DEFENDING T&E SPECTRUM THROUGH AUTOMATED FREQUENCY MANAGEMENT METRICS CALCULATION

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ABSTRACT

Because of its economic value, there has been growing pressure to sell off spectrum currently allocated for defense purposes. These pressures come at a time when Department of Defense (DoD) spectrum needs are growing at an exponential pace, thus prompting heightened efforts to clearly demonstrate both the need and the responsible, efficient use of electromagnetic spectrum. In response, the DoD has developed a baseline set of standard metrics to measure spectrum utilization, demand, efficiency, and operational effectiveness. The focus has now shifted toward developing the automated tools to calculate, plot, and display these metrics. The purpose of this paper is to describe progress toward developing a Spectrum Management Metrics Toolkit (SMMT) to fill this need and its potential role in helping to analyze and defend Test and Evaluation (T&E) spectrum usage and needs.

INTRODUCTION

On June 7, 1995, a bill proposing the reallocation of 275 Megahertz (MHz) of government spectrum was brought to the floor of the U.S. Senate for a vote. The spectrum targeted for reallocation included the entire 225-400 MHz band, which the DoD had declared two years earlier to be the single most critical spectrum resource of our military tactical forces, both nationally and within the North Atlantic Treaty Organization (NATO). Focused primarily on the potential windfall that an auction for this spectrum would provide for the U.S. Treasury, the Senate passed this legislation by a voice vote. The DoD had been given no notice that the bill was even under consideration until the day of the vote. Had the bill not been altered at the last minute to exclude this band, the DoD would have had nine months to vacate the band [1].

Recurring efforts to reallocate DoD's electromagnetic spectrum for commercial applications pose an unwitting threat to our national security interests. This paper outlines the nature of the spectrum access challenge and the rising pressure for more widespread reallocation of this critical resource. It then describes the potential impact of spectrum loss in the Test and Evaluation (T&E) environment—as this application domain is a representative microcosm of the DoD spectrum management challenge. The paper concludes by describing recent efforts to develop metrics and tools designed to help the DoD establish its telemetry spectrum needs and demonstrate responsible, efficient use of this resource.

GROWING PRESS FOR SPECTRUM ACCESS

Effective spectrum and frequency management is essential to the success of United States (U.S.) military operations. Military operations increasingly rely on the ability to maintain full access and reliable control of the radio frequency (RF) spectrum for communications, radar, electronic warfare, remote fires, avionics, global positioning, logistics, medical support, and signals intelligence uses. Information dominance cannot be achieved without it. Consequently, effective spectrum and frequency management is central to present and future warfare plans, including Force 21, the Army After Next, the Expeditionary Aerospace Forces, and the Marine Expeditionary Forces.

The DoD's needs for electromagnetic spectrum are already significant and continue to grow at an exponential pace. The 2000 Defense Science Board report, Tactical Battlefield Communications, for example, estimates an anticipated growth rate in demand exceeding 18 percent per year [33333333]. Another report projected military spectrum demands to grow 70 percent in the decade leading up to 2010 [8].

Meanwhile, there is growing pressure to further reduce the DoD's allocation of spectrum. Much of this pressure is driven by a rapid growth in public demand for broadband wireless electronics, which is creating new private sector demands for spectrum access. Unquestionably, access to spectrum is central to a broad range of business and consumer communication, research and development (R&D) and information technology (IT) purposes, such as private and public telecommunication operations (e.g., mobile phone networks, wireless Internet communication, aviation, shipping, defense, public safety), broadcasting, radar, astronomy and various other applications including countless short-range, low-power wireless devices [11]. Additional pressure stems from perceptions that the DoD is hoarding spectrum, that it no longer needs as much spectrum, and that it is an inefficient user.

Outside the continental United States (U.S.), where U.S. forces require spectrum coordination with host and surrounding nations, spectrum-related issues are even more pronounced. Many nations view wireless communications services as the backbone for their future economic development, which means they are increasingly asserting their sovereign spectrum rights. Their spectrum allocations differ significantly from those used in the U.S., often making it difficult to conduct planned operations efficiently.

These and other factors have inevitably created recurring cycles of legislative activity to sell off portions of the DoD spectrum.

In 2006, for example, the FCC auctioned spectrum licenses in the 1710-1755 Megahertz (MHz) band that had previously been allocated for federal use. To meet the continued demand for commercial wireless services, NTIA assessed the viability of reallocating the 1755-1850 MHz band for private sector applications. This band was assigned to more than 20 federal users, including the DoD [12].

More recent legislative trends are equally troubling. Title VI of the Middle Class Tax Relief and Job Creation Act of 2012—also known as the Public Safety and Spectrum Act, or Spectrum Act, for short—seeks to expedite increased access to spectrum for commercial mobile broadband through spectrum reallocation, reassignment of spectrum rights, and changes in procedures to repurpose spectrum used by the federal government. Among other things, the act also includes provisions to apply spectrum license auction revenues toward deficit reduction. Further legislation of this kind clearly establishes a trend toward reducing federal government control of spectrum in favor of competing concerns. For example, the Efficient Use of Government Spectrum Act of 2013 (H.R. 2739, Representative Matsui) required the release of spectrum that was in use at the time by the DoD for shared use or auction. The Federal Spectrum Incentive Act of 2013 (H.R. 3674, Representative Guthrie) established that federal spectrum users are eligible to participate in incentive auctions like those being implemented for television broadcasters.

Further efforts to relinquish spectrum will almost certainly continue to rise with the emergence of new technologies like telemedicine, driverless vehicles, advanced robotics, cloud computing, and machine-to-machine communications (the Internet of Things).

Meanwhile, historical notions of spectrum allocation, assignment, and management are also changing dramatically. What was once a static, one-dimensional property is becoming a dynamic, multifaceted commodity. The original framework of spectrum allocation was based on the idea owning parts of the spectrum for a pre-defined purpose. The notion of spectrum ownership is shifting in response to recent developments in software-programmable radios and radars, spread-spectrum waveforms, digital signals, spectrum-sharing technology, and dynamically assigned frequency that allow users to share common spectrum, separated by frequency, location, time and waveform under the control of supervisory systems. The cost of upgrading, or even to move operations from the current band to some other frequency band, can be daunting. Twenty years ago, the military had already invested heavily in spectrum-using equipment including more than 800,000 radio frequency (RF) emitters worth over $100B [7].

These pressures prompt heightened concerns that rapidly growing DoD spectrum needs will soon reach a point where they can no longer be met—ultimately precipitating a corresponding erosion in our military's technological edge.

IMPACT ON THE T&E ENVIRONMENT

Today's T&E environment is a living microcosm of the larger spectrum management challenge facing DoD. The T&E environment requires war-like access to spectrum under the "train as you fight" and "test as you use" doctrines and involves the highly coordinated application of various resource types—including telemetry spectrum. This orchestration process and the numerous constraints involved present special problems in spectrum management. According to one source, the spectrum available for telemetry and instrumentation is inadequate to support the pace of activities in crowded areas like the R-2508 complex [3]. Lack of sufficient access to the needed spectrum comes at a cost. Historically speaking, flight testing accounts for as much as 15 percent of the cost of developing a new aircraft [4]. Test programs often involve hundreds of workers and can last months or even years. For large test programs, unplanned test delays can cost somewhere between $1 million to $3 million [5]. Taken together, an estimated $60 million a year is lost on test ranges today due to delays caused by telemetry spectrum shortages [6].

If the DoD hopes to maintain the spectrum it needs for T&E purposes, it will have to clearly demonstrate both the need for that spectrum and the responsible, efficient use of the spectrum. It must also dramatically improve its ability to quantitatively establish the technical, cost, schedule, and safety risks of reduced access and control.

Much of the difficulty in doing so stems from the lack of well-defined metrics and tools to:

- Accurately estimate current and future spectrum needs;
- Account for *actual* versus *scheduled utilization* of the spectrum that is allocated, so as to demonstrate responsible stewardship of the spectrum; and
- Quantify the cost and schedule implications of the loss of needed spectrum.

There has been precious little in the way of methods, metrics, and tools available to make these kinds of assessments. Consequently, those charged with securing and defending spectrum needed for T&E purposes have had little beyond anecdotal evidence to support their argument.

In response to these challenges, the Defense Science Board recommended that specific research and development (R&D) efforts be undertaken [3], including those aimed at developing improved operational and technical methods and advanced tools to promote more efficient spectrum use.

The Spectrum Efficiency Through Metrics (SETM) effort directly supports these goals by applying frequency metrics standards to monitor, assess, and improve the efficient use of spectrum while simultaneously working to give leaders the tools needed to defend access to T&E spectrum. The effort leverages many years' worth of research invested to define a baseline set of standard metrics for spectrum utilization, demand, efficiency, and operational effectiveness. These metrics are formalized in the RCC FMG Spectrum Management Metrics standard [2222]. The RCC FMG standard will provide the springboard for developing automated tools to calculate, plot, and display frequency management metrics.

SPECTRUM MANAGEMENT METRICS TOOLKIT OVERVIEW

Perhaps the most visible product of the SETM effort will be a set of tools designed to calculate, plot, and display frequency management metrics. Collectively, we refer to this set of tools as the Spectrum Management Metrics Toolkit (SMMT).

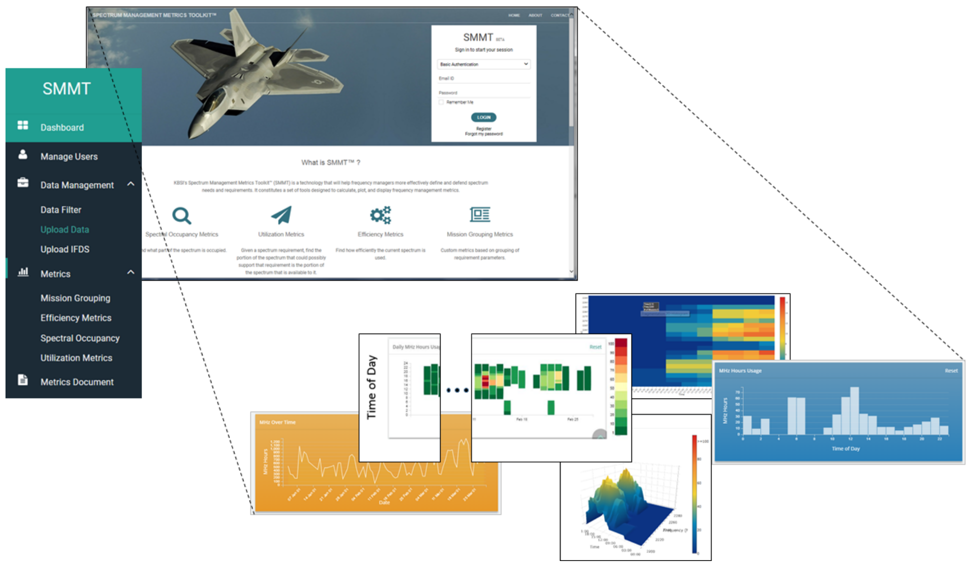

Figure 1. SMMT

The SMMT is architected as an enterprise level web application designed to ensure confidentiality and integrity of the data and the analysis results. As such, it provides a baseline set of enterprise system functions including SSO[1], RBAC, etc. As an interim measure to support end user testing, the SMMT also supports secure deployment using https:\\ with basic authentication. The toolset features an Angular 2.0 front end and a Node JS back end that uses a SQLite or MS-SQL database engine. The SMMT also provides a basic menu structure, a configurable dashboard interface, and an extensible library of metrics calculation and display “widgets” based on those found in the RCC FMG standard.

Some of the SMMT’s key capabilities include the following:

- Provides a manual data import capability allowing users to load analysis data from various data sources ingested through a “drag-and-drop” interface.
- Allows users to define persistable filters to be applied to the data for analysis purposes.
- Provides a set of metrics calculation and display “widgets” using various chart types.
- Supports “cross-filtering” or "brushing and linking" across metrics widgets, meaning that a change made in the filtering criteria for one widget is automatically propagated to related metrics widgets.
- Supports the composition of personalized dashboards spanning metrics calculation types.

[1] The SMMT supports authorized access to the web application using either basic authentication (custom) or single-sign-on (Active Directory).

Based on the RCC standard, the SMMT is designed to support calculation and display of frequency management metrics in the following categories:

- Spectrum Occupancy
- Utilization
- Spectrum Reuse
- Efficiency
- Frequency Scheduling Operational Metrics
- Predictive and “What-if” Metrics
- Frequency Request Groupings

The paragraphs below provide a brief, representative overview of metrics in some of the more familiar metrics categories.

Spectral occupancy metrics are based on a time-frequency grid. These metrics in this category operate much like measuring occupancy in an apartment building. Consider an apartment building with four apartments that are up for lease this month. Percent Occupancy (PO) measures the extent to which the apartments available are leased out to residents. If there is one occupant in each apartment, PO is 100%. If only two of the four apartments are leased out to an occupant, PO is 50%. The PO metric disregards reuse, or concurrent occupancy. Thus, if each apartment had six occupants, PO would still be 100%. Percent Occupancy with Reuse (POWR) measures reuse of the spectrum. Reuse, or concurrent occupancy by more than one user of the spectrum, may be made possible through maintaining sufficient spatial separation to avoid interference, or by using multiple access methods. Returning to our apartment building example, if three of the apartments had one occupant while the fourth apartment had two occupants, POWR is defined to be 125%. Other metrics in this category measure how densely cells on a time-frequency grid are packed that are occupied (i.e., ignoring unused cells), the percentage of cells that are occupied with more than one occupant (regardless of how densely they are packed), etc.

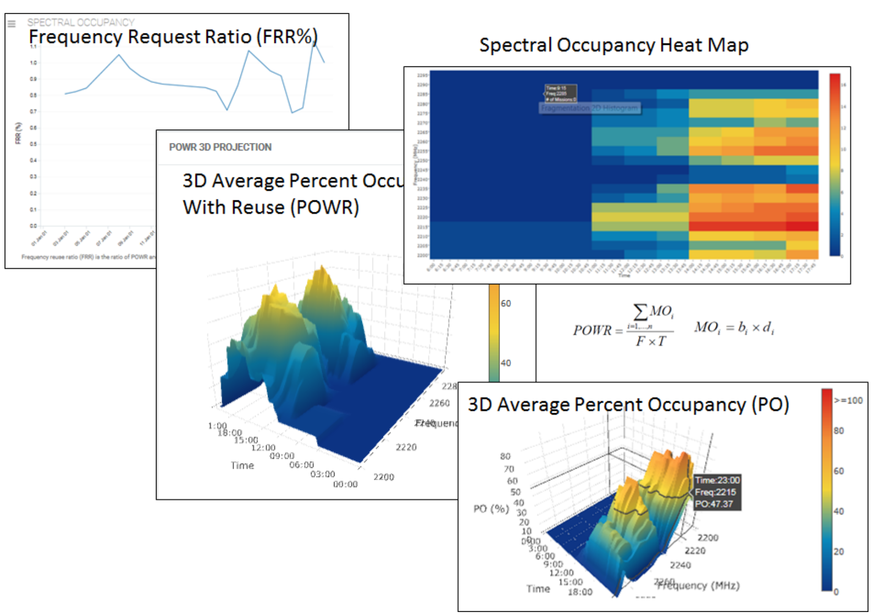

Figure 2. Occupancy Metrics

Efficiency metrics measure how efficiently the spectrum is being used and the extent to which technology and process change affect efficiency. Two forms of efficiency improvement are addressed: (1) advances in transmitter technology which allow more bits per second to be transmitted in the same bandwidth and (2) advances in scheduling technology (e.g., introduction of scheduling optimization algorithms). The metrics in this category attempt to answer questions like, “How much data are we transmitting?”, “How much data is being transmitted per unit of spectrum per unit time (i.e., cost)?”, and “Is the amount data being transmitted increasing as expected by having invested in technology and/or process change?” For example, the Average Mission Modulation Efficiency (AMME), which measures bitrate per unit of spectrum, would be expected to be vary based on the chosen modulation method (e.g., PCM/FM, SOQPSK or FOPSK). Each method has a theoretical performance—just like the EPA estimates a car’s miles per gallon for city versus highway driving. But we know that the ideal performance may be affected by other factors, such as operating around mountains or imposing power restrictions. Charts that plot AMME as a function of modulation method help to surface what is actually possible.

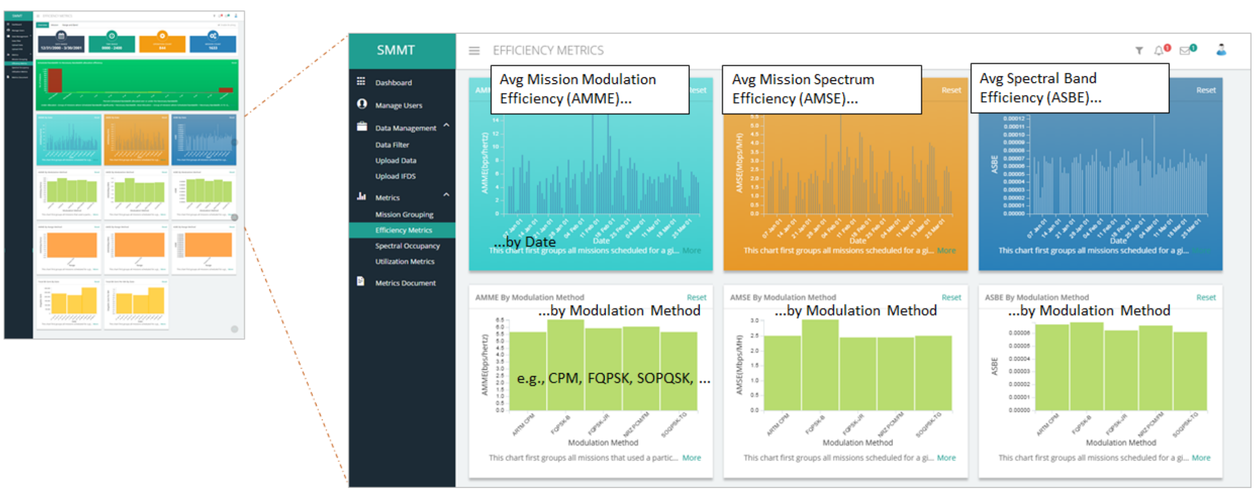

Figure 3. Efficiency Metrics

As viewed by the standard, Spectrum Utilization is defined in terms of spectrum availability. That is, in addition to actual occupancy in time, space, and frequency, access to spectrum may be denied to others for contingency purposes or as a consequence of the scheduled missions creating spectral fragmentation to a degree that unused spectrum cannot be scheduled. An example of the former case includes scheduling (but rarely actually using) a channel to execute in-flight termination of a missile in flight (i.e., reserving a frequency to initiate a self-destruct command, if required). Correspondingly, Spectrum Utilization metrics in the standard seek to answer questions like, “Can a given time-frequency request be accommodated given what has already been scheduled?”, “What is the probability of being able to schedule a frequency request requiring a larger bandwidth?”, “What does a typical frequency request look like?”, “How has the likelihood of accommodating a typical frequency request changed with time?”, etc. A heat map provided in the tool plots the number of frequency scheduling requests for a given bandwidth and duration in hours. In this example, we see that the most popular frequency request profile calls for 1.5 to 2.5 MHz of bandwidth for 1 to 2 hours. A companion heat map plots the likelihood that that a request calling for a certain bandwidth and duration can be scheduled. In this case, for the most popular request profile, the probability of it being scheduled is 70%. Of course, the more bandwidth required (moving vertically up the chart) and the longer the duration (moving horizontally to the right of the chart), the lower one's chances.

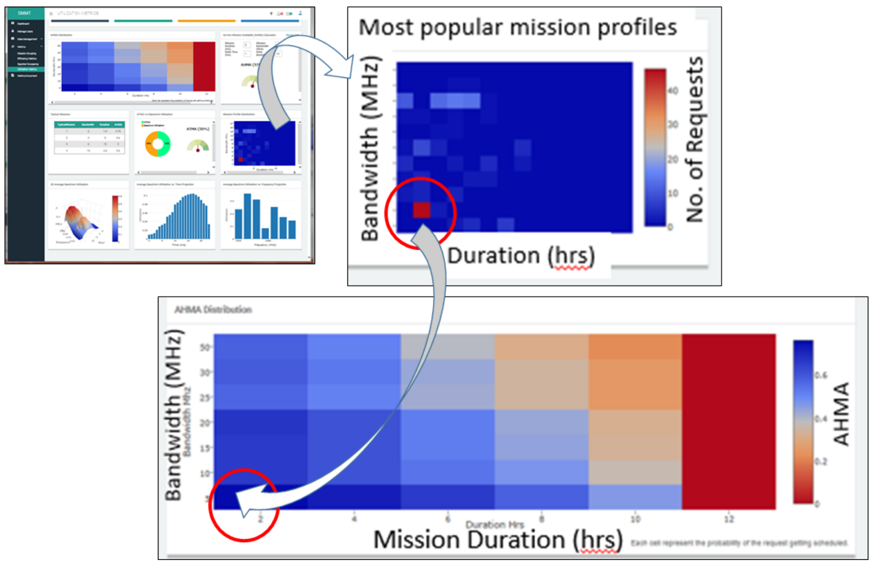

Figure 4. Utilization Metrics

CONCLUSIONS

Assured access to electronic spectrum is essential to the success of U.S. military operations both now and in the future. T&E spectrum needs are a vital component of that requirement. It is in that domain of spectrum application that we develop and maintain a decisive technological advantage. The two are inextricably linked. As more advanced technologies emerge, T&E spectrum needs will continue to grow. Many project that growth to be exponential. Meanwhile, the more crowded the spectrum becomes, the more it will become necessary to spread testing missions in time. Of course, doing so lengthens the development time between new generations of fielded weapons technology. Longer lead times, in turn, make it easier for enemy concerns to close the gap and achieve technological parity, or worse.

As evidenced by the past, economic pressures to increase the scope of commercial spectrum use will continue to drive further reallocations of DoD spectrum. If the DoD hopes to maintain the spectrum it needs for T&E purposes, it will have to clearly demonstrate both the need for that spectrum and the responsible, efficient use of the spectrum. It must also dramatically improve its ability to quantitatively establish the technical, cost, schedule, and safety implications of reduced access and control.

The emergence of the RCC's frequency management metrics standard coupled with tools like the one presented in this paper seek to provide the means to better manage and defend needed T&E spectrum.

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