SSTD Observations on Improved Spectrum Sharing

Anthony Rennier
Foundry Inc.
Severn, MD, USA
trennier@foundryinc.com

Mike DiFrancisco
Virginia Tech Applied Research Corporation
Arlington, VA, USA
Mike.DiFrancisco@vt-arc.org

Howard McDonald
Defense Spectrum Organization
DISA
Annapolis, MD, USA
howard.j.mcdonald6.civ@mail.mil

Joy Cantalupo
Defense Spectrum Organization
DISA
Annapolis, MD, USA
josephine.m.cantalupo.civ@mail.mil

Michael Bowman
Defense Spectrum Organization
DISA
Annapolis, MD, USA
michael.w.bowman55.civ@mail.mil

Abstract— ISART 2022 Call for Papers Topic Area: Data Sharing & Transparency. **This paper provides observations, based on the AWS-3 Spectrum Sharing Test and Demonstration (SSTD) program activities, for how data sharing, transparency, and objective research and development (R&D) can facilitate opportunities to improve spectrum sharing arrangements. Topics of the paper include: 1) considerations for developing interference protection criteria (IPC), 2) realistic commercial wireless emission models, 3) dynamic/active spectrum sharing, and 4) economic considerations.**

Keywords—Advanced Wireless Services 3 (AWS-3), Spectrum Sharing Test and Demonstration (SSTD), Spectrum Sharing, Long Term Evolution (LTE), Aggregate Interference, interference protection criteria (IPC), Model Validation, Dynamic Spectrum Sharing.

I. INTRODUCTION

In July 2012, the Department of Commerce, National Telecommunications and Information Administration (NTIA), Commerce Spectrum Management Advisory Committee (CSMAC) convened working groups with membership from Federal agencies and commercial wireless operators to investigate the feasibility of sharing spectrum between commercial and federal systems. Working groups 2, 3, 4, and 5 considered the compatibility of federal systems in the 1755-1780 MHz band with commercial LTE User Equipment (UE). The working groups published their final reports in 2013 [2][3][4][5]. These reports provided much of the technical basis for the Federal Communications Commission (FCC) Report and Order (R&O) (FCC 14-31), dated 31 March 2014. This R&O established service, allocation, and technical rules for the AWS-3 bands: 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz. It also established requirements for commercial wireless broadband operators to coordinate with the Federal agencies when seeking to build out systems in the 1755-1780 MHz band.

On 29 January 2015 the FCC completed an auction of AWS-3 bands. The auction, which was designated Auction-97, raised (in net bids) a total of $41,329,673,325, with 31 winning bidders winning a total of 1,611 licenses. The auction exceeded all expectations in terms of money raised and its completion initiated a 10-year transition period where most DoD systems operating in 1755-1780 MHz will cease or move operations to another band. Auction-97 winners that want to commence operations in pre-defined geographic Coordination Zones (CZs) must engage in the coordination process by submitting coordination requests (CRs) to DoD and other Government agencies to be granted early access, or early-entry to the spectrum licenses they purchased within defined CZs. Commercial deployments outside of the CZs are available immediately and are not required to go through the CR process. Within DoD, DSO and each Military Service assess whether the expected aggregate interference from UEs operating within a laydown specified in a CR will exceed the designated IPC for incumbent DoD receivers and identifies which of the LTE sectors within a CR are approved for early-entry.

II. ORGANIZATION OF THIS PAPER AND RELATED ISART 2022 PAPERS

This paper describes spectrum sharing observations and lessons learned under the SSTD Program. Section III of this paper provides an overview of the SSTD Program. Section IV describes some of the observations and lessons learned under the SSTD Program.

There are several other ISART 2022 papers related to the processes, findings, and lessons learned during the SSTD Program. These papers include:

- *AWS-3 Spectrum Sharing Assessment Process Improvement* – describes the approach and processes used on the SSTD Program
- *SSTD Findings on AWS-3 Spectrum Sharing Assessments* – describes the findings relative to AWS-3 spectrum sharing assessments.
- *Greenman: A Sector-based LTE Emission Model* – describes an advanced LTE emission model developed under the SSTD Program.
- *Pathloss-Based Sector Uplink Emissions Model (PBSUEM) for LTE Aggregate Interference Prediction* – describes an uplink LTE emissions model for predicting aggregate interference.
- *Application of Gaussian Mixture Modeling Methods to Analysis and Prediction of Cellular Communications*

Pathloss Distributions - describes machine learning techniques used for predicting LTE interference.

- *A Comparison of Data-driven Clutter Loss Clustering Models for New Site Interference Assessment* – Describes a Machine Learning techniques used for predicting clutter loss.

III. SSTD Program Overview

The SSTD Program was established to 1) Facilitate Expedited and Expanded Entry (FEEE) of commercial deployments into the 1755-1780 MHz band, 2) Identify, Assess, Test/demonstrate, and Operationalize (IATO) coexistence assessments, interference mitigation, and other spectrum sharing enablers that support increased sharing between LTE and incumbent DoD systems, and 3) to support DoD's use of LTE technologies.

To achieve its objectives, the SSTD Program focuses on four broad technical areas for improvements, referred to as initiatives, focused on AWS-3 spectrum sharing. These are:

1) Assessment of the Aggregate Interference from early-entry LTE systems,

2) Characterization of LTE systems and their uplink emissions,

3) Propagation Modeling between early-entry LTE systems and DoD receivers, and

4) Characterization of DoD Receiver performance in the presence of LTE uplink emissions.

Multi-organizational technical teams have been formed in each of these four initiatives to conduct research and analyses in support of an increasingly realistic assessment of spectrum sharing between DoD and AWS-3 LTE early-entry commercial deployments. Figure 1 illustrates the technical focus of each of these teams. In addition to their technical work, each team facilitates, engages, and collaborates with government communities of interest as well as AWS-3 licensees.

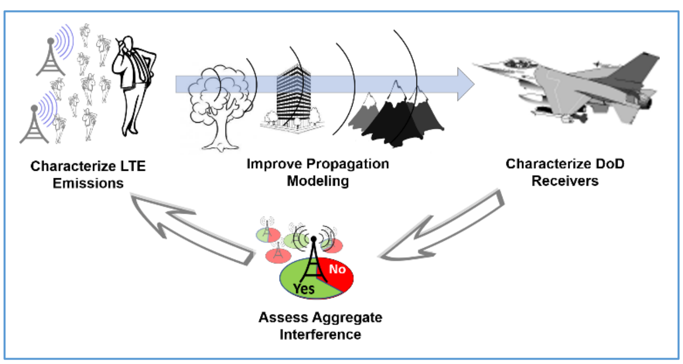

Fig. 1. AWS-3 Early-Entry Assessment

This paper provides observations, based on the SSTD program activities. It includes considerations for better receiver IPCs, developing realistic commercial wireless emission models, dynamic/active spectrum sharing, and the economics associated with spectrum sharing.

IV. SSTD Observations and Lessons Learned

A. Interference Protection Criteria

The start of any meaningful spectrum sharing analysis is to understand at what point does sharing turn into an operational impact to one or the other of the sharing parties. In other words, how much interference is too much; when does it become harmful? There are many challenges with obtaining the information required to answer this question. Here are just a few.

- Attack Surface - Understanding the point at which interference becomes harmful (or degraded performance) to a system is one of the questions that an adversary wants to know when designing spectrum-based countermeasures. Whether the goal of the countermeasure is to impact operations or operate without detection, knowing the IPC of a target system is useful information. While not always a concern, systems that are known to have adversaries must consider the risk associated with revealing the actual IPC.
- Variable and Dynamic - IPC's are inherently contextual in nature. For example, the IPC needed during nominal or normal operations for a system is almost certainly different than that which is required in anomalous scenarios. Unless a dynamic spectrum sharing arrangement is in place that allows real-time adjustments to interference levels, an IPC must capture the worst-case scenario to ensure 100% operational integrity.
- Model Uncertainty - The only way to assess a candidate IPC with certainty, is to test it by setting up a target scenario and then directly observing the system performance. While some amount of testing is likely required for all systems, it is usually impractical or impossible to test all desired operational scenarios. This leads to IPC assessments that are based on some amount of modeling and the uncertainty that even the best models bring.
- Risk Management – Wrapped into the question of IPCs and operational impacts is the question of risk management. For spectrum sharing, an approach to risk management is to first create a set of interference-based real-world system performance impacts ranging from barely noticeable to catastrophic. Then, based on interference models, estimate the likelihood that each interference-based system impact will occur. In addition, the operational consequences attributed to those system impacts would be essential to complete the Likelihood vs Consequences matrix that is embraced in the risk assessment community as a means of supporting risk-based decision-making. A simple example of a risk assessment for the level of interference that could affect a wireless link monitoring rain clouds at a farmer's market is shown in Table 1.

Table 1. Example of Assessing Risk Management for Interference to a Farmer's Rain Cloud Monitor

Interference Level	System Performance	Real-World Consequence	Likelihood

(at a Rain Cloud Monitor)		of a Rain Event	
Below -85 dBm	Maximum system resolution - Can detect rain 1 hour in advance	99% of product tables are covered – $100 Loss	95%
-85 to -80 dBm	Reduced system resolution - Can detect rain 10 minutes in advance	50% of product tables are covered – $1000 Loss	4.9%
Over -80 dBm	Link failure - Cannot detect rain in advance	0% of product tables are covered – $5000 Loss	0.1%

Without a risk management assessment, the Farmer's market organizers might opt to establish an IPC of -85 dBm for the Rain Cloud Monitor so that maximum achievable benefit can be realized. However, if the spectrum sharing partner in this scenario is a commercial wireless provider and organizers estimate that the market can increase sales by $1,000 a day if customers have better service for their mobile devices, an IPC of -80 dBm might be the best answer. Losing $1,000 4.9% of the time is acceptable if you are making $1,000 extra 100% of the time.

Real-world risk assessments are more complex and difficult than the Farmer's market example. Add to this the fact that, many times, the catastrophic scenario might involve the safety of life, and the questions related to risk management can be difficult.

Each of the individual challenges listed here can lead stakeholders to increase the IPC requirement for a system and when combined, the increase can become substantial. For example, a stakeholder might conclude that after a risk assessment, 3 dB of increased IPC was sufficient to address issues with providing an attack surface, but when combined with the uncertainty of the models that yielded the 3 dB assessment, may decide that 6 dB is needed.

In order to address the IPC challenges, it is important to understand that they are ultimately unsolvable but improvable with sufficient Research and Development (R&D) resources and a willingness of stakeholders to share data and be transparent. For example, in the SSTD program, researchers worked with stakeholders to assess the desired signal levels associated with some AWS-3 operational scenarios. These desired signal levels were then incorporated into an IPC based on Signal to Interference plus Noise ratio (SINR), replacing the previous Interference to Noise ratio (INR) IPC that did not consider this important factor. This is just one example of the kind of IPC improvements that are possible if there are sufficient R&D resources, a willingness to share data, and transparent collaboration.

B. Commercial Wireless Emissions

For AWS-3 spectrum sharing, understanding real commercial wireless emissions is a key item. During the CSMAC 2012 meeting, a baseline LTE uplink characterization report was created that included a recommendation for an LTE Uplink emissions model. The report included, among other things, recommendations for:

- LTE Sector Morphologies with Inter-Site Distance (ISD) of LTE Base Stations – All LTE sectors in the US were modeled as either Urban (ISD – 1732 meters) or Rural (ISD – 7000 meters) based on their proximity to a metropolitan area.
- Number of UEs – The number of UEs simultaneously transmitting in a sector. Three UEs per 5 MHz of uplink bandwidth.
- Network Loading – The average percentage of available Physical Resource Blocks (PRBs) occupied per Transmission Time Interval (TTI) is 100%.
- UE Effective Isotropic Radiated Power (EIRP) – An Urban and Rural Cumulative Distribution Function (CDF) that represented the Outdoor EIRP for UEs in each morphology. The Outdoor EIRP is the UE EIRP after considering the reduction in power expected due to Building Exit Loss (BEL) for UEs that are assumed to be indoors.

The recommendation, while simple and easy to implement, had several shortcomings that came to light after a series of collaborations between SSTD and AWS-3 commercial wireless organizations. Some of the short comings include:

- Too few Morphologies – Forcing all LTE sectors into only two morphologies is an oversimplification of real-world sectors and does not allow lower interference power sectors to be identified for spectrum sharing approval. Examples of low interference power sectors include small cells and those with base station antennas that are indoors.
- Too many UEs – While 3 UEs per 5 Mhz and higher does occur, real LTE deployments do not see that level of sustained activity.
- Too many PRBs – While 100% PRB occupancy does occur, real LTE deployments do not see that level of sustained activity.
- Low Fidelity BEL – A fixed BEL doesn't represent the real-world RF isolation that LTE UEs experience and reduces the visibility into how FCC rule making for maximum UE transmit power affects interference levels.
- Hand Up and Down – In most cases commercial wireless organizations have multiple bands to choose from when providing service to their customers. An AWS-3 sector with no other bands available would likely hold onto UEs much longer and at much higher power than one living in a multi-band environment. For example, an AWS-3 indoor sector providing service to UEs in a building could be expected to also provide service to UEs outside the building at higher power levels to overcome the BEL if no outdoor AWS-3 sector were available. However, the presence of an outdoor AWS-1 sector would likely mean the UEs would hand down to the AWS-1 sector as soon as it left the building. LTE Emission models that don't consider real world multi-band operations would miss assess this scenario.

The commercial wireless organizations' willingness to share data and be transparent about their operational networks have already led to direct improvements in the government's LTE Uplink emissions model with more improvements on the way.

C. Validation, Verification, and Good Will

Perhaps the two most substantial benefits accrued from the SSTD and AWS-3 licensee data sharing and transparency collaborations, come in the form of support for DoD validation/verification and Government/Industry good will.

Model Validation and Verification

At the onset of SSTD, a set of component models (LTE Emissions, Path Loss, Receiver Characterization) along with models for aggregating the interference power over a large set of geographically diverse sectors, were developed. However, uncertainty about the models was high, and as discussed in Section A, model uncertainty leads to overly protective sharing assessments. To address the uncertainty and provide a means to validate and verify aggregate interference assessments, SSTD approached an AWS-3 commercial carrier to collaborate on Carrier Coordinated Testing (CCT). These measurement events involved making high-quality power measurements in AWS-1 bands while simultaneously collecting LTE configuration and operational data from the commercial wireless carrier operating in the band. With these two data sets in hand, stakeholders were able to see direct evidence of how well the aggregate interference models performed by comparing the prediction to the measured data.

Figure 2 shows an example from a Denver, CO CCT event. Here it can be seen how different aggregate interference models relate to real-world data.

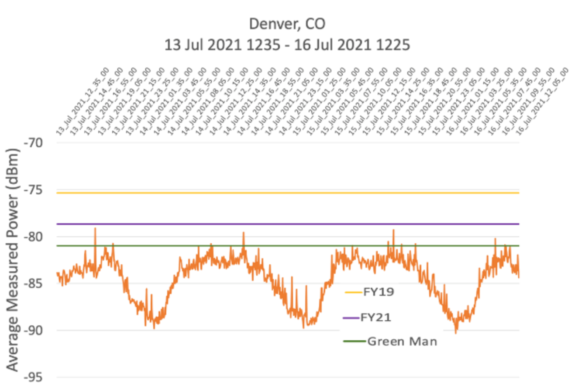

Fig. 2. Denver CO CCT Event - Model Predictions and Measured Data

Good Will

A less tangible but no less important benefit of data sharing, transparency, and collaboration comes in the form of good will established amongst spectrum sharing organizations. When any two organizations begin to work together, questions about competency and trustworthiness are likely in play. This is perhaps truer with the organizations that have conflicting objectives, such as is the case with AWS-3 Early Entry assessments. The government would like to maintain an interference-free environment and the AWS-3 licensees would like to immediately leverage their investment in spectrum licenses.

One way to alleviate concerns that conflicting objectives are leading to skewed technical assessments is to agree to a data-driven, fact-based approach that is transparent and open to validation by all parties. Even lesser issues, like justifying the extra work to collaborate and share data, can be alleviated if both parties understand and trust that the data will be used fairly and intelligently.

For SSTD, early challenges with getting LTE operational/configuration data as well as best practices for LTE emission modeling from commercial wireless carriers were overcome by demonstrating technical competency and adopting a policy of full transparency in how the data would be used and benefit the pursuit of the objectives.

D. Dynamic Spectrum Sharing

Spectrum-use requirements are rarely constant and real-world operational scenarios that contribute to the impacts of spectrum sharing, over a given period, are almost never constant. Add to this, the uncertainty associated with models that predict the impacts of future spectrum sharing and you have a recipe for overly conservative spectrum sharing provisions. For example, it may be true that 3 times a year a worst-case scenario leads to interference due to spectrum sharing, and the uncertainty of models used to predict this worst-case event leads to an additional 3 dB of protection. However, what about the rest of the time, and what if the model predictions were already conservative? This is what static spectrum sharing leads to. A system for dynamic spectrum sharing can adaptively adjust to those 3 worst cases of interference during the year while allowing less conservative sharing during the remainder of the time.

E. Economic Considerations

When compared with IOC, the current set of SSTD recommendations to assess AWS-3 spectrum sharing are quite different. On average, the estimates of aggregate interference, levels have been reduced by at least 10 dB. As discussed earlier in this paper, many factors contributed to these improvements. Data sharing amongst government stakeholders and AWS-3 licensees allowed guesswork about commercial wireless operations to be replaced with real data. Transparency amongst the participants provided a deeper understanding of spectrum sharing assessments and established goodwill/trust that the best possible outcome was the common objective.

The third factor required to achieve these improvements was R&D resourcing. Without a substantial research and development effort bringing together a diverse set of subject matter experts to work on a common set of requirements, none of the difficult questions would have been answered. Without additional resources, the current and future unanswered questions about spectrum sharing will not be answered. Wireless technologies have been, and continue to be, in a state of rapid development and change while the amount of spectrum has not changed at all. The only way to create space for future wireless technologies is to invest in spectrum sharing.

One way to assess the economic impact of spectrum sharing is to look at recent auctions. In AWS-3 over $41B was spent to acquire licenses for the band. Even a modest increase in spectrum sharing that allowed a 10% increase in the use of AWS-3 bands would yield $4B in benefits. Another way to look at the economic impact of spectrum sharing assessments is to consider what CSMAC 2012 might have concluded about sharing the AWS-3 band, if today's aggregate interference assessments were available then. Given the substantial opportunities for AWS-3 sharing, that we now know exist, perhaps many more government systems would have been identified as candidates for permanent sharing in AWS-3 bands. What tangible and intangible benefits may have been realized if they knew then what we know now?

V. Conclusions

This paper provided observations, based on the AWS-3 SSTD program activities, for how data sharing, transparency, and R&D facilitate opportunities to improve spectrum sharing arrangements. Considerations are discussed for better IPCs, developing realistic commercial wireless emission models, dynamic/active spectrum sharing, and the economics associated with spectrum sharing. Maximizing spectrum sharing is a difficult and resource-intensive pursuit but when compared to the cost of spectrum, is well worth the effort.

Acknowledgements

The SSTD program and its results have been a collaborative effort among many organizations across DoD and supporting organizations. We acknowledge the substantial contributions of:

- **DISA/DSO**: Ryan Saunders, Stuart Schutta, Chris Johnson, Bob Schneider, et al.
  - Johns Hopkins Applied Physics Lab: Steve Jones, Jerry Hampton, Steve Yao, Brian Choi, Arnab Das, Kalle Kontson, Candace Carducci, Tom Hanley, Feng Ouyang, et al.
  - MITRE: Darcy Swain Walsh, Jeff Correia, Evan Ding, Cameron Patterson, Jerediah Fevold, JD Shyy, Aston Knight, Jared Burdin, Venki Ramaswamy, et al.
  - Peraton: Lynn Cumberpatch, Stuart Kennison, Donna Krizman, Jesse Warner, Tom Shanholtz, et al.
  - Virginia Tech Applied Research Corp: Mike Smith, Antoine Soyoh, et al.
  - RKF Engineering: Ted Kaplan, Jeff Freeman, Bill Sweet, Sasha Marshack, et al.
- **Navy Academy**: Chris Anderson
- **Navy Surface Warfare Center (NSWC) – Dahlgren**: Ken Carrigan, Bob Zanella, Stacy Barker, Carlos Gonzalez-Reyes, Abby Anderson, et al.
  - Vectrus: Nate Ellingson, et al.
- **Army Spectrum Management Office**:
  - HII (Alion): Nick Canzona, et al.
- **Air Force Spectrum Management Office:** Arsenio Ibay
  - HII (Alion): Bob Martin, Eric Germann, Jason Green, et al.
- **NTIA Institute for Telecommunication Sciences**: Eric Nelson, Paul McKenna, Chriss Hammerschmidt, et al.
- **NIST**: Jason Coder, Melissa Midzor, et al.

References

[1] "Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 1 (WG 1) 1695-1710 MHz meteorological-satellite". https://www.ntia.doc.gov/publications

[2] "Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 2 (WG 2) 1755-1850 MHz law enforcement video, explosive ordnance disposal, and other short distance links". https://www.ntia.doc.gov/publications

[3] "Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 3 (WG 3) Report on 1755-1850 MHz Satellite Control and Electronic Warefare". https://www.ntia.doc.gov/publications

[4] "Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 4 (WG 4) Report on 1755-1850 MHz point-to-point microwave". https://www.ntia.doc.gov/publications

[5] "Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 5 (WG 5) Report on 1755-1850 MHz airborne operations". https://www.ntia.doc.gov/publications