WRITING BETWEEN THE LINES – THE STORY OF SPECTRUM AGGREGATION

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ABSTRACT

In order to meet the increasing demand for spectrum to support future DoD test and evaluation (T&E) requirements in an environment of decreasing spectrum availability, the DoD requires new spectrum aggregation and spectrum management technologies. Advanced radio technologies that sense and aggregate non-contiguous blocks of spectrum into a larger communication channel capable of supporting higher user data rates are needed. Moreover, the T&E community must more effectively manage and use the spectrum that is available to it, and utilize new paradigms in which spectrum is dynamically allocated on a non-interference basis to multiple, concurrent users and in a way that meets both planned and unplanned changes to mission requirements, and real time channel conditions, factoring in both Federal and non-Federal users of spectrum.

The objective of the Adaptive Spectrum Aggregation and Management (ASAM) project is to develop technologies that will sense available spectrum, aggregate white space within fragmented frequency bands to create communication channels, and dynamically allocate those channels across multiple range users using algorithms that increase spectrum utilization and efficiency while applying policy constraints. The ASAM project is sponsored by the Test Resource Management Center (TRMC) and was awarded in 2016 through the National Spectrum Consortium.

This paper will describe the ASAM project and technical challenges associated with its development.

INTRODUCTION

In 2017, it has become common knowledge among members of the test and evaluation (T&E) community that two trends are occurring. First, there is an increasing demand for spectrum both inside and outside the DoD. Second, usable electromagnetic spectrum is finite, and as a result these two distinct user groups are competing for the same limited resource. The voice of the telecommunications industry grows louder, and the needs of the T&E community, while growing in scope, are seemingly becoming less important. Spectrum relocation is a frequently discussed topic in our conferences, and the DoD is making significant investment in spectrum relocation as well as in developing new technologies which enable the DoD to operate using not only new frequency bands, but new paradigms, including those of greater levels of spectrum re-use and spectrum sharing. This paper introduces one of these new paradigms, one which is already ubiquitous in the commercial telecommunications sector and in our daily personal lives, whether we are aware of it or not – spectrum aggregation. The first part of this paper describes a new R&D effort focused on implementing spectrum aggregation technology as well as dynamic spectrum access in a way that supports telemetry. The second part of this paper presents an especially compelling use case for spectrum aggregation and illustrates how accessing white spaces - small unused portions – in spectrum gives us access to more of this precious resource and ultimately allows us to communicate more information. It is much like reading, and writing, between the lines on a page. This paper tells that story.

THE BODY

In order to meet the increasing demand for spectrum to support future DoD T&E requirements in an environment of decreasing spectrum availability, the DoD requires new spectrum aggregation and spectrum management technologies. Advanced radio technologies that sense and aggregate non-contiguous blocks of spectrum into a larger communication channel capable of supporting higher user data rates are needed. Moreover, the T&E community must more effectively manage and use the spectrum that is available to it, and utilize new paradigms in which spectrum is dynamically allocated on a non-interference basis to multiple, concurrent users and in a way that meets both planned and unplanned changes to mission requirements, and real time channel conditions, factoring in both Federal and non-Federal users of spectrum. The Test Resource Management Center (TRMC is sponsoring the Adaptive Spectrum Aggregation and Management (ASAM) project, which will combine carrier aggregation techniques, such as those applied in commercial cellular Long Term Evolution – A (LTE-A) implementations, with cognitive radio technologies for dynamic, policy-based spectrum allocation and management. Together these technologies will form the building blocks of a communications system which meets the T&E community's need to operate within new bands that have historically been too fragmented to support T&E requirements in a spectrum environment which is dynamic. The ASAM system is being designed to sense available spectrum, aggregate white space within fragmented frequency bands to create communication channels, and dynamically allocate those channels across multiple range users using algorithms that increase spectrum utilization and efficiency while applying policy constraints.

A key feature of this new technology is dynamic management of spectrum to support concurrent test activities, with an emphasis on sensing and aggregating non-contiguous bands in a spectral environment that may be fragmented by multiple users. Another key feature of the technology is that it continually updates spectrum allocation to increase overall system spectrum efficiency. The spectrum allocation algorithms presented in this proposal maximize total system utility based on the user defined policy constraints.

The ASAM system will perform the following functions:

- Sense unused portions of spectrum, or white space, within telemetry bands available on a DoD ranges. The band(s) of interest may be highly fragmented by different Federal and non-Federal users. Sensing may be performed either by base stations (BS) on the ground or by the test articles (TA) themselves.

- Identify sub-channels to be aggregated to create a single, logical channel to support test requirements out of unused portions, or white space, in spectrum. Selection of actual portions of telemetry spectrum to be aggregated will be driven by a number of factors, including not only availability of white space in spectrum but also estimated signal-to-noise (SNR) on subchannels, known interference locations, required communications rates for users, relative priority of users, user location, and other constraints such as sub-channel reservations or blackouts as established by pre-defined or ad hoc policy. The overall selection and distribution of sub-channels across multiple test articles will be optimized at the system level. Selection of sub-channels by the ASAM system will be dynamic, and the system will automatically adapt to time varying changes in spectrum availability.
- Aggregate and access available white space to create a full duplex communication link at the required data rate for a given test article. The ASAM system will employ orthogonal frequency division multiplexing, as this modulation scheme affords flexible access to unused portions of spectrum.

ASAM Concept of Operations

The following scenario highlights key features of the ASAM system, and illustrates how ASAM benefits test operations on a range with multiple-users and sources of interference. In this scenario, five test articles and two sources of interference on a test range illustrate the ASAM capability.

Test Article 1 (TA1) is a legacy system and is not equipped with the ASAM technology, so test engineers assign it a fixed, contiguous frequency range for its test.

Test Article 2 (TA2) is equipped with ASAM technology, but for historical programmatic reasons, test engineers also pre-assign it a contiguous frequency range for its test. The ASAM system is running in the test, and the system is configured to allow dynamic changes to the spectrum used by TA2 if a need arises.

Test Article 3 (TA3) and Test Article 4 (TA4) are also equipped with ASAM technology, and their onboard ASAM modules are set up to sense and aggregate optimal frequency bands for the test without an initial assignment of bands. The ASAM system uses a combination of factors to arrive at this solution, including user-defined policy, required data rates, and test priority. The test missions of TA3 and TA4 are of equal priority, but TA3 requires a higher data rate for the series of tests to be conducted. Also, TA3 will be operating on part of the range subject to significant degradation due to channel effects such as multi-path. TA4, on the other hand, will be operating on part of the range subject to interference from Interferer1, an operational system that does not coordinate spectrum allocation with the range.

At the beginning of the day, test engineers load the ASAM ground system with data that specifies which frequencies are available to ASAM-equipped test articles and which frequencies have been allocated to other non-ASAM equipped test articles or to other systems, such as training or operational assets, in the vicinity. This information is entered into ASAM through the system Policy Editor in the control room. Test Article (TA) 1 has been allocated a fixed range of frequencies that will remain unchanged during the test, as TA1 is not equipped with ASAM.

Though equipped with ASAM, TA2 has also been pre-assigned a frequency range for the test, but the ASAM configuration allows changes to the frequencies used during the test if TA2 experiences interference or if a frequency allocation change is required for overall system optimization. TA3 and TA4 are configured to fully use the ASAM capability, and frequency allocation is not pre-assigned for those test articles. The ASAM system will arrive at an optimal frequency assignment for those test articles, given the policy constraints of the total system, including the off-limit frequencies used by TA1, known interferers such as Interferer1, the initial assignment of frequency to TA2, test priorities for all systems, anticipated channel model parameters, and required data rates.

TA1 and TA2 begin their tests using pre-assigned frequency bands. TA3 and TA4 move onto different parts of the range to conduct their tests and rely on the ASAM system to sense and aggregate the optimal frequency usage for those systems given the underlying policy constraints entered into the system. The ASAM system modules on TA3 and TA4 communicate with the ASAM ground node and at the same time determine the amount of interference they experience on various channels in their respective locations on range, and the ASAM system determines an optimal frequency allocation. Communications between the ASAM modules on TA3 and TA4 is not required. TA3 is assigned a contiguous frequency range that provides an optimal solution given its high data rate requirements and location on the range that is prone to multi-path effects. The ASAM system module on TA4, on the other hand, ends up using non-contiguous set of frequencies due to the interferers operating in the vicinity in which it is operating. The ASAM system aggregates these non-contiguous white spaces into a single communications channel for TA4.

Interferer2 from a nearby training-activity begins to transmit in some of the non-contiguous blocks of spectrum used by TA4 as well as in some of the frequencies that were pre-assigned to TA2. Spectrum used by TA1 and TA3 are not impacted by Interferer2. Fortunately, TA2 and TA4 are equipped with the ASAM capability. The ASAM modules onboard TA2 and TA4 detect the additional noise on channels they are using, and the ASAM modules onboard each of those systems identifies new sub-channels to use. This determination is governed by overarching policy, such as the frequency allocation to TA1, and measured interference on various sub-channels. TA2 and TA4 adapt to the change in channel conditions caused by Interferer2, and their tests continue unimpeded.

Finally, TA5 enters the range for testing. It is a lower priority test, and there are no contiguous blocks of spectrum available to meet its data throughput requirements. However, because it is ASAM-equipped, it utilizes a number of non-contiguous channels that when combined meet its throughput requirements.

<u>Upper C-band Use Case – Benefits of Spectrum Aggregation</u>

A particularly compelling application which highlights the benefits of spectrum aggregation can be found in the Upper C-band from 5925-6700 MHz. Currently, the 5925-6700 MHz band is dedicated to non-Federal users, and includes a combination of fixed-satellite earth stations in the band 5925-6425 MHz and to a lesser extent in the 6525-6700 MHz band, which are used for fixed-satellite Earth-to-space communications; fixed service stations used for terrestrial communications; and in the 6425-6525 MHz band mobile broadcast service used for electronic news gathering and event video distribution.

Resolution 416 from the 2017 World Radiocommunication Conference (WRC-07), entitled *Use of bands 4400–4940 MHz and 5925-6700 MHz by an aeronautical mobile telemetry application in the mobile service*, considers and recognizes the growing needs for spectrum for Aeronautical Mobile Telemetry (AMT) flight test purposes as well as the existing allocation of 5925–6700 MHz to fixed service (FS), mobile service (MS), and fixed-satellite service (FSS) users, and resolves that administrations authorizing use of 5925–6700 MHz shall use criteria that prevent or reduce potential interference from AMT to incumbent users to acceptable levels.

Techniques for sharing the band among AMT airborne transmitters and the incumbent users are addressed in detail in the International Telecommunications Union's (ITU) Report ITU-R M.2119*, Sharing between aeronautical mobile telemetry systems for flight testing and other systems operating in 4400-4940 and 5975-6700 MHz bands*. The conclusions from that Report are that if a set of criteria are applied to AMT, sharing with incumbents in the 5925-6700 MHz band can occur without further coordination and without risk of interference to incumbents.

One of the technical measures identified in the report is establishment of a 450 km x 24 km coordination zone, defined by the location and orientation of each fixed or mobile service receiver antenna, outside of which AMT can be conducted with no further coordination with the incumbent user. Within the described 450 km x 12 km zone, AMT may still be possible but requires further bilateral coordination.

By applying the 450 km x 24 km coordination zone criterion to all fixed service and fixed-satellite service receivers within 600 km of four test ranges, Edwards AFB, NAS Pax River, Eglin AFB, and Wichita Test Center, and also by considering the frequency assignment of those incumbent receivers, one can reach several key conclusions. First, there is a significant amount of unexploited spectrum available for AMT within the 5925-6700 MHz band. Second, this spectrum is highly fragmented, much of it in smaller than 5 MHz-wide blocks. In order make the most efficient use of this fragmented spectrum is to employ a communications technology which can aggregate non-contiguous white spaces to form a single communications channel. To harvest the most amount of spectrum, the AMT system would be able to access distinct 1-2 MHz portions of the band. Third, due to the physical locations of the incumbent receivers, each point in the test area may have a different set of 1 MHz blocks available for aggregation. As one would expect, some overlap in the set of white spaces available between adjacent physical locations on the range exists, but the AMT system must be capable of accessing different blocks of data dynamically, as a function of its location on the range.

A detailed analysis of Edwards AFB, following the methodology described above (i.e. applying the Resolution 416 coordination zone criteria to each point on the range, and excluding all 1 MHz sub-bands used by FS stations within the coordination zone of that point on the range), shows that 100% of the Edwards AFB test area has at least 30 MHz of spectrum available through aggregation within the 5925-6425 and 6525-6700 MHz sub-bands. The same analysis shows that 93% of the test area has at least 50 MHz of available spectrum; and 40% of the test area has at least 100 MHz of spectrum available through aggregation.

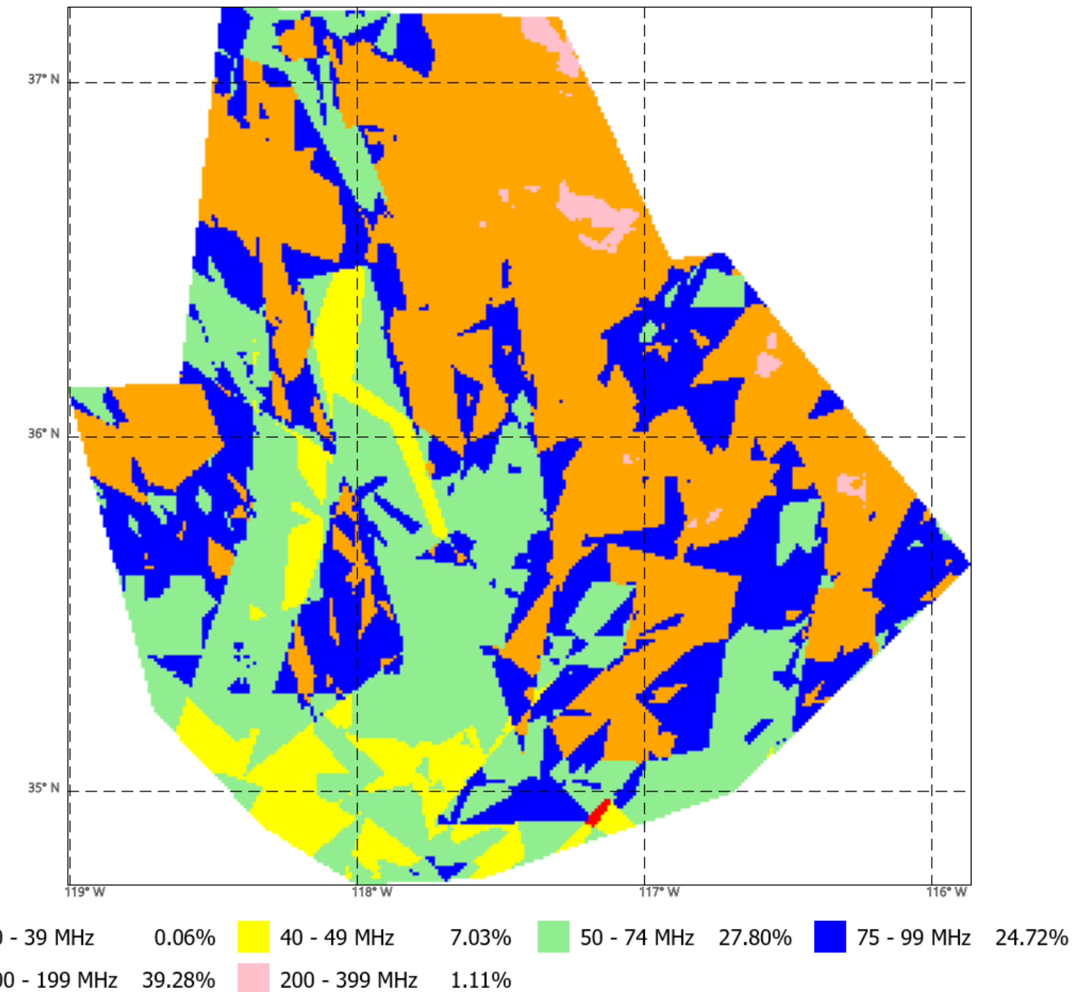

Figure **1** below illustrates the amount of spectrum in megahertz, that become available to support AMT at Edwards AFB through the use of spectrum aggregation techniques.

The same analysis conducted for the test areas at Eglin AFB, NAS Pax River, and Wichita Test Center yields similar results. At NAS Pax River, 100% of the test area has at least 25 MHz of aggregated spectrum available by applying the 450 km x 12 km criterion; 98% of the test area has at least 40 MHz of spectrum available; and 59% of the test area has at least 50 MHz of spectrum. At Eglin AFB, 100% of the test area has at least 40 MHz of available spectrum; and 90% of the test area has at least 100 MHz of available spectrum. At Wichita Test Center, 100% of the test area has at least 50 MHz of available spectrum; and 71% of the test area has at least 100 MHz of unused, aggregated spectrum available. Figure 2, Figure 3, and Figure 4 show total aggregated spectrum available for AMT at NAS Pax River, Eglin AFB, and Wichita Test Center, respectively.

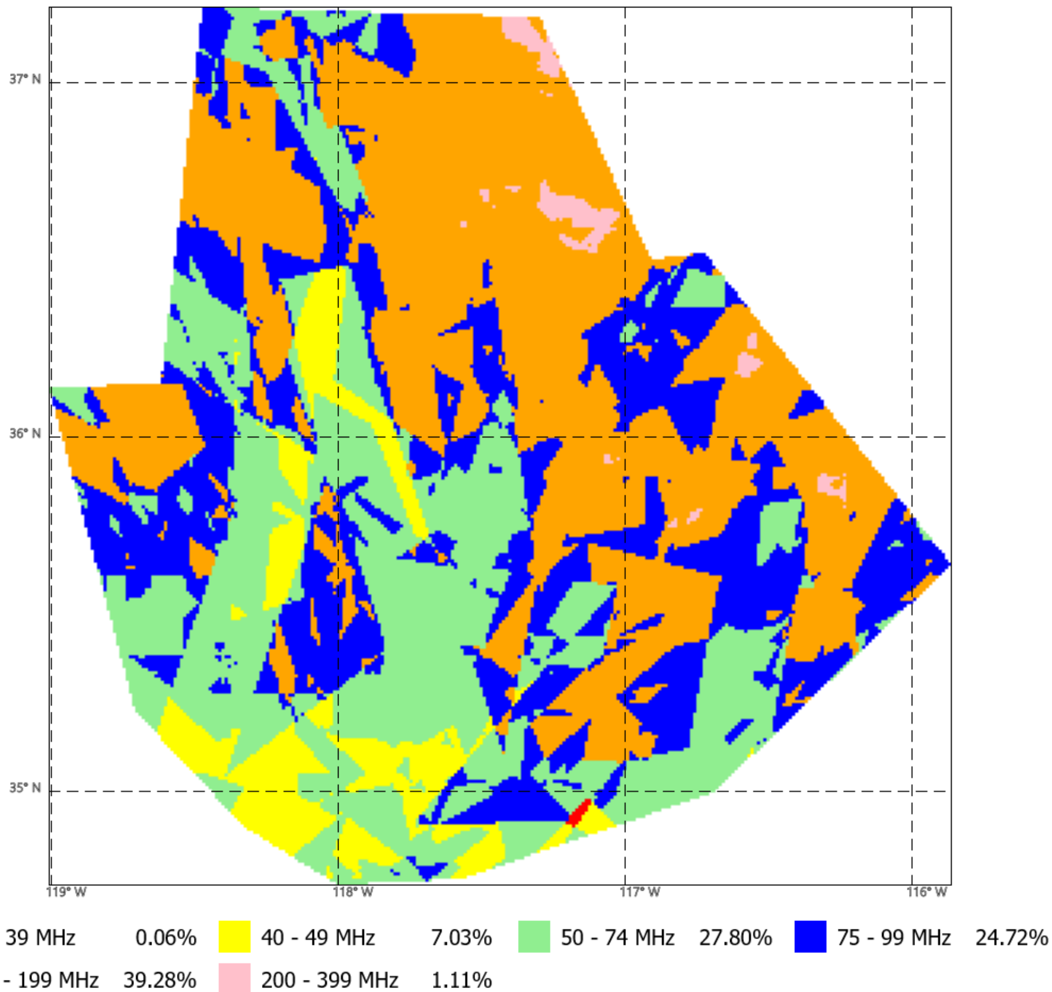

Figure 1. Aggregated Spectrum Available for AMT at Edwards AFB

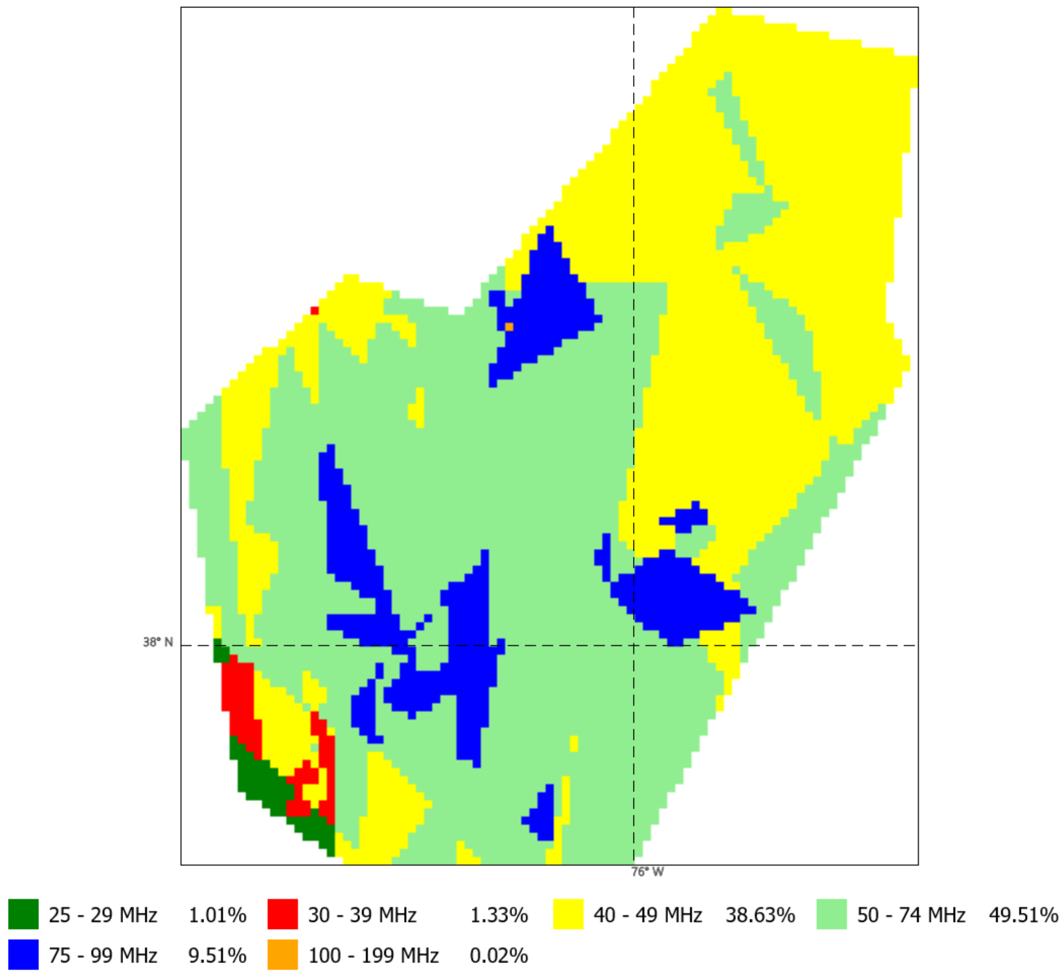

Figure 2. Aggregated Spectrum Available for AMT at NAS Pax River

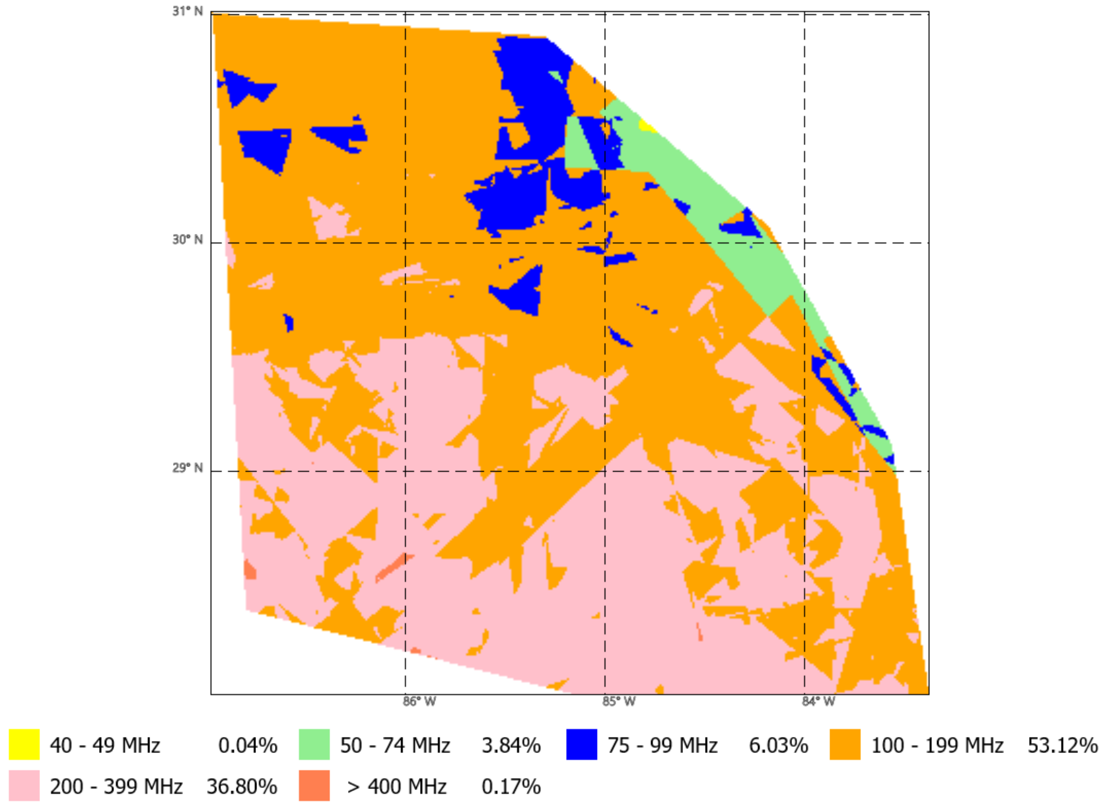

Figure 3. Aggregated Spectrum Available for AMT at Eglin AFB

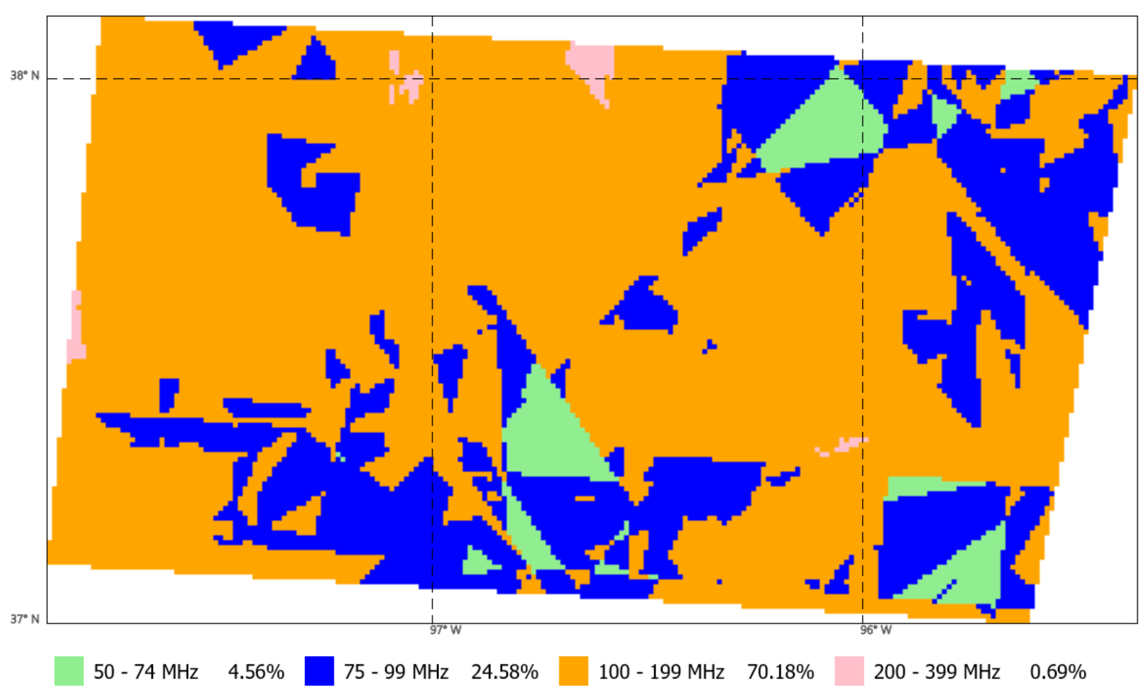

Figure 4. Aggregated Spectrum Available for AMT at Wichita Test Center

The keys to exploiting the whitespace segments lies in use of spectrum aggregation and dynamic spectrum access technologies. Because each point on the range has its own specific set of unused 1 MHz blocks of spectrum, an airborne AMT transmitter must have the capability to adjust the spectrum it accesses, as a function of its physical location on the range.

CONCLUSIONS

The benefits of spectrum aggregation are clear, particularly as we continue to move forward into a new era in which demands on spectrum – and its importance in our lives - will continue to grow. Spectrum aggregation, particularly when combined with technologies that effect dynamic access to spectrum, will enable more efficient use of existing telemetry bands by the T&E community and at the same time enable access to new bands, and to sharing among different sets of users, including those within and outside the DoD. This paper has presented a compelling example of the benefits of these technologies in the upper C-band, which is considered by its incumbent users to be too congested to support any additional use by the DoD. Certainly, with the advent of spectrum aggregating technologies and communications systems that have the ability to dynamically adjust the spectrum they access, our understanding and assumptions about how efficiently we can truly use this precious and finite resource we call spectrum can, and will, change.

ACKNOWLEDGMENT

This effort has been sponsored by the U.S. Government under Other Transaction number W15QKN-15-9-1004 between the NSC, and the Government. The US Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon.

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