propagation model mode, and other propagation models (IF-77, JEM, and updated HF models).

The PMW currently operates on our sponsors' internal, secure networks or on a secure site hosted by ITS, allowing only our sponsors to have access to their data. Thanks to the large selection of GIS databases available, customers can choose to include terrain, satellite, and aircraft imagery, ground transportation infrastructure, building data, and population distribution. By developing PMW, ITS assists Government agencies in efficiently managing their telecommunications infrastructure through sound system planning and interference detection for national security and public safety.

National Weather Service PMW

Under a multi-year interagency agreement, ITS provides the National Weather Service (NWS) with Web-based Propagation Analysis Services based on the PMW VHF service. NWS is mandated to provide the Nation with a round-the-clock source of weather reports and timely hazard information. This is accomplished through the NOAA Weather Radio system, which broadcasts continuously on specified frequencies.

The goal of this system is to provide access to potentially life-saving information to at least 95 percent of the U.S. population in the event of a national emergency. To continue to meet or exceed this broadcast coverage goal, NWS engages in ongoing expansion efforts that provide new or upgraded transmitters in many locations around the country. ITS provides NWS with customized web-based propagation analysis services used to plan the location and characteristics of new transmitters to optimize coverage.

NWS engineers log into the PMW, which is hosted on their customized server housed at ITS, to run propagation analyses. The PMW can produce a report showing population coverage for a selected propagation analysis based on U.S. Census 2010 population data divided into 90 square meter areas. Using this system and its databases, planners of the national alert system can verify and improve coverage by their large, diverse radio transmission system.

For more information on the locally-hosted PMW contact Julie Kub, (303) 497-4607, jkub@its.bldrdoc.gov or George Engelbrecht, (303) 497-4417, gengelbrecht@its.bldrdoc.gov. For more information on the NWS PMW contact Teresa Rusyn, (303) 497-3411, trusyn@its.bldrdoc.gov or Kristen Davis, (303) 497-4619, kristen@its.bldrdoc.gov

ITS Tools and Facilities

Audio Visual Laboratories

Subjective Testing Facilities

Subjective testing means gathering opinions from a group of users. This is the most accurate way to measure the perceived quality of a phone conversation or video stream.

Designing a subjective test can be tricky. The way one asks a person's opinion can influence the answer the person will give. Experts create ITU Recommendations that list "best practices." These attempt to minimize unwanted influence on a person's answer. When subjective tests are designed with care, they can be highly repeatable; that is, results are the same regardless of where or when the test takes place.

A controlled test environment can enhance repeatability. A person's attention is focused on the task at hand since the lighting is controlled, there is little or no background noise, and there are no visual distractions. A controlled room also frees the experimenter from considering environmental variables when analyzing the test results. ITS has three such rooms: two are identically constructed sound isolation chambers; one is a secluded, quiet room.

The two identical rooms can be connected to allow two persons to converse using audio, video, or both. This type of testing can reveal problems that are not apparent when people only listen to audio recordings or view video. Key examples are audio and video delay—if either is too great, communication can be impaired.

The third subjective test room is a larger, quiet room with a window. This room provides flexibility, but a little less control. Currently, the third test room looks like a living room. This sets a different context for questions about audio and video quality.

Audio Visual Laboratory facilities at ITS. Top: The video workstation includes a broadcast quality television, studio quality speakers, and uncompressed capture of HDTV. Acoustical foam reduces background noise, so that subtle audio impairments can be heard. Middle: Subjective test room set up as a real world living room. Bottom: Sound isolation booth set up for an audiovisual subjective test, with a broadcast quality television and studio quality speakers. Photos by Andrew Catellier.

Unique Capabilities

Because subjective testing is so time intensive and requires such expensive resources, only a few organizations in the United States perform them. Significant expenses are:

- Subjective test facility construction and operation
- Accurate audio and video play back
- Experiment design and implementation
- Production of audio and video recordings that match the test purpose
- Simulation of audio and video systems

ITS has proven expertise in designing and conducting subjective experiments. Over the past two decades, ITS has published the results from dozens of subjective experiments.

One surprisingly difficult problem is audio and video playback. Many audio and video players cannot guarantee that every person will see and hear exactly the same audio or video. ITS uses studio-quality hardware and special purpose software tools to ensure reliable playback. These playback systems often push cutting-edge computer hardware to its limit.

Simulating modern audio and video distribution is expensive because there are many methods in use in the telecommunication industry. The ITS audiovisual lab has a variety of hardware and software tools that encode, transmit, or play audio and video, and simulate how people use audio and video today. These tools span a wide range of audio and video services:

- Broadcast quality audio and video
- Satellite and cable TV
- Video on demand
- Streaming Internet video
- Video teleconferencing
- Cell phone audio and video
- VoIP

Audio and Video Capabilities

The ITS audiovisual lab supports standard definition (SD) television, high definition television (HDTV), three-dimensional television (3DTV), and monophonic, stereophonic, and 5.1-channel audio streams.

Equipment available includes:

- Studio quality analog and digital video recorders with 2 to 8 audio channels
- Digital audio recorders
- Analog audio mixing, filtering, and equalization
- Studio quality video monitors, monitor loudspeakers, and headphones
- Telephone handsets
- Subjective test chambers compliant with ITU-T Rec. P.800, ITU-R Rec. BT.500, and ITU-T Rec. P.900
- Various hardware and software encoders and decoders
- Internet protocol network error simulator compliant with ITU-T Rec. G.1050

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Automated Wideband Noise Measurement System

Several years ago, ITS developed an automated wideband noise measurement system. The measurement system consists of an antenna, ITS custom-built preselector, vector signal analyzer (VSA), and personal computer. The cornerstone of the system is the VSA that permits wideband noise measurements in up to 36 MHz of bandwidth and the recording of digitized in-phase/quadrature (I/Q) samples of the entire noise signal.

The ability of this system to record actual I and Q signal data in a wide bandwidth provides many options for processing and further use of the data. The preselector contains a fixed bandpass filter tuned to the measurement frequency, a low pass filter, and a low-noise amplifier (LNA). The filters can be easily exchanged to conduct noise measurements at different frequencies. This configuration provides for a very sensitive measurement system with a noise figure (NF) of approximately 3 dB. The system uses a quarter-wave monopole antenna, tuned to the desired measurement frequency and mounted on a ground plane.

The personal computer is used to run software developed by ITS to control the noise measurement system. This software allows the user to set the measurement frequency, bandwidth (span), number of data points, and other parameters. Once the measurement is started, the software will automatically collect data at user-defined time intervals for a user-specified duration. The software can also perform and display results of noise diode calibrations, spectrum captures, and single manual noise measurement data captures. To provide a high degree of RF shielding between the measurement equipment and the antenna, as well as AC power, temperature control, and shelter, the noise measurement system is currently housed in the RSMS-4G measurement vehicle.

While the system is fully capable of, and has been used for, conducting outdoor noise measurements, several limitations of the system have become apparent. These limitations include a susceptibility to signal overloads, the inability to adjust the analog sampling rate, limited anti-aliasing filtering, no capability to include an external intermediate frequency (IF) filter before the digitizer, and a restriction on center frequency agility. A two-channel measurement system was designed to overcome these limitations. It consists of one very sensitive RF channel and another less sensitive RF channel, and is more fully described in the section on Radio Propagation Measurement Capabilities on page 76. Measurements are taken on both channels simultaneously with processing used to extract the composite data.

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Boulder Labs Frequency Manager

An ITS staff person acts as the Boulder Labs Frequency Manager, chairing the Boulder Labs Interference Committee. This committee protects the Department of Commerce Boulder Laboratories campus and the Table Mountain Radio Quiet Zone facilities from harmful radio frequency interference by evaluating new transmitters before they begin operating. Propagation analyses using various propagation prediction models or field measurements may be required to resolve potential electromagnetic interference problems.

The Committee has jurisdiction over all Government and private industry users seeking permission for frequency usage at the Table Mountain Radio Quiet Zone, and over stations in the area that meet the following conditions of effective radiated power (ERP) and radial distance:

- All stations within 2.4 km.
- Stations with 50 W or more ERP within 4.8 km.
- Stations with 1 kW or more ERP within 16 km.
- Stations with 25 kW or more ERP within 80 km.

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Green Mountain Mesa Field Site

The Green Mountain Mesa Field Site is located on the main Department of Commerce Boulder Laboratories campus. The site is used year round for outdoor wireless network research and was extensively refurbished in FY 2010. Improvements included installation of a portable building situated on a concrete pad to securely house the fiber and power distribution. A new 16.8 meter (55 foot) tower was also constructed and raised to support research and evaluation of LTE 4th generation wireless technology. The site is connected to the ITS laboratories via both fiber optic and 802.11 links, and to the Table Mountain Field Site via a microwave link. The fiber optic link provides access to the ITS local area network (LAN) while the 802.11 link connects to the ITS Wireless Networks Research Center. The site can provide six independent duplex fiber channels to the ITS lab. This allows research to be conducted over an isolated one-mile outdoor Wi-Fi link. The fiber connectivity provides a LAN connection to the outdoor wireless router and the capability to operate remote data collection equipment.

The outdoor router, located on an 24 meter (80 foot) tower, provides long-range 802.11 links to other sites. These links provide 802.11b services and are also used for network performance testing. The site's unique location, several hundred feet above the main Department of Commerce campus, allows for the provisioning of wireless test links over a large portion of eastern Boulder County.

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A cluster of antennas used to test different telecommunications technologies at the Green Mountain Mesa Field Site. Photo by Jeff Bratcher.

High Performance Computing Cluster

The HP blade computing cluster is an extensible platform with multiple CPU cores. It is primarily used for running propagation prediction models with large amounts of terrain data in parallel. The cluster allows researchers to make significant progress towards achieving real-time results that are highly desirable for many consumers of propagation modeling data. Customized software developed at ITS allows this capability to be leveraged for ITS and joint research projects in many ways. The cluster runs both GNU/Linux and Windows Server® and also has the capability for virtualization of many client operating systems. The blade system is housed inside a climate-controlled server room with high available power and battery power backup. There is sufficient capacity to enable rapid response to new computing challenges with new hardware or techniques. All servers include redundant disk arrays, and backup to a large disk store. The room is physically secured through an access control and security system that logs entry by authorized personnel.

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Public Safety Audio and Video Laboratories

One of the most challenging aspects of public safety communication is the harsh noise environment in which public safety practitioners must effectively establish and conduct communications. The Public Safety Audio Laboratory (PSAL) and Public Safety Video Laboratory (PSVL) are facilities for investigating the voice and video quality of public safety communication systems in harsh environments. The PSAL consists of digital systems for mixing, storage, and distribution of audio; sound attenuated chambers for effective isolation; and ITU-compliant head and torso simulators (HATS) for acoustic coupling to radio interfaces. The PSVL consists of cameras, video capture systems, video coding and decoding systems, network simulators, video editing stations, and props.

The PSAL is built on a foundation of digital audio mixing and distribution. All audio mixing, distribution, storage, and filtering are conducted in the digital realm with 48 kHz sampled audio. This provides a high-quality, distortion-free distribution system that is not impacted by other equipment in the laboratory. The digital capabilities include: digital mixing, 24 track digital recording, 8 channel digital input and output to Windows-based computers, digital audio tape (DAT), and 1/3 octave digital filters. Usage of analog audio signals is kept to a minimum by 1) digitizing analog inputs at the input and keeping them digital throughout any processing, and 2) only performing digital-to-analog conversion on signals that are to be converted to acoustic signals.

An ITU-Standard head and torso simulator (HATS) set up in a sound-isolated booth for testing in the PSAL. Photo by Andrew Catellier.

The more specialized equipment in the PSAL includes the two HATS systems. The HATS systems are defined by the ITU in Recommendations P.58 (Head and torso simulator for telephonometry), P.57 (Artificial ears), and P.51 (Artificial mouth). These recommendations specify the physical characteristics and acoustical/electrical interface characteristics that enable a consistent simulation of the speaking and hearing frequency responses of the “average” human. The HATS enable consistent acoustic input to communications equipment under test and provide a “willing subject” that will not suffer hearing loss when exposed to harsh noise environments for extended periods.

The PSAL system provides a reproducible acoustic path that enables emulation of the harsh noise environments encountered by public safety practitioners. The recorded output from the system can be used in a number of ways. For example, the recordings might be analyzed by an objective measurement technique such as ITU Recommendation P.862 Perceptual evaluation of speech quality (PESQ) or an objective intelligibility estimator such as ABC-MRT which was recently developed in the PSCR program. Alternatively, the recordings might be incorporated into a subjective test experiment where listeners determine the intelligibility or the quality of the recorded signals..

The primary role of the PSVL is to support research on video quality for public safety applications. To accomplish this mission, scenes that contain selected elements unique to or typical of public safety responder uses are created and filmed on high-definition cameras. These scenes include simulations of surveillance cameras (indoor and outdoor), in-car police cameras, and search and rescue robot cameras, among others. The video is then captured and edited on the PSVL workstations. Selected scenes are processed through controlled versions of the communication systems that are typical of what a jurisdiction might consider purchasing. The communication systems processing includes compression schemes and simulated wired and wireless networks.

To determine if a system is adequate for use in specified applications, first responders view the video and attempt to perform certain tasks such as identifying an object or reading a license plate. The results of these tests provide data for developing recommendations. Together, the PSAL and PSVL provide valuable insight into the requirements for public safety audio and video communications.

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Public Safety RF Laboratory

ITS's Public Safety RF Laboratory (PSRF Lab) supports the PSCR Broadband Demonstration Network, a test bed that manufacturers may use to hone public safety mobile communications products incorporating LTE, a new generation of mobile broadband access technology, before they are brought to market. This effort also includes development of techniques to bridge LTE and P25 land mobile radio technologies currently in use. While the PSRF Lab's test and measurement capability is primarily intended to support development and maturation of public safety mobile communications technology, the underlying infrastructure and analysis facilities can support a much broader range of tests and radio equipment. This excess capability is available to other Federal agencies on a first-come, first-served basis.

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Left: Test bench in the PSRF laboratory. User equipment (UEs) from multiple manufacturers in multiple formats are tested for performance characteristics and interoperability. The middle shelf holds measurement instruments. Right: It is important that tests be conducted under realistic conditions. The PSRF laboratory has a collection of public safety protective equipment of different types that can be used in tests to ensure compatibility with the UEs under test. Here, face masks and air tanks with different microphone and personal alarm systems. Photos by Lilli Segre.

Radio Propagation Measurement Capabilities

ITS designs, develops, and maintains a number of mobile and static RF measurement systems that address a very broad range of wireless scenarios in frequencies from 10 MHz to 300 GHz. All measurement systems are modular and easily configurable for specific measurement purposes. The RSMS system, fully described in the next section, allows mobile or stationary RF measurements from 10 MHz and 40 GHz, both in laboratory settings and at field sites, attended or unattended. Another mobile propagation measurement system covers a frequency range from 20 MHz to 30 GHz. An extremely high frequency (EHF) measurement system for frequencies from 30 to 300 GHz is currently under development as part of the Millimeter Wave Research program described on page 23. In FY 2013, ITS designed and configured a unique measurement system optimized to detect specific signal types for 3.6 GHz maritime radar band occupancy measurements.

The mobile propagation measurement system developed in FY 2012 for improved outdoor noise measurement has two operational modes: 1) narrowband channel probe 2) broadband channel probe. The narrowband mode has high accuracy, dynamic range, and sensitivity, and excellent immunity to interference. A continuous-wave (CW) signal is transmitted and received using a spectrum analyzer, vector signal analyzer, or sound card/communications receiver combination. The received data contain path loss, a slow-fading profile, and fast-fading information. The system is operated as a broadband channel probe by applying binary phase shift keying (BPSK) modulation to the transmitted signal using a pseudorandom number code with a user-selectable number of bits. Post-processing yields a channel impulse response from which useful parameters (e.g. delay spread, basic path loss) can be extracted. It is capable of measuring fast- and slow-fading phenomena and path loss.

Over the past five years, a new ultrawideband propagation measurement system has come on line. It consists of a commercial-off-the-shelf vector network analyzer (VNA), transmit and receive antennas, and an analog optical link. The VNA is configured to perform 2 port S-parameter transmission measurements between fixed transmit and receive antennas. The system covers a frequency range of 20 MHz to 18 GHz and is used to measure time- and frequency-domain propagation phenomena at distances of 2–300 meters. It is configured in a stepped-frequency mode, and S_{21} data (amplitude and phase) are acquired and stored. The resulting frequency-domain data are post-processed, inverse Fourier transformed, and time gated to yield propagation parameters such as delay spread and basic path loss.

This system has high accuracy and is ideal for precision propagation measurements and model development/validation. The frequency- and time-domain signal processing yield high-dynamic range and excellent immunity to RF interference. The system transmits very low power levels (typically +5 dBm) and has low interference potential to existing wireless services. It has been used extensively for near-Earth propagation measurements at Table Mountain with excellent path loss and channel impulse response data obtained. Indoor and building penetration measurements are also performed using this system. This system also has excellent range resolution capabilities that permit the isolation and evaluation of selected propagation events.

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Radio Spectrum Measurement System

The RSMS measurement system includes a comprehensive suite of test equipment, custom-built hardware and software, specialized measurement and analysis techniques, and the extensive expertise of engineers with years of radio frequency (RF) research experience. The objective of the program is to ensure that the Institute has access to the most advanced software and hardware so that it can perform accurate and complete RF measurements between 10 MHz and 40 GHz. The RSMS system and related ITS engineering expertise are available for use by industry and other government agencies on a cost-reimbursable basis under CRADAs and IAs, respectively.

Hardware

While not defined by any single hardware configuration, the system uses state-of-the-art spectrum analyzers, digital oscilloscopes, vector signal analyzers, vector signal generators, and signal intercept and collection systems. This equipment is often fused with RF preselectors, custom built by ITS engineers using state-of-the-art microwave components, to allow measurement of high-dynamic-range signals such as those from radars and communication systems. Overall measurement dynamic range of up 140 dB can be achieved by RSMS systems, extending the nominal 80 dB of instantaneous dynamic range available with precision test equipment. The modular design of the RSMS measurement platforms allows mobile or stationary measurements, both in laboratory settings and at field sites. Deployments of RSMS assets can use the RSMS-4 mobile laboratory or be constructed at field sites from individually-shipped modules.

RSMS-4 Mobile Laboratory

An integral part of the system is a measurement vehicle, now in its 4th generation. The vehicle has a highly-shielded enclosure (60 dB isolation from the ambient environment) with three full-size equipment racks, three 10 meter telescoping masts, and a 20 kW diesel generator with power conditioning, as well as Internet connections and a climate control system. The RSMS-4 mobile laboratory can be deployed to remote field sites where many operational systems are located and can operate independently from systems under test.

RSMS-5G Software

The RSMS software package is now in its 5th generation (RSMS-5G) of development. It is dynamic and flexible, incorporating automated, semi-automated, and manual techniques for radio emission measurement and analysis. ITS used modern software tools to develop this version, simplifying the design and implementation of new measurement algorithms. The resulting decreased dependency on third party software and compatibility with multiple operating systems has extended the application life-cycle, reduced overall costs, and provided flexibility to continue to keep pace with rapid advances in RF technology.

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Radio System Software Simulator

Spectrum sharing is based on interference protection criteria (IPC) such as the allowable interference power to noise power ratio (INR). The allowable INR ensures that performance of Federal radio services is not degraded to the point where the service can no longer satisfy its mission.

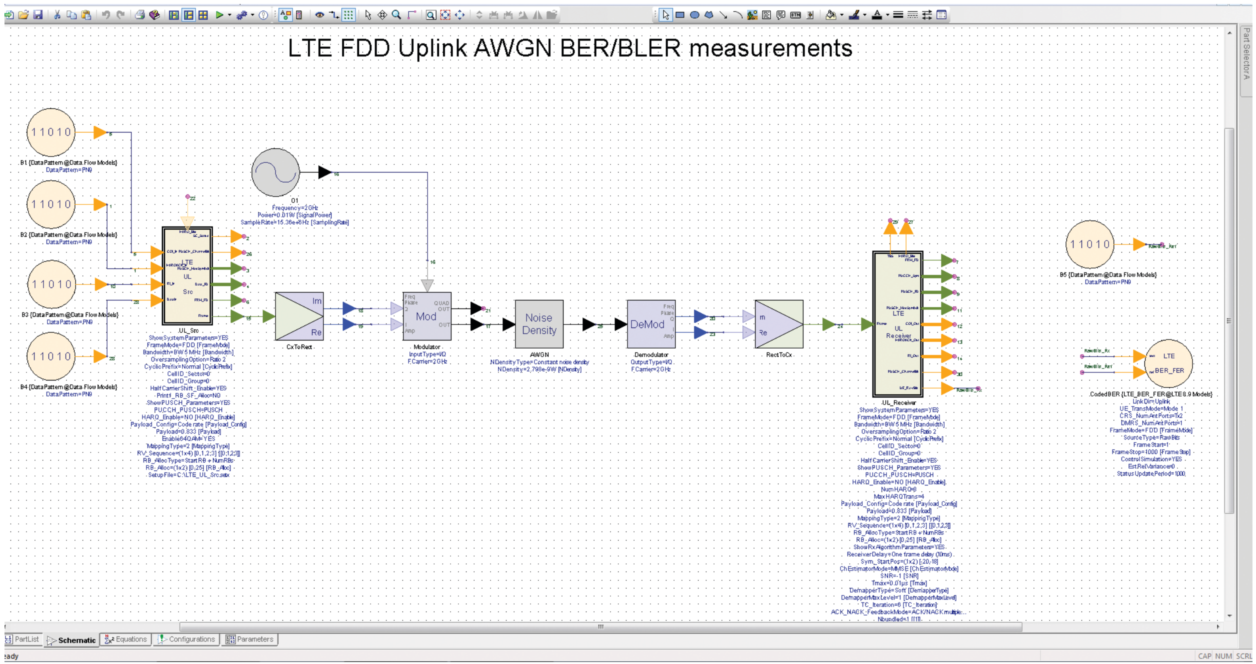
Allowable INR is usually determined with radio system field measurements. In these measurements, engineers measure radio system performance as they vary interference power. Typically, a vector signal generator is used to inject the interfering signal into the receiver. For a communication system, performance degradation might be measured with bit or packet error rates. For a radar system, the performance degradation is measured with probability of detection.

Field measurements have several disadvantages including

- Having to travel to the radio system location
- Having to remove the radio system from service while tests are performed
- Limited access to error rate or probability of detection performance metrics

A radio system software simulator run on a personal computer can potentially overcome these difficulties. Simulations proceed in the same manner as field measurements, i.e., the interfering signal is injected into the receiver and performance is measured. However, the simulator can be used at any time in the engineer's office without having to take the system out of service. Performance metrics are readily accessible.

Another advantage of software simulation is unlimited access to intermediate signal processing signals. Access to these signals enables the engineer to identify subsystems that are most sensitive to the interfering signal and recommend ways to "harden" the victim receiver to the interference.



A screen shot from the radio system software simulator workspace. The workspace contains various functional blocks, including from left to right, data sources, LTE transmitter baseband processor, frequency modulator, receiver noise adder, frequency demodulator, LTE receiver baseband processor, and data sinks for computing bit error rate. Text below functional blocks contain block parameters. Interference would be added to the received signal the same way receiver noise is added.

During FY 2014, ITS researched various off-the-shelf commercial radio system software simulators and purchased one that met our requirements. The simulator can emulate and interoperate with cellular equipment conforming to LTE Release 8/9 and LTE-Advanced Release 10 broadband radio services (BRS) standards, and with wireless local area networks conforming to IEEE 802.11 a, ac, ad, b, g, and n standards. The simulator is also capable of modeling non-coherent and coherent radar systems as well as non-linear effects such as amplifier gain compression. Finally, it can use the same vector signal generator interference waveform files used in field measurements to inject interference.

Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older ones can result in electromagnetic compatibility (EMC) problems. Although theoretical models and simulations provide useful information in guiding design decisions, the complexity of modern systems and the existing spectral environment often require real-world measurements of a proposed system's effects within its operating environment to determine its impact on other spectrum users.

Another problem is to adequately produce controlled interfering signals with known characteristics in environments where suspected interferers may be unavailable for tests and measurements. This includes situations such as laboratory investigations of possible interference from ship- or aircraft-mounted radars or terrestrial or space-based communications systems. In these sorts of situations, a system is needed that simulates the spectral emissions of other devices with high fidelity. An example of these needs is the requirement to determine the thresholds at which various types of interference from communication transmitters are manifested as observable interference effects in radar receivers. Another example would be to determine the source(s) of interference from terrestrial services to space-based communication links.

To meet these needs, ITS engineers have developed capabilities to generate interference signals. These signals can be coupled directly into a system under test or they can be transmitted through space into a target system's receiver to more accurately gauge its response to a real interference situation.

ITS engineers generate interference by first using high-speed digitizers (vector signal analyzers (VSA)) to record interference waveforms in bandwidths up to 36 MHz. They subsequently radiate or hardline-couple those signals into victim receivers using vector signal generators (VSG). Alternatively, VSGs may be preprogrammed with the requisite mathematical information to create particular waveform modulations, such as quadrature phase shift keyed (QPSK) signals.

The ITS interference signals can be transmitted with high-power amplifiers to generate high-power interference at frequencies up to 26 GHz. The advantages of using VSGs to generate interference include simplicity of operation and use, plus the ability to replicate very complex interference waveforms with complete confidence in the fidelity of the simulated signal to the characteristics of the original signal from which it was derived.

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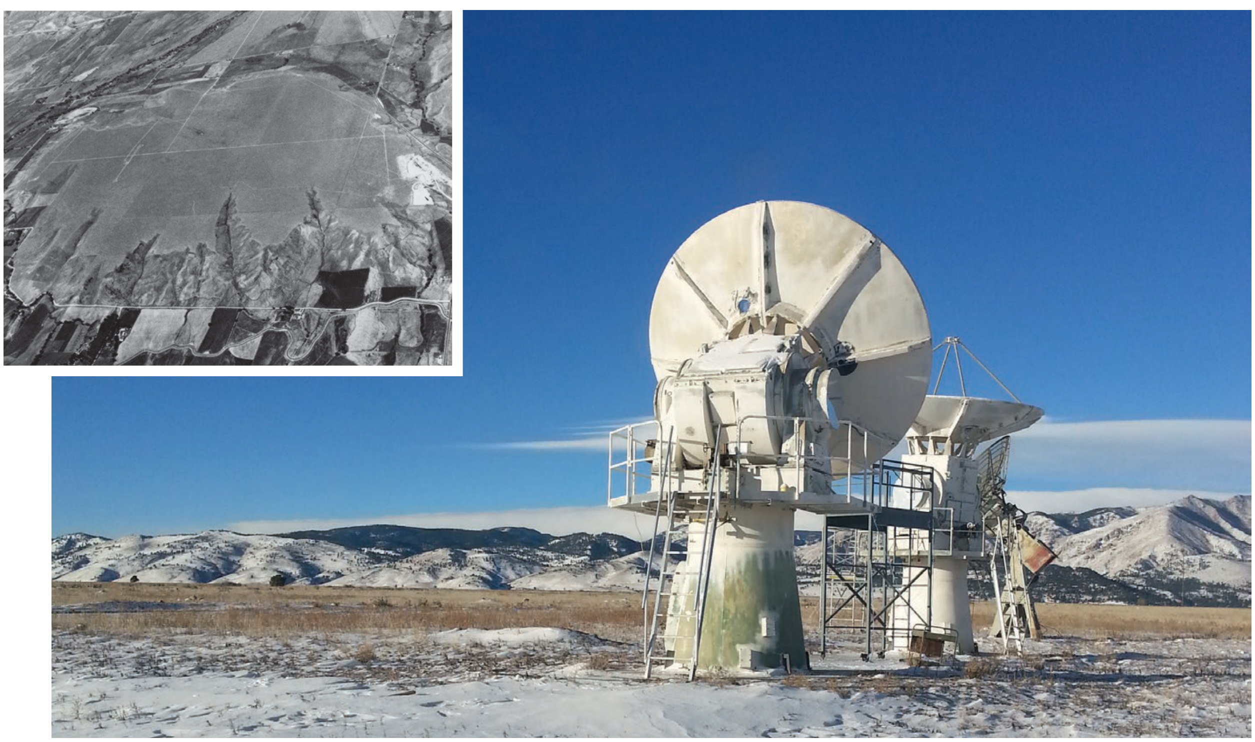
Table Mountain Field Site and Radio Quiet Zone

The Table Mountain Field Site and Radio Quiet Zone is located north of Boulder and extends about 4 kilometers (2.5 miles) north-south by 2.4 kilometers (1.5 miles) east-west, an area of approximately 1,800 acres. The site is designated as a Radio Quiet Zone where the magnitude of external signals is restricted by state law and Federal regulation to minimize radio frequency interference to sensitive research projects. Site power distribution is by means of buried line to avoid interference. Partnerships and cooperative research activities with other entities are encouraged at the site—see the articles on CRADAs for the Use of Table Mountain on page 6 and Interagency Agreements for the Use of Table Mountain on page 12.



The two 60 foot parabolic dish antennas on Table Mountain. Behind these, one of three smaller dish antennas previously used by another agency that are presently being refurbished to be re-purposed for radio research. Photo by Wayde Allen. The inset shows an aerial photograph of the plateau, c. 1964. Photo courtesy Roberts Commercial Photography.

Facilities at the site include:

- Spectrum Research Laboratory—A state-of-the-art facility for research into radio spectrum usage and occupancy. Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other.
- Open Field Radio Test Site—As a flat-topped butte with uniform 2% slope, Table Mountain is uniquely suited for radio experiments. Lack of perimeter obstructions and relatively homogeneous ground facilitates studying outdoor radiation patterns from bare antennas or antennas mounted on structures.
- Mobile Test Vehicles—There are several mobile test equipment platforms available at the site, ranging from four-wheel drive trucks to full-featured mobile laboratories.
- Large Turntable—A 10.4 meter (34 foot) diameter rotatable steel table mounted flush with the ground. Laboratory space underneath houses test instrumentation and control equipment, and motors to rotate the turntable. The facility can be operated remotely by computer.
- Two 18.3 Meter (60 Foot) Parabolic Dish Antennas—These two antennas are steerable in both azimuth and elevation and have been used at frequencies from 400 MHz to 6 GHz.
- Radar Test Range—A large open space just south of the Spectrum Research Laboratory is available for testing radar systems.

Learn more online at: http://www.its.bldrdoc.gov/resources/table_mountain.

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Wireless Networks Research Center

The Wireless Networks Research Center (WNRC) provides a common laboratory area for research in wireless networks and wireless network access technologies. The WNRC allows ITS to consolidate efforts in several areas, such as the RF/network interface. This work uses RF link characterization correlated with low-level network management protocols to develop PCS-to-PCS interference models, wireless network propagation models, noncooperative wireless measurement, and wireless network discovery. RF/network interface measurement devices are used to make detailed measurements of PCS and cellular networks. One device uses a series of PCS/cellular phones to extract low-level protocol messages, network management information, and RF signal quality parameters. Another has the ability to perform provider-independent PN offset scans and CDMA2000 level 3 message logging.

The WNRC contains an experimental IEEE 802.11b wireless local area network (WLAN). ITS has conducted a series of wireless Voice over IP (VoIP) tests utilizing this infrastructure. The WLAN resources include IP packet logging equipment that can be used in network measurements. A code domain analyzer (CDA) measurement capability, used to collect both short and long-term Walsh channel data for any target IS-95 base station, has been added to the WNRC. The CDA operates in both the cellular and PCS frequency bands and can be used in fixed or mobile environments. The WNRC is used to conduct ITS research in the area of inter-PCS interference, in support of the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC-RAN. ITS also has the capability to simulate PCS interference using a series of ITS-implemented interference models.

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ITS Activities in FY 2014

Publications and Presentations in FY 2014

NTIA Publications

> *An open exchange of scientific ideas, information, and research achieves the Department's vision for an informed society that uses objective and factual information to make the best decisions.*[1]

Chriss Hammerschmidt, "Broadband Spectrum Survey in the San Diego, California, Area," NTIA Report TR-14-498, December 2013. http://www.its.bldrdoc.gov/publications/2741.aspx

NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement Sciences system to collect spectrum occupancy data for radio frequency assessments. This report shows measured frequency data spanning spectrum from 108 MHz to 10 GHz in the metropolitan area of San Diego, California, during the months of May and June 2012.

Frank H. Sanders , John E. Carroll, Geoffrey A. Sanders, Robert L. Sole, "Effects of Radar Interference on LTE Base Station Receiver Performance," NTIA Report TR-14-499, December 2013. http://www.its.bldrdoc.gov/publications/2742.aspx

In response to proposals to introduce new radio systems into 3550–3650 MHz radio spectrum in the United States, the authors have performed measurements and analysis on effects of interference from a variety of radar waveforms to the performance of a Long Term Evolution (LTE) base station receiver. This work has been prompted by the possibility that LTE base station receivers may eventually share spectrum with radar operations in this spectrum range. The base station receiver that was tested used time division duplex (TDD) modulation. Radar pulse parameters used in this testing spanned the range of both existing and anticipated future radar systems in the 3100–3650 MHz spectrum range. LTE base station receiver data throughput rates, block error rates (BLER), and internal noise levels have been measured as functions of radar pulse parameters and the incident power level of radar pulses in the base station receiver. The authors do not determine the acceptability of radar interference effects on LTE base station performance. Rather, these data are presented for the use of spectrum managers and engineers who can use this information as a building block in the construction of frequency-and-distance separation curves for radar transmitters and LTE base station receivers, supporting possible future spectrum sharing at 3.5 GHz.

Michael Cotton, Roger Dalke, "Spectrum Occupancy Measurements of the 3550–3650 Megahertz Maritime Radar Band near San Diego, California," NTIA Report TR-14-500, January 2014. http://www.its.bldrdoc.gov/publications/2747.aspx

This report presents spectrum occupancy data of the 3550–3650 megahertz (MHz) maritime radar band measured in June 2012 near San Diego. In this band, the military operates SPN-43 air marshaling radar systems with well-defined signal characteristics. A measurement system and frequency-swept technique were designed specifically to detect SPN-43 emissions. Over the two-week measurement duration in June 2012, we observed multiple systems operating simultaneously in band, spectral spreading of SPN-43 emissions, and out-of-band pulsed emissions that spanned the entire band of interest. In this presumably high-usage mostly military spectrum environment and at a low occupancy threshold (i.e., -83 dBm in a 1 MHz bandwidth at the output of a 2 dBi antenna), mean band occupancy was {36.6, 7.5}% during {weekdays, weekends}. There was a {40.0, 59.8}% chance that the band was empty and a {18.4, 2.3}%

1. Department of Commerce Administrative Order DAO 219-1, Public Communications

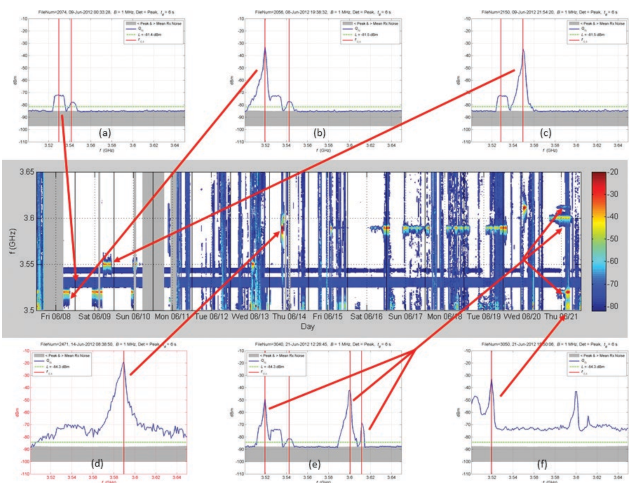


Figure 11 from TR-14-500 shows a spectrogram of measurements taken in the 3.6 MHz band June 8–21, 2012, near San Diego. Signal level is mapped to color and plotted versus time and frequency. Details on observations of interest are shown in the callouts surrounding the spectrogram.

chance that the band was full. During weekdays, spectrum usage was dominated by out-of-band pulsed transmissions that spanned the entire band at a relatively low level (approximately 10 dB above the low threshold level). These signals were superimposed on the stronger SPN-43 signals. On average during weekdays, transmissions occurred every four hours with a mean transmission length of approximately 1.5 hours. In contrast, weekend spectrum usage was primarily SPN-43 transmissions at 3.59 GHz arriving every 29 hours (on average) with a mean transmission length of approximately 9 hours. Measured SPN-43 signal amplitudes were at times strong enough to overload the measurement system (exceeding the -83 dBm threshold level by more than 60 dB). Statistical considerations that arise when measured data are used to characterize spectrum occupancy are also discussed in this report. Covered topics include channel occupancy definition, estimation, and uncertainty.

Andrew Catellier and Luke Connors, "Web-Enabled Subjective Test (WEST) Research Tools," NTIA Handbook HB-14-501, January 2014. http://www.its.bldrdoc.gov/publications/2748.aspx

The Web-Enabled Subjective Test software allows researchers to conduct subjective tests on multiple devices with aggregated data collection and reporting. The system leverages modern Web technologies and infrastructure to deliver test stimuli to typical mobile devices and personal computers. Devices with a modern web browser may be tested wherever a network connection is available. If resources allow, many subjects may participate in the test at one time. This unique capability allows for diverse and interesting subjective test plans. This manual describes how to install the WEST software on an Ubuntu Linux-based system.

Chriss Hammerschmidt, "Broadband Spectrum Survey in the Chicago, Illinois, Area," NTIA Report TR-14-502, February 2014. http://www.its.bldrdoc.gov/publications/2756.aspx

NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement System to collect spectrum occupancy data for radio frequency assessments. This report shows measured frequency data spanning spectrum from 108 MHz to 10 GHz in the metropolitan area of Chicago, Illinois, during a two week period in September 2012.

Editorial Review Board, "ITS Publication Handbook, Volume I: Policy," NTIA Handbook HB-14-503, March 2014. http://www.its.bldrdoc.gov/publications/2752.aspx

This is the third edition of a handbook intended to help Institute for Telecommunication Sciences (ITS) staff produce reports and papers in accordance with ITS, National Telecommunications and Information Administration, Department of Commerce, and Federal Government standards. It is based on the "ITS Publications Handbook," last updated in 2008, and the "Quick Reference Guide to ITS Publications," published in 1993. Volume I, "Policies," describes policies applicable to the preparation and quality review of manuscripts for publication and discusses policy issues such as the use of commercial names in ITS publications. Volume II, "Style Guide," provides guidelines for the publication of documents so that their appearance is uniform, consistent, and appropriately formal. Templates and best practices formerly included in Volume III have been included in a set of procedures developed to support this handbook.

Editorial Review Board, "ITS Publication Handbook, Volume II: Style Guide," NTIA Handbook HB-14-504, March 2014. http://www.its.bldrdoc.gov/publications/2753.aspx

This is the third edition of a handbook intended to help Institute for Telecommunication Sciences (ITS) staff produce reports and papers in accordance with ITS, National Telecommunications and Information Administration, Department of Commerce, and Federal Government standards. It is based on the "ITS Publications Handbook," last updated in 2008, and the "Quick Reference Guide to ITS Publications," published in 1993. Volume I, "Policies," describes policies applicable to the preparation and quality review of manuscripts for publication and discusses policy issues such as the use of commercial names in ITS publications. Volume II, "Style Guide," provides guidelines for the publication of documents so that their appearance is uniform, consistent, and appropriately formal. Templates and best practices formerly included in Volume III have been included in a set of procedures developed to support this handbook.

Margaret H. Pinson and Lucjan Janowski, "AGH/NTIA: A Video Quality Subjective Test with Repeated Sequences," NTIA Technical Memorandum TM-14-505, June 2014. http://www.its.bldrdoc.gov/publications/2758.aspx

This report provides full technical details for the video quality subjective test AGH/NTIA. Analyses of this dataset appear in separate publications. The purpose of this document is to provide design details that are beyond the scope of a conference paper or journal article. Subjective experiment AGH/NTIA includes multiple instances of the same stimuli rated three or six times by the same subject. The goal is to provide insights into the suitability of subject screening methods, the impact of source video reuse on subjective data, and the behavior of subjects when repeatedly rating the same stimuli.

Geoffrey A. Sanders , John E. Carroll, Frank H. Sanders, Robert L. Sole, "Effects of Radar Interference on LTE (FDD) eNodeB and UE Receiver Performance in the 3.5 GHz Band," NTIA Report TR-14-506, July 2014. http://www.its.bldrdoc.gov/publications/2759.aspx

In response to proposals to introduce new radio systems into 3.5 GHz radio spectrum in the United States, the authors have performed measurements and analysis on effects of interference, from a variety of radar waveforms, to the performance of a prototype 3.5 GHz Long Term Evolution (LTE) network, consisting of one base station (an eNodeB) and one client (referred to as user equipment or UE) utilizing frequency-division duplexing (FDD). This work has been prompted by the possibility that LTE receivers may eventually share spectrum with radar operations in this spectrum range. Radar pulse parameters used in this testing spanned the range of both existing and anticipated future radar systems in the 3.5 GHz spectrum range. Effects of radar interference on the LTE uplink and downlink throughput, block error rate (BLER), and modulation coding scheme (MCS) were measured. Additionally, for the uplink tests, resource block (RB) usage and UE transmit power were recorded. Effects on LTE performance are presented as a function of radar pulse parameters and the incident power level of radar pulses into the LTE receivers. The authors do not determine the interference protection criterion for LTE networks. Rather, the data presented can be used by spectrum managers and engineers as a building block in the construction of band sharing criteria for radar transmitters and LTE receivers, supporting possible future spectrum sharing at 3.5 GHz.

Frank H. Sanders, John E. Carroll, Geoffrey A. Sanders, Robert L. Sole, Lawrence S. Cohen, "EMC Tests and Measurements for Spectrum Sharing Between LTE Signals and Radar Receivers," NTIA Report TR-14-507, July 2014. http://www.its.bldrdoc.gov/publications/2760.aspx

In response to proposals to introduce new Long Term Evolution (LTE) microcell Citizens Broadband Service (CBS) radio systems into 3550–3650 MHz (3.5 GHz) radio spectrum in the United States, the authors have performed measurements and analysis on effects of LTE interference on the performance of a type of radar receiver that might eventually share spectrum with such systems. LTE and Gaussian noise interference were injected into a radar receiver; Gaussian noise was a proxy for aggregated interference sources and one type of LTE. Interference was injected into a radar receiver so as to appear coincident with synthetic radar targets on the radar's display. The targets' baseline (non-interference) probability of detection (Pd) was 90 percent. With interference present, the targets' Pd was measured and recorded as a function of LTE signal (both on-tuned and off-tuned) and Gaussian noise interference levels. Additional data presented in this report include: the radar receiver's antenna radiation pattern, RF front end frequency response, IF-stage frequency response, noise figure, and RF overload response up to an input power of -4.6 dBm. A measured LTE emission spectrum is also provided. Using these data, spectrum management personnel can perform electromagnetic compatibility (EMC) analyses for possible future spectrum sharing between LTE transmitters and this type of radar receiver.

"ISART 2012 Proceedings. Developing Forward Thinking Rules and Processes to Fully Exploit Spectrum Resources: Case Study 2—Exploring Approaches for Real-Time Federal Spectrum Sharing," NTIA Special Publication SP-14-508, September 2014. http://www.its.bldrdoc.gov/publications/2776.aspx

The 13th Annual International Symposium on Advanced Radio Technologies, held in Boulder, Colorado, July 24–26, 2012, presented the second conference focused on Developing Forward Thinking Rules and Processes to Fully Exploit Spectrum Resources. Following on from the previous two ISARTs, ISART 2012 looked at Case Study 2—Exploring Approaches for Real-Time Federal Spectrum Sharing. Topics covered included The Federal Spectrum Ecosystem, Current Federal Efforts that Can Increase Spectrum Sharing, Institute for Telecommunication Sciences Spectrum Survey Activities, TV White Space Tutorial, Fresh Approaches to Spectrum Sharing, and Validating and Regulating New Sharing Schemes. The keynote speaker was Larry Strickling, Assistant Secretary of Commerce for Communications and Information, National Telecommunications and Information Administration. This volume of proceedings is taken directly from the court reporter's transcription of the conference. A best effort has been made to correct spellings of names and terms of art, but it is in no way an "edited" transcript.

Outside Publications

Stephen D. Voran, "Using articulation index band correlations to objectively estimate speech intelligibility consistent with the modified rhyme test," 2013 IEEE International Workshop on Applications of Signal Processing to Audio and Acoustics, October 20–23, 2013, pp. 1–4. http://www.its.bldrdoc.gov/publications/2738.aspx

We present an objective estimator of speech intelligibility that follows the paradigm of the Modified Rhyme Test (MRT). For each input, the estimator uses temporal correlations within articulation index bands to select one of six possible words from a list. The rate of successful word identification becomes the measure of speech intelligibility, as in the MRT. The estimator is called Articulation Band Correlation MRT (ABC-MRT). It consumes a tiny fraction of the resources required by MRT testing. ABC-MRT has been tested on a wide range of impaired speech recordings unseen during development. The resulting Pearson correlations between ABC-MRT and MRT results range from .95 to .99. These values exceed those of the other estimators tested.

C. Baylis, J. Martin, M. Moldovan, R. J. Marks II, L. Cohen, J. de Graaf, R. Johnk, F. Sanders, Analysis Considerations for Radar Chirp Waveform Spectral Compliance Measurements," IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 3, pp. 520–529, June 2014. http://www.its.bldrdoc.gov/publications/2787.aspx

The measurement of a radar chirp waveform is critical to assessing its spectral compliance. The Fourier transform for a linear frequency-modulated chirp is a sequence of frequency-domain impulse functions.

Because a spectrum analyzer measures the waveform with a finite-bandwidth intermediate-frequency (IF) filter, the bandwidth of this filter is critical to the power level and shape of the reported spectrum. Measurement results are presented that show the effects of resolution bandwidth and frequency sampling interval on the measured spectrum and its reported shape. The objective of the measurement is to align the shape of the measured spectrum with the true shape of the signal spectrum. This paper demonstrates an approach for choosing resolution bandwidth and frequency sampling interval settings using the example of a linear frequency-modulation (FM) chirp waveform.

Margaret H. Pinson, Marc Sullivan, Andrew Catellier, "A new method for immersive audiovisual subjective testing," Eighth International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM 2014), Chandler, AZ, January 30–31, 2014. http://www.its.bldrdoc.gov/publications/2754.aspx

An immersive subjective test method is proposed in which subjects view each source stimulus only once. In order to encourage a subject's engagement with test content, longer stimuli are used. Distractor questions are used in addition to the traditional MOS scale in order to focus the subject on the intended application. A speech quality experiment is conducted with this method, and the results compared to those obtained with traditional methods. The consistent rank ordering among datasets demonstrates the validity of the immersive method.

Steve Voran, "Practice Sessions for Subjective Speech Quality Tests," VQEG eLetter, vol. 1, iss. 1, pp. 5–7, March 2014. ftp://vqeg.its.bldrdoc.gov/eLetter/Issues/VQEG_eletter_vol01_issue1.pdf

Subjective testing requires careful design and execution. This article describes the goals and design of practice sessions used before subjective speech quality tests conducted by the author.

Alan D. Skillicorn, Michael Kelley, Thomas J. Taylor, Eric Nelson, "Towards More Effective Spectrum Sharing," 2014 National Wireless Research Collaboration Symposium (NWRCS), pp. 123–126, 15–16 May 2014. http://www.its.bldrdoc.gov/publications/2788.aspx

In response to the Presidential Memorandum on Wireless Innovation and the recommendation of the President's Council of Advisors on Science and Technology (PCAST), the federal government has begun the process of organizing a National Advanced Spectrum and Communications Test Network (NASCTN) under the auspices of the U.S. Department of Commerce (DoC). The intent of this organization is to provide a single place for information about and access to all federally owned, operated or funded spectrum test facilities. This paper describes the NASCTN effort and the processes that are being developed to support its role as a focal point for spectrum sharing testing in the federal government.

Lucjan Janowski and Margaret H. Pinson, "Subject Bias: Introducing a Theoretical User Model," Fifth International Workshop on Quality of Multimedia Experience (QoMEX 2014), Singapore, 18–20 September 2014. http://www.its.bldrdoc.gov/publications/2774.aspx

We propose a model for rating behavior based on subject bias and subject error. Evidence for subject bias can be found in freely available subjective experiments. When subject bias is removed from ratings, the sensitivity of statistical comparisons between stimuli usually improves. According to our model, subject biases characterize the subject pool. These between-subject differences are important when analyzing and comparing people. On the other hand, it is advantageous to remove subject bias when analyzing mean opinion score. We conclude that bias acts like a random variable within ratings.

Presentations

- Stephen D. Voran, "Using Articulation Index Band Correlations to Objectively Estimate Speech Intelligibility Consistent with the Modified Rhyme Test," 2013 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA'13), New Paltz, NY, October 23, 2013.
- Nick DeMinco, Paul McKenna, and Robert T. Johnk, "A Propagation Model for Close-in Distances and Very Low Antenna Heights Based on Both Electromagnetic Theory and Measured Data," 2014 National Radio Science Meeting (NRSM) of the U.S. National Committee (USNC) of the International Union of Radio Science (URSI), Boulder, Colorado, January 8, 2014.
- Robert T. Johnk, Chriss A. Hammerscmidt, Mark A. McFarland, and John J. Lemmon, "A fast-fading mobile channel measurement system," National Radio Science Meeting (USNC-URSI) 2014, Boulder, CO, January 10, 2014.
- Margaret Pinson, "A new method for immersive audiovisual subjective testing," Eighth International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM 2014), Chandler, AZ, January 30, 2014.
- Margaret Pinson, Keynote Address, Eighth International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM 2014), Chandler, AZ, January 31, 2014.
- Andrew Catellier, "Using Articulation Index Band Correlations to Objectively Estimate Speech Intelligibility Consistent with the Modified Rhyme Test," International Wireless Communications Exposition (IWCE) 2014, Las Vegas, NV, March 26, 2014.

Andrew Thiessen provided an update on PSCR's efforts representing FirstNet in 3GPP to initiate global standards development for LTE technology at IWCE 2014.

- Robert T. Johnk, "In-Building Measurement Status Report," International Wireless Communications Exposition (IWCE) 2014, Las Vegas, NV, March 26, 2014.
- Andrew Thiessen, "DHS OIC Project 25 Compliance Assessment Program Roadmap," International Wireless Communications Exposition (IWCE) 2014, Las Vegas, NV, March 26, 2014.
- Andrew Thiessen, "Public Safety Standards Development," International Wireless Communications Exposition (IWCE) 2014, Las Vegas, NV, March 27, 2014.
- Michael Cotton, "NTIA's new Spectrum Monitoring Pilot Project," Wireless Spectrum Research and Development (WSRD) Workshop on Understanding the Spectrum Environment: Using Data and Monitoring to Improve Spectrum Utilization on at the National Science Foundation in Arlington, VA, March 31, 2014.
- Paul McKenna, "Point-To-Area Propagation Model Analysis Method," ITU-R Propagation Workshop, 8th European Conference on Antennas and Propagation (EuCAP 2014), The Hague, Holland, April 10, 2014.
- Julie Kub, "Creating the propagation modeling website (PMW) and Solving Software Obstacles" at the GISCO 2014 Spring Conference, Parker, CO, April 25, 2014.
- Margaret H. Pinson, "Overview Tutorial on Video Quality Assessment," Motorola Solutions Annual Science Advisory Board Internal Technology Summit, Schaumburg, IL, May 1, 2014.

- Eric Nelson, "Recent ITS Spectrum Sharing Related Work," National Wireless Research Collaboration Symposium (NWRCS), Idaho Falls, ID, May 15, 2014.
- Bob Johnk, "Indoor/In-Building Coverage Testing," PSCR Stakeholder's Meeting, Westminster, CO, June 4, 2014.
- Christopher Redding (with Camillo Gentile of NIST), "Extended Range Cell Testing," PSCR Stakeholder's Meeting, Westminster, CO, June 4, 2014.
- Joel Dumke, "Visual Acuity and Task-Based Video Quality in Public Safety Applications," PSCR Stakeholder's Meeting, Westminster, CO, June 4, 2014.
- Stephen Voran and Andrew Catellier, "PSCR Speech Intelligibility Work–Past, Present, Future," PSCR Stakeholder's Meeting, Westminster, CO, June 5, 2014.
- Anna Paulson (with Tracy McElvaney of NIST), "LNGN Priority Services Testing and Evaluation," PSCR Stakeholder's Meeting, Westminster, CO, June 5, 2014.
- Andrew Thiessen (with Barry Luke of NPSTC), "Standards Development & Requirements Gathering," PSCR Stakeholder's Meeting, Westminster, CO, June 5, 2014.
- Andrew Thiessen, "Local Control," PSCR Stakeholder's Meeting, Westminster, CO, June 5, 2014.
- Bob Johnk, "Indoor/In-Building Coverage Testing," APCO International 80th Annual Conference & Expo, New Orleans, LA, August 3, 2014.
- Rob Stafford, "Extended Range Cell Coverage Testing," APCO International 80th Annual Conference & Expo, New Orleans, LA, August 3, 2014.
- Michael Cotton, Keynote Address, Microsoft Spectrum Observatory Think Tank Meeting, Redmond, WA, August 6, 2014.

ITS Standards Leadership Roles in FY 2014

ITS provides technical contributions to standards development organizations (SDO), standards related organizations (SRO), and other organizations that informally contribute to standardization. For over half a century, ITS has held technical leadership roles and provided research-based technical contributions to support U.S. Administration positions in formal national and international SDOs. These include:

- International Telecommunication Union Radiocommunication Sector (ITU-R)
- International Telecommunication Union ITU Telecommunication Standardization Sector (ITU-T)
- Alliance for Telecommunications Industry Solutions (ATIS)
- 3rd Generation Partnership Project (3GPP)
- Telecommunications Industry Association (TIA)

> *"Federal agencies and departments shall consult with voluntary, private sector, consensus standards bodies and shall, when such participation is in the public interest and is compatible with agency and departmental missions, authorities, priorities, and budget resources, participate with such bodies in the development of technical standards."*
> *(15 U.S.C. §272 Note: Utilization of Consensus Technical Standards by Federal Agencies)*

In recent decades, the scope of this technology transfer effort has expanded to support the technical working groups of organizations such as the National Public Safety Telecommunications Council (NPSTC) and the Video Quality Experts Group (VQEG). Reports produced by these bodies inform the deliberations of SDOs and are important precursors to technical standardization. They also inform the policy deliberations of regulatory bodies such as NTIA, FirstNet, and the FCC. ITS provides technical leadership and expertise to these groups through formal and informal contributions.

Standards Leadership Positions Held by ITS Staff in FY 2014

- **Christopher J. Behm:** U.S. Chair of International Telecommunication Union Radiocommunication Sector (ITU-R) Study Group 3 (SG 3, Radiowave Propagation). U.S. Chair of SG 3 Working Party (WP) 3L.
- **Randall S. Bloomfield:** U.S. Department of Commerce Delegate to 3GPP SA (Service and System Aspects) Working Group 2 (Architecture).
- **John E. Carroll:** Delegate to ITU-R Study Group 1 (SG 1, Spectrum Management) WP 1A (Spectrum engineering techniques) and Study Group 5 (SG 5, Terrestrial Services) WP 5B (Maritime mobile service including the Global Maritime Distress and Safety System (GMDSS)); the aeronautical mobile service and the radiodetermination service).
- **Paul M. McKenna:** International Chair and U.S. Chair of ITU-R SG 3 WP 3K (Point-To-Area Propagation).
- **Margaret H. Pinson:** Head of U.S. Delegation to ITU-T SG 9 (Integrated Broadband Cable Networks and Television and Sound Transmission) and to ITU-R SG 6 WP 6C (Programme production and quality assessment). Associate Rapporteur for Questions 2/9 (Measurement and control of the end-to-end quality of service (QoS) for advanced television technologies) and 12/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9) in SG 9. Member of ITU-T SG 9 Intersector Rapporteur Group Audiovisual Media Accessibility (IRG-AVA). Co-chair of the Video Quality Experts Group (VQEG) and of VQEG's Independent Lab Group (ILG).
- **Patricia J. Raush:** U.S. Co-chair and Head of Delegation of ITU-R SG 3 WP 3J (Propagation Fundamentals).
- **Teresa Rusyn:** Chair of the Drafting Group and Rapporteur of ITU-R SG 3 Correspondence Group 3K3.
- **Frank H. Sanders:** Delegate to ITU-R SG 5 WP 5B and Chair of WP 5B Radar Correspondence Group (RCG, Radar Technical Spectrum Issues). Delegate to ITU-R SG 1 (Spectrum Management) WP 1A (Spectrum engineering techniques).
- **Andrew P. Thiessen:** U.S. Department of Commerce Delegate to 3GPP Technical Study Group Radio Access Network (TSG RAN) and to Technical Study Group Service and System Aspects (TSG SA) and to Working Groups SA1 (Services) and SA2 (Architecture). Member of the ATIS Wireless Technologies and Systems Committee (WTSC) Systems and Networks Subcommittee (SN). Vice-Chair of the Technology and Broadband Committee and Chair of the Broadband Working Group, National Public Safety Telecommunications Council. Member, on behalf of PSCR, of the Global System for Mobile Communications Association (GSMA) Operators Group.
- **Bruce R. Ward:** Member, 3rd Generation Partnership Project (3GPP) Technical Specification Group for Service and System Aspects Working Group 1 (TSG SA WG1, Services)
- **Arthur A. Webster:** International Chair of ITU-T SG 9. SG 9 representative for Telecommunications for Disaster Relief and to several ITU-T Joint Coordination Activities such as those on the Internet of Things (JCA-IoT) and Child Online Protection (JCA-COP). SG 9 contact for Electronic Working Methods Co-chair of VQEG. Member of the U.S. Delegations to the ITU World Telecommunication Standardization Assembly (WTSA); ITU-T SG 16 (Multi-Media Coding, Systems and Applications), Review Committee (REVCOM), and Telecommunication Standardization Advisory Group (TSAG); and ITU-R SG 6 WP.6C and Coordination Committee for Vocabulary (CCV). U.S. Department of Commerce voting member for ATIS Network Performance, Reliability and Quality of Service Committee (PRQC) and Packet Technologies and Systems Committee (PTSC). NTIA voting member for the Society of Cable Telecommunications Engineers (SCTE)Data Standards Subcommittee (DSS). Observer for ITU-T SG 12 (Performance, QOS and QOE) and Standards Committee for Vocabulary (SCV).

ITS Projects in FY 2014

Cooperative Research and Development Agreements

Public Safety 700 MHz Broadband Demonstration Agreements

Operate various elements of an LTE network in a laboratory test bed and over-the-air (OTA) network to test interoperability of public safety communications equipment under simulated field conditions. Sixty-eight equipment manufacturers/resellers and wireless carriers who intend to supply 700 MHz LTE equipment and service to public safety organizations had CRADAs in place under this program in FY 2013.

CRADAs for the Use of Table Mountain

Areté Associates

Use the Table Mountain Field Site as a field location to safely test and demonstrate LADAR technologies under development in atmospheric conditions and at distances relevant to potential applications.

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

FIRST RF Corporation

Use the Table Mountain Field Site as a field location to fully test the functionality of new antenna designs during product development.

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

Lockheed Martin Coherent Technologies

Use the Table Mountain Field Site for field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

Nutronics, Inc.

Use the Table Mountain Field Site as a field location to safely and accurately test the Adaptive Tactical Laser System (ATLAS) compensated beacon adaptive optics (CBAO) system Under development.

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

University of Colorado Research and Education Center for Unmanned Vehicles

Use the Table Mountain Field Site as a field location to safely and accurately test collective and autonomous sensing and communication technologies for small unmanned aircraft.

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

Radar Measurements

Raytheon

Measure the emission spectrum, out-of-band emissions, and emission characteristics of a radar developed by the Raytheon Company for the U.S. Navy. Collect data at a Raytheon facility in El Segundo, CA, to ascertain the radar's compliance with the NTIA RSEC emission mask limits and provide it to the sponsor to complete the Stage 4 ELCID document.

Project Leader: Geoffrey A. Sanders, (303) 497-7600, gsanders@its.bldrdoc.gov

Spectrum Measurement CRADAs

CTIA-The Wireless Association®

Address technical assumptions, parameters, and approaches to evaluating the compatibility of commercial broadband and incumbent government systems in the 1755-1780 MHz segment of the 1755-1850 MHz band. Measure spectrum occupancy to provide data showing the percentages of time and time durations the incumbent systems are received above predetermined power threshold, model propagation and aggregate effects to facilitate determination of separation that ensures interference avoidance, and perform laboratory measurements of interference effects on individual systems.

Project Leader: Chriss Hammerschmidt, (303) 497 5958, chammerschmidt@its.bldrdoc.gov

Video Quality Research

Intel

Develop new subjective testing methods and related tools to investigate the impact of different camera and image format parameters on the quality of images. As one of the related tools, create a set of test images and make them available royalty-free to other researchers and developers for similar investigations.

Project Leader: Margaret H. Pinson (303) 497-3579, mpinson@its.bldrdoc.gov

Government Projects

NTIA Science and Engineering Projects

Audio Quality Research

Develop and evaluate new techniques for encoding, decoding, and analyzing speech signals. Provide algorithms, software, and technical expertise to other ITS programs. Provide technical presentations and laboratory demonstrations as requested.

Project Leader: Stephen D. Voran, (303) 497-3839, svoran@its.bldrdoc.gov

Broadband Wireless Standards

Provide leadership and technical support to committees (e.g., ITU-R SG 3/WP 3K, 3J, 3M, and 3L, TIA TR-8) developing broadband wireless communications standards that affect Federal agencies' use of the services. Building on previous ITS work, develop model comparisons for each propagation model.

Project Leader: Paul M. McKenna, (303) 497 3474, pmckenna@its.bldrdoc.gov

Center for Advanced Communications: Spectrum Monitoring Capability

Conduct two quick-start spectrum monitoring measurements on the East coast in the 3.6 GHz band with an unattended system based on a high-end spectrum analyzer platform. These measurements will provide a performance benchmark for developing a network to collect spectrum data from a network of remote sensors deployed in select areas and configured for certain radio bands.

Project Leader: Michael G. Cotton, (303) 497 7346, mcotton@its.bldrdoc.gov

Center for Advanced Communications: System Simulation Capability

Develop a system simulation capability to support spectrum engineering studies by evaluating new system compatibility scenarios. Evaluate commercially available simulation software and assess its accuracy using previously conducted measurements as a benchmark.

Project Leader: Robert J. Achatz, (303) 497 3498, rachatz@its.bldrdoc.gov

Effects of the Channel on Radio Systems

Identify, model, and characterize a small number of radio systems and use these to predict the effects of the channel on others. Use the results to predict how interference introduced by new spectrum engineering methods impacts legacy systems.

Project Leader: Robert J. Achatz, (303) 497 3498, rachatz@its.bldrdoc.gov

International Standards Support

Provide objective, expert leadership and key technical contributions in ITU-T and related U.S. industry committees responsible for developing broadband network performance, Quality of Service/Quality of Experience (QoS/QoE), and resource management standards.

Project Leader: Arthur A. Webster, (303) 497 3567, awebster@its.bldrdoc.gov

RSMS Development

Provide new and innovative measurement hardware and software tools for current and future RSMS capabilities. Project future needs and develop long-term strategies for building the necessary tools.

Project Leader: Geoffrey A. Sanders, (303) 497 6736, gsanders@its.bldrdoc.gov

RSMS Enhancements

Support RSMS operations through the development and maintenance of software, hardware, systems, and equipment.

Project Leader: John E. Carroll, (303) 497 3367, jcarroll@its.bldrdoc.gov

RSMS Operations

Provide NTIA with critical measurement support to determine radio spectrum usage across the U.S.; resolve interference problems involving Government radio systems; and determine the emission characteristics of radio transmitter systems that may affect Government operations.

Project Leader: John E. Carroll, (303) 497 3367, jcarroll@its.bldrdoc.gov

Table Mountain Modernization

Maintain and upgrade the Table Mountain Field Site infrastructure, ensure a safe working environment there, and provide logistical support for research activities at the field site.

Project Leader: J. Wayde Allen, (303) 497 5871, wallen@its.bldrdoc.gov

Video Quality Research

Develop technology for assessing the performance of digital video transmission systems. Improve measurement technology for multimedia definition (MD) and high definition (HD) video systems. Facilitate the development of international video quality measurement standards by participating in both the Independent Lab Group (ILG) of the Video Quality Experts' Group (VQEG) and as a proponent for new reduced reference (RR) measurement technology for standard definition (SD) and HDTV systems.

Project Leader: Margaret H. Pinson, (303) 497 3579, mpinson@its.bldrdoc.gov

NTIA/OSM Projects

2.7 GHz Interference

Program a Vector Signal Generator with the representative waveforms of radars operating in the 2700–2900 MHz band and inject these waveforms into FAA ASR-8, -9, and -11 radars to see what level of interference-to-noise ratio (I/N) degrades their performance.

Project Leader: Frank H. Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov

5 GHz Dynamic Frequency Selection (DFS) Expansion

Perform measurements and analysis of electromagnetic compatibility (EMC) issues between incumbent radar systems in the 5 GHz spectrum band and unlicensed systems operating in the same spectrum and using Dynamic Frequency Selection (DFS) to avoid interfering.

Project Leader: Frank H. Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov

Digital Receiver Compatibility with Radar Signals

This project supports the U.S. Administration's spectrum sharing initiatives by studying electromagnetic compatibility between incumbent radar systems and digital receivers. The emphasis is on radars and digital receivers that will operate together in spectrum around 3500 MHz. The effects of radar signals on digital (primarily Long Term Evolution, or LTE) receivers will be determined so as to provide spectrum managers and engineers with the information that they need to know for spectrum sharing at 3500 MHz to move forward.

Project Leader: Frank H. Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov

Interference to Noise Criteria for Radars

This project supports the evaluation of sharing options in the 2700-2900 MHz band between the Federal Aviation Administration's (FAA) Airport Surveillance Radars (ASRs) , used for short range ATC control/monitoring, and the National Weather Service's (NWS) NEXRAD radars used for weather prediction, monitoring, and severe weather alerts. Studying the EMC compatibility between these systems may allow for the development of more precise radar frequency assignment procedures, possibly making spectrum available for commercial systems.

Project Leader: John E. Carroll, (303) 497 3367, jcarroll@its.bldrdoc.gov

Propagation Engineering Support

Provide technical support to NTIA/OSM in advancing telecommunications and networking infrastructure development, improving U.S. telecommunications trade opportunities, advancing information technology, and promoting more efficient and effective use of the radio spectrum.

Project Leader: Paul M. McKenna, (303) 497-3474, pmckenna@its.bldrdoc.gov

Radar Engineering Support

Support USWP5B, USJRG, and the U.S. Administration's positions in ITU-R WP 5B and Joint Rapporteur Group (JRG) 1A-1C-5B by providing position papers, technical reports, and attendance in these forums. Also support the Radar Correspondence Group (RCG) and the JRG 1A-1C5B and RCG Web sites.

Project Leader: Frank H. Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov

Spectrum Coordination Portal

Prepare the information technology infrastructure for development of the Spectrum Engineering Tool (SET), the planned single point of entry to access automated analytical tools for both the 1695 MHz and the 1755 MHz frequency bands.

Project Leader: Patricia J. Raush, (303) 497 3568, praush@its.bldrdoc.gov

Spectrum Sharing Test Bed Support

Evaluate equipment that uses Dynamic Spectrum Access (DSA) technology within the 410-420 MHz and 470-512 MHz bands to assess and address potential interference to incumbent spectrum users.

Project Leader: Eric D. Nelson, (303) 497 7410, enelson@its.bldrdoc.gov

Other Agency Projects

Department of Commerce / NIST / Communications Technology Laboratory

Development of Millimeter Wave Radio Channel Measurement Systems

Perform research to provide industry and standards bodies with the information and technology needed for development of next generation mobile communication systems in the extremely high frequency (EHF) band (30–300 GHz),

Project Leader: Peter Papazian, (303) 497-5369, ppazian@its.bldrdoc.gov

Public Safety Communications Research and Testing

Facilitate standards development efforts aimed at nationwide public safety communications interoperability and information sharing through direct participation and technical contribution to the appropriate Standards Development Organizations. Conduct scientific analyses, laboratory and field measurements, and test and evaluation activities to accommodate technical elements of the PSCR program and other related Federal programs supported by NIST. Maintain state-of-the-art laboratory facilities, conduct field pilots, develop formal/informal training courses, test tools, and conduct technical feasibility studies of emerging public safety interoperability technologies.

Project Leader: Andrew P. Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov

Department of Commerce / NOAA / National Weather Service

Enhancements to Propagation Modeling Website (PMW VHF)

Develop and enhance a web-based multipurpose GIS propagation modeling tool to predict NOAA Weather Radio coverage and integrate 2010 population data to verify that NWR "All Hazards" radio transmissions reach 95% of the population of the U.S. as mandated by law.

Project Leader: Teresa Rusyn, (303) 497-3411, trusyn@its.bldrdoc.gov

NOAA Weather Radio Receiver Tests

Test the responses of selected commercial NOAA Weather Radio (NWR) receivers to various simulated NWR transmissions using a series of repeatable measurement methods. Compile and report on the characteristics and responses of the tested receivers As applicable, determine whether the receivers comply with the standards set down in CEA 2009.

Project Leader: Raian F. Kaiser (303) 497 5491, rkaiser@its.bldrdoc.gov

Department of Commerce / NOAA / Office of Habitat Conservation

Electronic Collaboration Systems Research

Develop, test, and refine an electronic collaboration tool as a platform for improved communication, productivity, and quality of service in support of the BP oil spill injury assessment and subsequent restoration. Provide training and technology transfer.

Project Leader: Amanda C. Alsafi, (303) 497-4201, aalsafi@its.bldrdoc.gov

Department of Defense (DoD)

Propagation Modeling Web site (PMW) IOCM Functionality

Create, validate, and verify a new IOCM model. Implement the new IOCM model within the PMW HF environment using a modern programming architecture.

Project Leader: Julie Kub, (303) 497-4607, jkub@its.bldrdoc.gov

DoD / U.S. Air Force

FPS-117 and RNSS EMC/Spectrum Study

Assist the Air Force to examine mitigation techniques between RNSS signals and radar systems operating in the 1215–1390 MHz frequency band. Perform radar emission measurements on the AN/FPS-117. Spectral emission data will be used to quantify the amount of energy, if any, that is radiated in the EESS and WMTS bands, 1390–1400 MHz, and to provide a complete FPS-117 emission spectrum, a determination of transmitter bandwidths, calculated spurious and harmonic emission levels, and, if possible, a plot of the azimuthal antenna pattern.

Project Leader: John E. Carroll, (303) 497-3367, jcarroll@its.bldrdoc.gov

DoD / U.S. Army

Propagation Modeling Web site (PMW) VHF Enhancements—GIS Server Map

Provide the ability to view PMW analyses on an open-source GIS mapping program, incorporating the GIS software directly into the PMW VHF installation so that additional software is not required and the user receives immediate feedback to ensure that they entered the input parameters correctly, before exporting the data. Configure the PMW VHF software to display background imagery such as countries, cities, states, roads, etc. behind the analysis plots. Users will be able to zoom in or out of specific map regions, select which analyses they would like to display on the Web map, and use the resulting Web map for reporting and analyses.

Project Leader: Kristen Davis, (303) 497-4619, kdavis@its.bldrdoc.gov

Department of Homeland Security (DHS) / Office for Interoperability and Compatibility

Public Safety Communications Research

Provide applied science and engineering expertise to the Department of Homeland Security (DHS) and Project SAFECOM. Solve telecommunications interoperability and information sharing problems among local, state, Federal, tribal, and international Justice, Public Safety, Homeland Security agencies by addressing voice, data, image, video, and multimedia information transfers.

Project Leader: Andrew P. Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov

DHS / Office of the CIO

Analyses for Spectrum Sharing in Federal Bands

Provide engineering and technical support to DHS Office of the CIO for the study of the possibility of interference between DHS communications equipment (entrant) and other Federal communications equipment (incumbent) in a band proposed for sharing.

Project Leader: Christopher Behm (303) 497-3640, cbehm@its.bldrdoc.gov

DHS / Office of Emergency Communications

Coordination Support for the Office of Emergency Communications

Provide support for public safety stakeholder involvement with the PSCR Public Safety Broadband Demonstration Network and the development of public safety broadband requirements and standards in applicable broadband committees and meetings.

Project Leader: Andrew P. Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov

DHS / U.S. Coast Guard

Evaluation of Interference to Marine Radars

Develop computer models of typical solid state and magnetron-based 2900–3100 band marine radar receivers and perform EMI analyses and parametric studies of potential interference from Broadband Wireless devices operating within the band, and from devices and radars operating in adjacent bands. Where necessary, supplement these computer models by measurements performed on selected radar receivers. Develop recommended Marine Radar receiver selectivity standards to minimize interference from and define reasonable adjacent band/out-of-band emissions (OOBE) limits for broadband wireless devices. Monitor related Broadband Wireless spectrum reallocation efforts and FCC regulatory actions and rulemaking efforts.

Project Leader: Robert J. Achatz, (303) 497 3498, rachatz@its.bldrdoc.gov

Department of Transportation / Federal Railroad Administration

Railroad Telecommunications Study

Provide engineering services and products to the Federal Railroad Administration Office of Research and Development, including testing VNB digital radios' audio quality in a railroad environment, evaluating the efficacy of the VHF channel plan, evaluating propagation models as applied to railroad environments, and verifying RF performance metrics of very narrowband digital radios. Prepare technical contribution pertaining to railroad telecommunications for the Association of American Railroads' Wireless Communications Committee.

Project Leader: John M. Vanderau (303) 497-3506, jvanderau@its.bldrdoc.gov

DOT/ Federal Highway Administration

Evaluation of 802.11ac/DSRC Modeling

Perform electromagnetic compatibility (EMC) analysis for the Dedicated Short-Range Communication System (DSRC), as it relates to sharing spectrum with unlicensed devices operating in and adjacent to the 5850 to 5925 MHz band. Identify interference scenarios and determine the parameters required for an EMC analysis of both the DSRC and other systems and the appropriate analysis models. Identify all the variables that might cause reduced system performance, determine their potential impact and select the worst case set. Evaluate the resulting 802.11ac/DSRC modeling using live test data.

Project Leader: Nicholas DeMinco, (303) 497-3660, ndeminco@its.bldrdoc.gov

First Responder Network Authority (FirstNet)

Public Safety Broadband Standards

Provide engineering support, scientific analysis, technical liaison, and standards body participation to advance the development of standards for public safety communication system products and services intended to operate over the nationwide first responder broadband network under development.

Project Leader: Andrew P. Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov

FirstNet Test Bed

Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the identification, development, and validation of interoperability standards for the Justice, Public Safety, Homeland Security community, and other communication system products and services supporting wireless telecommunications and information technology needs. Perform technical assessments and evaluations of existing and emerging commercial products and services that may provide interim solutions for various interoperability scenarios.

Project Leader: Andrew P. Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov

National Archives and Records Administration

NARA e-Government Study

Provide the technical backbone for a prototype of the proposed electronic Federal Record Center (eFRC). Working closely with NARA archivists, design and implement a potentially large scale records management infrastructure to administer, store, and manage temporary e-records in compliance with well-established NARA RM requirements, including support for automation of NARA business processes through electronic workflow. Exercise the prototype and provide technology transfer on acceptance.

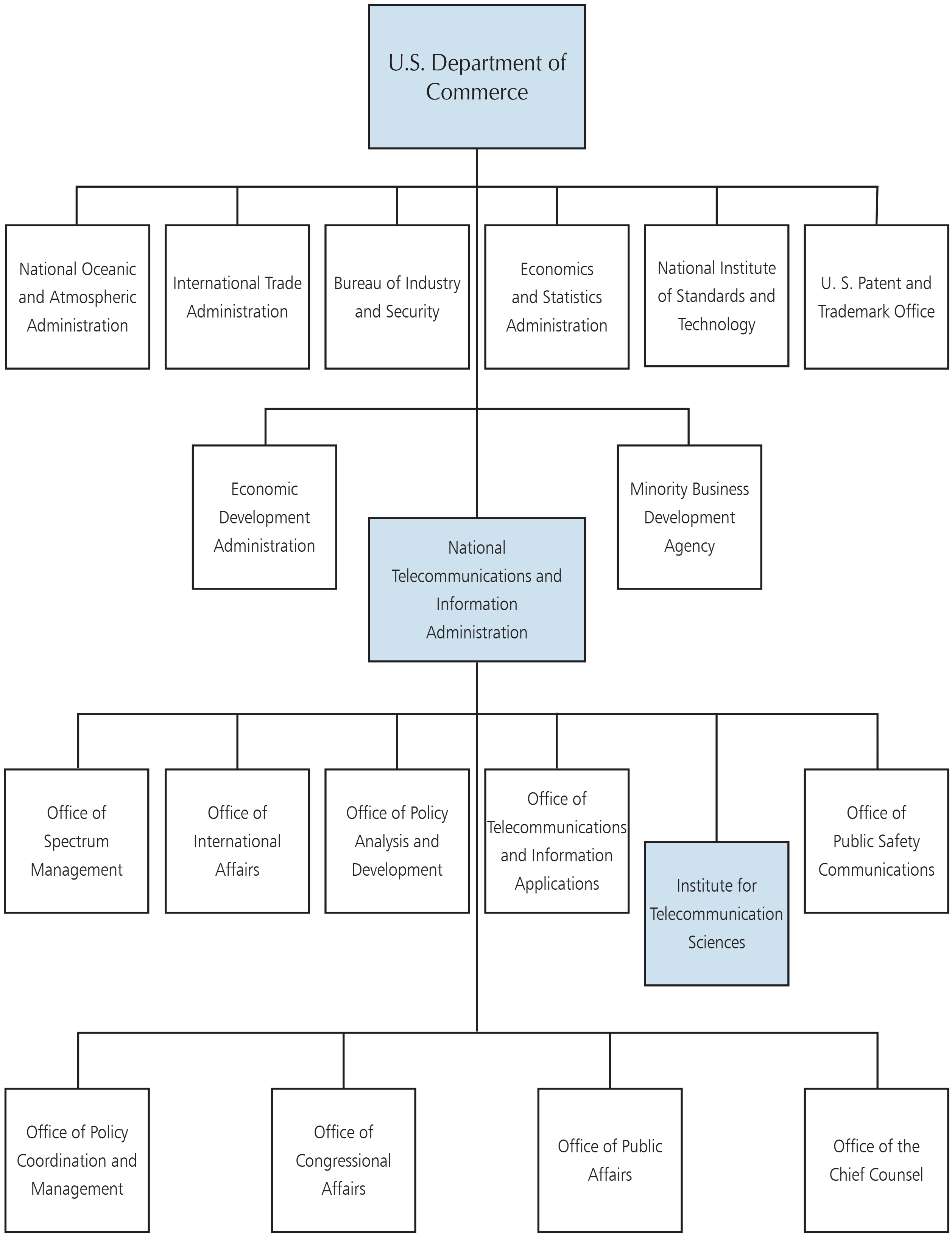
Project Leader: Amanda C. Alsafi, (303) 497-4201, aalsafi@its.bldrdoc.gov

Abbreviations/Acronyms

3DTV three-dimensional television
3G third generation cellular wireless
4G fourth generation cellular wireless
5G fifth generation cellular wireless
3GPP 3rd Generation Partnership Project
ABC-MRT Articulation-Index Band Correlation MRT
AC alternating current
ANSI American National Standards Institute
ATIS Alliance for Telecommunications Industry Solutions
AUGNet Ad Hoc UAV Ground Network
AVA audiovisual media accessibility
AVHD audiovisual high-definition television
AWGN additive white Gaussian noise
BPSK binary phase shift keying
BRS broadband radio service
CAC Center for Advanced Communications
CDA Code Domain Analyzer
CDVL Consumer Digital Video Library
CEA Consumer Electronics Association
CDF cumulative distribution function
CTL Communications Technology Laboratory
COTS commercial-off-the-shelf
COW cell on wheels
CRADA cooperative research and development agreement
CSMAC Commerce Spectrum Management Advisory Committee
CW continuous wave
DAT digital audio tape
dB decibel
DFS dynamic frequency selection
DHS Department of Homeland Security
DoC Department of Commerce
DoD Department of Defense
DSA dynamic spectrum access
DSRC dedicated short range communication system
EHF extremely high frequency
EMC electromagnetic compatibility
eNB eNodeB
EPC Evolved Packet Core
EPS Evolved Packet System
ERB Editorial Review Board
ERP effective radiated power
FAA Federal Aviation Administration
FCC Federal Communications Commission
FHWA Federal Highway Administration
FirstNet First Responders Network Authority
FLC Federal Laboratory Consortium
FM frequency modulation
FTTA Federal Technology Transfer Act
FY fiscal year
GHz gigahertz
GIS geographic information system
GLOBE Global Land One-km Base Elevation
GPS global positioning system
GSM Global System for Mobile Communications
GSMA GSM Association
HATS head and torso simulator
HD high definition
HDTV high definition television
HF high frequency
HRTe high-resolution terrain elevation
IA interagency agreement
IEC International Electrotechnical Commission
IEEE Institute of Electrical and Electronics Engineers
IF intermediate frequency
IF-77 ITS-FAA 1977 propagation model
IFSAR interferometric synthetic aperture radar
ILG Independent Lab Group
IP Internet protocol
IPC interference protection criteria
IRG-AVQA Intersector Rapporteur Group on Audiovisual Quality Assessment
I/Q in-phase/quadrature
ISART International Symposium on Advanced Radio Technologies
ITM Irregular Terrain Model
ITS Institute for Telecommunication Sciences
ITU International Telecommunication Union
ITU-R ITU Radiocommunication Sector
ITU-T ITU Telecommunication Standardization Sector
JRG Joint Rapporteur Group
JRG-MMQA Joint Rapporteur Group on Multimedia Quality Assessment
JTG Joint Task Group
kHz kilohertz
km kilometer
kW kilowatt
LADAR laser detection and ranging
LAN local area network

LF	low frequency
LF/MF	low frequency/medium frequency
LIDAR	light detection and ranging
LMR	land mobile radio
LNA	low-noise amplifier
LTE	Long Term Evolution
MD	multimedia definition
MF	medium frequency
MHz	megahertz
MOS	mean opinion score
MRT	Modified Rhyme Test
MSOD	Measured Spectrum Occupancy Database
NARA	National Archives and Records Administration
NASCTN	National Advanced Spectrum and Communication Test Network
NF	noise figure
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPSBN	Nationwide Public Safety Broadband Network
NPSTC	National Public Safety Telecommunications Council
NTIA	National Telecommunications and Information Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
OEC	Office for Emergency Communications
OIC	Office of Interoperability and Compatibility
OOBE	out-of-band emission
OSM	Office of Spectrum Management
OTA	over-the-air
P25	Project 25
PCS	personal communications service
PESQ	perceptual evaluation of speech quality
PMW	Propagation Modeling Website
PN	pseudorandom number
PRQC	Network Performance, Reliability and Quality of Service Committee
PSCR	Public Safety Communications Research
PSAL	Public Safety Audio Laboratory
PSRF	Public Safety RF Laboratory
PSVL	Public Safety Video Laboratory
PTSC	Packet Technologies and Systems Committee
QoE	quality of experience
QoS	quality of service
RAN	radio access networks
RF	radio frequency
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement System
SCTE	Society of Cable Telecommunications Engineers
SD	standard definition
SDO	standards development organization
SG	Study Group
SHF	super high frequency
SNR	signal-to-noise ratio
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TR	technical report
TSAG	Telecommunication Standardization Advisory Group
TSG	Technical Specification Group
TV	television
U.S.	United States
UAV	unmanned aerial vehicle
UE	user equipment
UHF	ultra high frequency
UN	United Nations
URSI	International Union of Radio Science
USGS	U.S. Geological Survey
USNC	United States National Committee
UWB	ultrawideband
VHF	very high frequency
VNA	vector network analyzer
VoIP	voice over Internet protocol
VoLTE	voice over Long Term Evolution
VQEG	Video Quality Experts Group
VQiPS	Video Quality in Public Safety
VQM	Video Quality Model
VSA	vector signal analyzer
VSG	vector signal generator
W	watt
WCIT	World Conference on International Telecommunications
WG	Working Group
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	wireless local area network
WNRC	Wireless Networks Research Center
WP	Working Party
WRC	World Radiocommunication Conference
WTSA	World Telecommunications Standardization Assembly
WTSC-RAN	Wireless Technologies and Systems Committee – Radio Access Networks

DOC/NTIA Organization Chart

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