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| Abstract | This document is intended as a contribution and response from the 1900.5 WG to the DoD’s RFI on Defense Spectrum Sharing |
| Purpose |  |
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# ENABLING DYNAMIC SPECTRUM SHARING VIA THE USE OF SPECTRUM CONSUMPTION MODELS

*Note: once the whitepaper is approved, the following text should be added:*

*“Whitepaper prepared and approved by the IEEE 1900.5 Working Group within the Dynamic Spectrum Access and Networks Standardization Committee (DySPAN-SC)”*

The IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC) is a component of the IEEE Standards Association, one of the Major Organizational Units of the Institute of Electrical and Electronics Engineers (IEEE). IEEE has about 420,000 members in about 190 countries and supports the needs and interests of engineers and scientists broadly. In submitting this document, DySPAN-SC acknowledges and respects that other IEEE Organizational Units may have perspectives that differ from, or compete with, those of DySPAN-SC. Therefore, this submission should not be construed as representing the views of IEEE as a whole.

DySPAN-SC is a consensus-based industry standards body for Dynamic Spectrum Access Networks (DySPAN), and has the following technical scope:

* dynamic spectrum access radio systems and networks with the focus on improved use of spectrum,
* new techniques and methods of dynamic spectrum access including the management of radio transmission interference
* coordination of wireless technologies including network management and information sharing amongst different dynamic spectrum access radio networks.

**Introduction**

Since 2012 the IEEE 1900.5 working group on Policy Language and Architectures for Managing Cognitive Radio for Dynamic Spectrum Access (DSA) Applications started working on IEEE standard 1900.5.2 with the aim to standardize a method for modeling spectrum consumption. The standard was completed in December of 2017. After receiving additional industry and feedback from entities that interact with DoD, the working group started an amendment to enhance the application domain of Spectrum Consumption Models (SCMs) and the clarity of the information model (schema) on which it is based. This standard is being upgraded to specifically address the needs of the DoD’s future Electromagnetic Battle Management (EMBM) System. The amendment should be finalized by early 2021.

Further, a recent technical report, funded by DoD, proposed using SCMs to define a novel spectrum sharing approach called spectrum highways. This approach can be used to manage sharing among disparate types of spectrum dependent systems (SDSs) consistent with the intent of this RFI. The report on spectrum highways can be downloaded from

<https://www.mitre.org/publications/technical-papers/spectrum-highways-rules-of-the-road-for-collaborative-radio-frequency-spectrum-sharing>

The content of this whitepaper does not take a position on questions A, D and M but does address the remaining questions of the RFI. It focuses not only on identifying novel ways to share the electromagnetic spectrum (EMS) with commercial users but argues for a sharing approach; which, if built, creates the core technologies that will enable DoD to achieve the goals in its new EMS Superiority Strategy.

**Description of SCMs and their standardization**

The IEEE 1900.5.2 standard defines an approach to model spectrum consumption via SCMs and the attendant computation methods and algorithms to arbitrate compatibility among these models. SCMs are used to capture the boundaries of RF spectrum use by all types of RF devices and systems of RF devices. These models enable Model-Based Spectrum Management (MBSM), which is spectrum management executed through the creation and exchange of SCMs. MBSM allows distribution of the spectrum management problem where spectrum users can model their use of spectrum independent of other users, without the need to reveal proprietary details, and share those models directly or via a MBSM system. A common set of algorithms can then be used to compute the compatibility of the models. The compatibility computation determines whether the spectrum uses expressed via SCMs will generate interference to one or more of the devices/systems considered in the computation.

SCMs capture the boundaries of spectrum use by capturing the key characteristics of RF systems and phenomena that determine spectrum use. Currently, as defined in IEEE 1900.5.2-2017, the modeling method uses 11 construct elements that can collectively capture transmission power, spectral emissions, receiver susceptibility to interference, intermodulation effects, propagation, antenna effects, location (both fixed and mobile), time of use, and radio behaviors that enable compatibility. These construct elements can also capture the uncertainty of what is being modeled. SCMs are machine readable and they can also serve as a means to convey RF spectrum use parameters to devices.

SCMs are complemented with defined methods for arbitrating the compatibility between models. A MBSM system is thus capable of managing coexistence of multiple types of users. Models can be constructed for any type of system that uses the RF spectrum and so compatibility can be managed among types of users differentiated by the purpose or service of their spectrum use. These methods support arbitrating compatibility based on both noise limited and interference limited spectrum sharing criteria.

SCMs can be used to specify policy. A set of multiple SCMs can be used to define the alternative operating regions in spectrum in the typical dimensions of space, time, and frequency as well as in the nuanced dimensions of coexistence such as modulation, coding, protocol, or polarization. This set of SCMs is defined as an authorization set by the standard. One or multiple sets of SCMs can further define constraints to operation. These SCMs capture real or notional systems that SDSs, despite operating within the boundaries of an authorization set, must not interfere. These sets are referred to as constraint sets. Constraint sets are equivalent to DoDs Joint Restricted Frequency List (JRFL). However, since SCMs are machine readable and are complemented with the standard algorithms to arbitrate compatibility, these JRFLs can support future systems that autonomously comply with the constraint sets they are given. Multiple constraint sets can be formed, each associated with a separate policy such as Taboo, Guarded, and Protected consistent with current JRFL classifications. Constraint sets can also serve as a way to define exclusion zones as used in CBRS. The permissive and restrictive policies that authorization and constraint sets provide can be as dynamic as the means to write and distribute the policies allows. It is feasible to build any type of SDS to autonomously comply with these types of machine-readable policies.

Complying with policy and coexisting in the congested and contested EMS are two different problems. Coexistence requires behaviors that ensure systems do not interfere. Hard problems such as preventing interference to hidden nodes (i.e., passive nodes that are receiving from a transmitter that cannot be detected) or resolving rendezvous (i.e., all devices of an SDS move to the same frequency selected) still need to be solved. Further, in contested environments, signals and interference from adversaries should not cause friendly systems to defer from operation if that operation can still be effective. Yet further, in a congested environment, it is important that sharing SDSs should be able to differentiate among themselves which should have precedence. SCMs allow the identification of the protocols that solve these problems. An exemplar of this approach of using an authorization set with a defined protocol for Dynamic Spectrum Sharing (DSS) is a Spectrum Highway.

**Description of Spectrum Highways**

The spectrum highway system is a new approach to dynamic spectrum access (DSA) that is highly efficient at managing the access and reuse of spectrum in time and in space. Additionally, it resolves problems of congestion, distinguishes spectrum use based on precedence of users and uses, coordinates the rendezvous of spectrum-dependent systems (SDS) devices, avoids features that can be easily attacked and enables autonomous maneuver in the EMS. Further, the underlying technology that enables spectrum highways will fully support heterogeneous uses in the same spectrum, making spectrum convergence feasible even among distributed autonomous devices.

This DSA technique is most easily visualized using highways (or roadways) as a metaphor. Following this metaphor, highways are created by setting aside spectrum in geographical locations and subdividing that spectrum into lanes.

Like vehicles on a highway, many SDSs can operate on the same lane of the highway, with their use separated either spatially or temporally, or on separate lanes for spectral separation. SDSs can autonomously move among the lanes and, if necessary, merge lanes for broader bandwidth access. They can also move among highways.

SDSs contend among themselves to use the highway lanes by using a signaling protocol that is highly effective at resolving contention in congested conditions, preventing hidden nodes, and orchestrating spatial reuse of the highway lanes. This same signaling is used to arbitrate precedence among the SDSs for lane access.

Similar to the way an emergency vehicle can alert other vehicles to its presence and precedence using a siren and flashing lights, an SDS can use the signaling methods of the highway. The signaling can indicate which SDS a contending device belongs thus removing the challenges of rendezvous.

The behaviors of SDSs that cause them to cooperate efficiently are created by the access protocol, its rules for access behavior, and authorizations given to SDSs that govern their use of precedence signaling when using highways.

Given a collection of SDSs designed to operate on highways, the concept of operations is to provide those SDSs with information about the highways and the precedence levels they are permitted to use and then let them operate autonomously thereafter. There is no requirement for SDSs to remain connected to a database and the use of signaling removes any ambiguity about spectrum availability.

In operation, each SDS autonomously decides which highways and lanes to use and cooperates with others on the same highway and lane using the access protocol and its associated rules. There is no burden on system operators.

This access paradigm can achieve the same results as access using a database, (e.g., the spectrum access system (SAS) used by the Citizen’s Band Radio Service in 3.5 GHz), without the need for constant connectivity between the devices and the SAS. Better, the devices can be mobile, thus avoiding the expense of professional installation, localization, and registration.

Spectrum highway DSA can achieve the same results as a sensor-based DSA approach without risk of interfering with passive users. As long as SDSs follow the rules for access and behavior on the highway, their use of the spectrum will be compatible with other SDSs on the highway. The autonomy and flexibility this approach provides, enable SDSs to have initiative in selecting the spectrum to use which gives them an advantage in a contest against an adversary.

The changes and adaptations in spectrum use that can occur on a highway can be executed within a few milliseconds with a high probability guarantee that the most important use is serviced first.

Spectrum highways enable sharing among any type of SDS such as communication systems like 5G, radars, and passive receivers and sensors. Policy on precedence can be used to make nearly perpetual access for commercial users that is interrupted only when higher priority primary users are both present and have an immediate need for access. The access mechanism is a use it or lose it method that makes the spectrum immediately accessible to general authorized access users when a higher priority commercial user does not have a need to use the spectrum and only until that commercial system has a need.

Complementing spectrum highways with the use of constraint sets allow a rapid way to selectively shut down parts of a highway to support sensitive uses of spectrum that are inappropriate to be arbitrated using the highways protocols.

In this new sharing approach, it is precedence in access that is auctioned or traded. The discreteness of precedence and its trade can give new technologies like blockchain a role in the future DSS ecosystem. This availability of spectrum encourages new entrants, the rapid development of technologies that can exploit spectrum highways, and a market that can respond to the demand for spectrum.

**Application**

There are many details in both spectrum consumption modeling and in the design and operation of spectrum highways that are not addressed above but are provided in the standard and in the cited spectrum highway report. The information above provides sufficient information to understand our answers to the questions of the RFI and the solutions that SCMs and spectrum highways provide.

1. **How could DoD own and operate 5G networks for its domestic operations?  What are the potential issues with DoD owning and operating independent networks for its 5G operations?**

The IEEE 1900.5 WG does not take position on this question.

1. **While the Department has made available the 3450-3550MHz spectrum band for 5G,  are there new technologies or innovative methods as to how additional mid-band spectrum currently allocated to DoD can be made available for 5G faster?**

Creating machine readable policy intends to enable rapid reallocations of spectrum to systems that can comply with this type of policy. Assuming the existence of systems that can respond to this machine-readable policy, changes in access can be as rapid or deliberate as the manager of the policy desires. However, the 5G business model generally demands a persistent availability of the spectrum. The question is whether it is appropriate for DoD to give up access to the spectrum to meet this demand for persistence.

The spectrum highway concept anticipates creating a sharing environment where unused spectrum can be made available nearly persistently to 5G providers but immediately reclaimed when there is demand and need. This reclamation will usually be highly localized to where and when the DoD uses the spectrum thus allowing the continued availability and no disruption to 5G elsewhere.

1. **What are other innovative ideas as to how 5G can share spectrum with high-powered airborne, ground-based and ship-based radar operations in the 3100-3550MHz spectrum band?**

The SCM and spectrum highway methods each provide a solution to protecting the operation of radars that are dynamic in terms of mobility, frequency of operation, and time of operation. Assuming an MBSM approach to managing this band of spectrum and systems that can respond to that management, protections can be provided as quickly as constraint sets can be written and distributed. The constraint sets can contain models of the regions that must be protected. These can be made abstractly and broadly like exclusion zones in CBRS, or precisely indicating individual tracks and times of operation.

Spectrum highways can be designed to specifically account for the needs of these high-power systems allowing them or surrogates to use a high precedence in gaining access. The purpose of using surrogates would be to enhance operation security. This reclamation of spectrum would be instantaneous based on demand and localized to where the use occurs without specificity or any data exchange indicating the location or identity of the system. Since highways are based on the use of SCMs, the constraint set methods described above can also be used to protect these radars.

1. **Are there other spectrum bands that can be made available to share quickly in the low and high band spectrum ranges?**

The IEEE 1900.5 WG does not take a position on this question.

1. **What types of technologies exist, or are anticipated, that will allow civilian users to share spectrum faster?**

The spectrum highway concept was conceived based on creating a DSS solution that provides an easy on ramp for new technologies and users to use spectrum. Like a new driver is permitted to drive across the highway infrastructure, new systems can be certified to operate on spectrum highways. Just as new drivers must learn the laws, signs, and signals of driving and demonstrate their adherence to these in operation, new spectrum highway SDSs would do the same. Just as individuals are able to benefit from the use of a highway as a passenger where only the operator of the vehicle must have the license, SDS function can be divided between systems that obtain access (i.e., the driver in this case) and those that actually use the spectrum accessed (i.e., the passenger in this case).

Although the first instantiation of this approach to DSS will not be fast (mostly for regulatory reasons), once it is proven, it can be repeated in any band with minimal modification to the sharing technology. Once a highway is designed, policy may allow any SDS that follows the rules of the highway design to participate as their ability to participate is certified.

1. **Do you foresee any national security concerns/issues with DoD sharing with commercial 5G?**

We see no issues in using either SCMs or spectrum highways as means to share with 5G. Rather, we see this as an enhancement to national security. The development and use of these technologies will provide DoD an increased agility in their use of spectrum and the ability to maneuver in spectrum.

1. **Is industry aware of any statutory, legal, regulatory or policy hurdles that need to be altered or reconsidered to allow DSS? If so, what are those?**

The MBSM and spectrum highway methods of DSS are new and must be supported by regulation. Considering that this concerns spectrum that is currently allocated to the DoD, trying to create this approach to DSS gives the DoD the opportunity to create and prove a regulatory approach that breaks the persistent assignment mold that stands as a major impediment to achieving its EMS superiority strategy.

1. **What are other current and perceived barriers that industry is aware of to DSS?**

Any DSS approach demands that participants play by the sharing rules. Given the variety of devices that might be built, it is very feasible that ill-informed or unscrupulous operators may cheat and gain unauthorized access and cause harmful interference. An advantage of the spectrum highway system is the ability to complement the design of the system with an enforcement infrastructure that can rapidly identify and localize those cheaters.

1. **How would DSS work with existing commercial spectrum bands?**

The MBSM and spectrum highway technologies do not create SDSs that are able to inject themselves into existing operations of commercial bands.

The MBSM approach to DSS could easily complement any existing commercial band with the assumption that the current users are willing to convey the spectrum that is available for sharing. Since SCMs can capture the role of behaviors in enabling compatibility, MBSM can be used to manage SDSs that are able to inject themselves, again assuming the incumbents are willing.

The spectrum highway approach to sharing is equally applicable to any band and could be applied to commercial bands. In this case, precedence would be first to the incumbent and then to the government systems that want to share the spectrum. The use it or lose it mechanism for access will allow secondary users access as soon as primary users are not using it and will cause the secondary users to relinquish the spectrum as soon as the primary user needs it. Incumbents should see little change in their access. Applying spectrum highways in commercial bands, however, will require upgrading the commercial systems and would be a long-term campaign.

1. **Could multiple DSS technical solutions coexist and under what conditions?**

A challenge in DSS is that multiple independent DSS SDSs would respond to the same observations and respond in a way that is destructive to each other. They all see the same whitespace and they move to it causing interference to the other. These type of DSS SDSs and methods are designed without consideration of congestion. They seek whitespace. What happens when congestion reduces and eliminates the availability of whitespace? In these traditional DSS approaches the contention for access results in congestion collapse, the tragedy of the commons, where there is a traffic jam and no system can gain access.

The spectrum highway design is the exception. It was conceived to deal with this problem. The signaling mechanism is highly effective in congestion resolving contention among hundreds of devices with greater than 99% probability of resolving to one. It orchestrates spatial reuse of spectrum. It is specifically designed to support DSS among many independent SDSs that can have very different missions and functions. There is a single DSS technology for access but there can be any number of technologies in the actual use of the spectrum. The only limitation is that the design of the highway must account for the anticipated users in terms of the sizing of the lanes, the timing of transmission opportunities, the levels of precedence allowed, and the range of the transmissions.

1. **How can spectrum modernization, including spectrum Information Technology (IT) modernization and automation, help facilitate faster spectrum sharing?**

MBSM and spectrum highways provide two complementary pieces to fully automate DSS.

SCMs are often referred to as a loose coupler. They are a common and machine readable method that allows spectrum management systems to convey their understanding of spectrum use to each other, for these spectrum management system to convey policy to SDSs that govern their operation in spectrum, for SDSs to convey to spectrum management systems their use of spectrum, and for SDSs to use in collaboration with each other to find mutually agreeable operating conditions.

Spectrum highways offers an even more exciting opportunity for autonomy. Many spectrally orthogonal highways can coexist in the same space and time. SDSs can autonomously maneuver across these spectrum highways choosing the highway and their lane of operation. These sorts of choices can be informed by AI-based technologies both local at the SDS specifically in the choice of lanes and as services like the way Waze provides information for optimal navigation on vehicular highways.

1. **Are there standards, including data standards, which could accelerate spectrum repurposing decisions?  If so, what are they?**

The IEEE 1900.5.2 Standard for Modeling Spectrum Consumption is already available and the updated 1900.5.2a version is anticipated in CY 21. The latter is being updated the orignial to specifically address issues of building EMBM.

The spectrum highway technology is new and is being considered by the workgroup for future standardization.

1. **Previously, when federal spectrum has been reallocated, federal operations have been required to share or relocate to other bands and commercial licensees have received exclusive licenses via auction.  The following questions relate to the above statement:**
	1. **Should DoD consider spectrum leasing as an alternative to reallocation? If so, how could it be implemented?**
	2. **What, if any, legal, policy, statutory and regulatory changes would be required to implement the proposed leasing approach?**
	3. **How could revenue be shared with DoD under a DSS leasing agreement or any type of leasing agreement?**

The IEEE 1900.5 WG does not take a position on this question. However, we do call out that with spectrum highways, it is not the spectrum itself but precedence that is the object of value. Its discreteness makes it manageable as both an auctioned or leased object. More interestingly, it has potential to be exchanged and tracked through blockchain allowing distributed, dynamic, and local markets.

**Conclusion**

The context of the DoD’s RFI seems to seek ways to address the drive to make the U.S. competitive in the 5G race that simultaneously benefits the DoD and enhances their ability to do their missions. This response has tried to demonstrate that going a little further and using the transfer of spectrum to build a completely different and automated approach to spectrum management will not only support this objective but also create the foundational technologies that will allow the DoD achieve some of the hardest goals sought in the EMS Superiority Strategy. MBSM and spectrum highways provide the ability to maneuver autonomously and collaboratively in spectrum. This maneuver can be as flexible and dynamic as warfighters choose to allow.

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