Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan: Responses

Pursuant to the Presidential Memorandum on Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy, November 13, 2023, the Secretary of Commerce, acting through the National Telecommunications and Information Administration (NTIA), released a National Spectrum Strategy (Strategy), November 13, 2023. The word "spectrum" in this context refers to the radio frequency portion of the electromagnetic spectrum. Strategic Objective 3.2 of the Strategy directs the U.S. Government, through the White House Office of Science and Technology Policy (OSTP) and in coordination with the Federal agencies, to develop a National Spectrum Research and Development Plan (R&D Plan). On behalf of OSTP, NITRD NCO sought public input for the creation of the R&D Plan. The R&D Plan will act as an organizing national document, providing guidance for government investments in spectrum-related research and offering valuable insights. The R&D Plan will identify key innovation areas for spectrum research and development and will include a process to refine and enhance these areas on an ongoing basis.

This document contains the 31 responses received from interested parties.

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Request for Information on the National Spectrum Research and Development Plan

ACT | The App Association

March 21, 2024

Submitted via SpectrumRnDplanRFI@nitrd.gov

NITRD National Coordination Office
National Science Foundation
2415 Eisenhower Avenue
Alexandria, Virginia 22314

RE: Comments of ACT | The App Association to the National Science Foundation's Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO), *Notice Request for Information on the National Spectrum Research and Development Plan* (89 FR 12871)

ACT | The App Association appreciates the opportunity to provide comments to the National Science Foundation's (NSF) Networking and Information Technology Research and Development National Coordination Office in response to its request for information on the National Spectrum Research and Development Plan.[1] The Plan is a critical vehicle to addressing the needs of spectrum-reliant services and missions, including fixed and mobile wireless broadband service, next-generation satellite communications, and more.

The App Association is a global trade association for small and medium-sized technology companies. Our members are entrepreneurs, innovators, and independent developers within the global app ecosystem that engage with verticals across every industry, powering an ecosystem the App Association represents approximately $1.8 trillion and is responsible for 6.1 million American jobs, while serving as a key driver of the $8 trillion internet of things (IoT) revolution.[2]

The App Association supports coordinated federal spectrum policy changes to enable next generation innovations in America. App Association economic analysis shows that deployment of 5G wireless networks will create 8.5 million jobs in the United States over the coming years, enabling improvements in economic productivity, employment, and consumer value.[3] 5G will affect the labor market through direct and indirect means;

[1] 89 FR 12871.

[2] ACT | The App Association, State of the App Economy (2022), https://actonline.org/wp-content/uploads/APP-Economy-Report-FINAL.pdf.

[3] James Prieger, "An Economic Analysis of 5G Wireless Deployment: Impact on U.S. and Local Economies" (Feb. 2020), *available at*

while the additional labor required to build out the network to deploy 5G will certainly create the most immediate demand for new jobs, the broadest impact on the labor market comes from new employment opportunities through the way access to 5G will enable new applications, services, ways of doing business, and general growth of businesses. Workers enabled by this will earn more than $560 billion during that time, create $1.7 trillion in additional output, and add over $900 billion to U.S. gross domestic product (GDP).[4]

The App Association continues to support coordinated federal efforts to bring broadband to Americans by finding new and innovative ways to open more spectrum for both licensed and unlicensed uses, as well as supporting infrastructure deployment. The small business tech developer community we represent is committed to advancing an equitable digital ecosystem that provides the opportunities for entrepreneurship for, and enhanced access to, America's underserved communities. The App Association therefore supports NSF's efforts to develop a develop a National Spectrum Research and Development Plan that will improve spectrum access and advance American innovation, connectivity, and competition by creating high-paying and highly skilled jobs and producing improvements to the overall quality of life.

We urge NSF's National Spectrum Research and Development Plan to align with the following:

- **Focus on Spectrum Sharing with Government Bands, Prioritizing Mid-Band and Millimeter Wave:** The prospect of countless connected devices entering our communications networks through nodes in homes, workplaces, or other last-mile connectivity endpoints will dramatically increase data flows across communications networks. The Plan should prioritize identification of new opportunities for reallocation and/or new sharing arrangements across spectrum bands, including for government-owned spectrum bands that may be ideal for commercial IoT use, particularly mid-band and millimeter wave bands. The Plan should contribute to the spectrum pipeline through a modernized process for evaluation of the most efficient uses of spectrum bands in which federal users operate, as well as in supporting a procedure for repurposement that will free up new spectrum across low, mid, and high bands consistent with sound interference protection principles. Furthermore, the Plan should embrace new artificial intelligence software-driven solutions to dynamic spectrum sharing solutions.

- **Addressing Unserved and Underserved American Communities:** The App Association urges NSF to advance diverse spectrum access opportunities including widespread, intensive, and low-cost access to spectrum-based services

https://ecfsapi.fcc.gov/file/10417521421416/ACT%20Ex%20Parte%20Notice%20re%205G%20Economic%20Analysis%202020.pdf.

[4] *Id*.

that will expand availability and accessibility in unserved and underserved communities. Given the integral role of small tech firms in advancing equity and diversity in digital communication services and products, NSF's plan should prioritize helping consumers and entrepreneurs adversely affected by persistent poverty or inequality, to access, leverage, and benefit from the wide range of opportunities made possible by advanced connectivity capabilities. Many App Association members are located in, and support, underserved communities across the country. The future of the app economy will depend on the strength and density of next generation networks, which are supported by myriad spectrum bands and different types of infrastructure, including small cell deployment, that seamlessly work together.

- **Building on Open Standardization Innovations:** We urge NSF to ensure the Plan maximizes the benefits of competition in next generation wireless capabilities by welcoming new entrants. For example, the strategy should prioritize leveraging the efforts of the O-RAN Alliance, which has developed an architecture for building the virtualized radio access network (RAN) on open hardware and cloud with embedded AI-powered radio control.[5] O-RAN, and open standardization processes like it, which stand to revolutionize America's communications networks by enabling network virtualization capabilities and removing vulnerabilities in the networks.[6]

[5] https://www.o-ran.org/.

[6] See., e.g., https://www.fcc.gov/news-events/events/forum-5g-virtual-radio-access-networks.

The App Association appreciates the opportunity to provide its recommendations on the Plan and is committed to collaborating with NSF to expand broadband internet access and adoption in America, expand the use of spectrum by all users, and ensure that the internet remains an engine for continued innovation and economic growth.

Sincerely,

[redacted]

Brian Scarpelli
Senior Global Policy Counsel

ACT | The App Association
1401 K St NW (Ste 501)
Washington, DC 20005
[redacted]

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

AERPAW

Response to "Request for Information on the National Spectrum Research and Development Plan"

NSF AERPAW Platform
North Carolina State University, Raleigh, NC
Contact: aerpaw-contact@ncsu.edu

The AERPAW platform would like to thank the opportunity to respond to this request for information (RFI) on the National Spectrum Research and Development Plan[1]. Our views based on the issues raised in the RFI are as follows.

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering. This includes, but is not limited to, the following:

- **Methods/approaches to increase coordinated investment in R&D amongst government agencies, academia, civil society, and the private sector**
- **Structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D**

Presently, there are four outdoor NSF PAWR platforms in the U.S. (POWDER, COSMOS, AERPAW, and ARA) which all have extensive capabilities related to spectrum measurements in various environments. Measurement data from these platforms for various spectrum related scenarios are being made publicly available by these platforms and new experiment types can be defined to collect data in various other spectrum related scenarios of interest. These platforms also allow running dynamic spectrum sharing (DSS) experiments in different environments, e.g. including scenarios that involve one or more autonomous vehicles. Such experiments can be initially developed in virtual environments in these platforms, where various fundamental research ideas on spectrum sharing and related artificial intelligence and machine learning approaches can be evaluated. The experiments can then be moved to real-world outdoor testbeds in bands that are supported by FCC experimental licenses.

Developing and operationalizing such platforms takes extensive effort that spans many years. As such, these PAWR platforms (and other similar large-scale outdoor wireless

[1] This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

testbeds) are invaluable national assets, and they can be used widely by the research community for research and experimentation on spectrum technologies. The existing capabilities of PAWR platforms allow remote development of spectrum experiments by the national research community. By using these platforms, experimenters will save long years of development effort to achieve similar capabilities at other sites and will save funding resources to be invested on other related research efforts on DSS. There may be capability gaps in the existing PAWR platforms – a survey of capabilities and shortcomings of existing outdoor spectrum testbeds including PAWR platforms would help identify such gaps. Funding agencies may then consider funding projects (not necessarily to the original PIs operating those testbeds) to address those gaps, to help mature and sustain each outdoor platform for long-term utilization of those platforms.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas. Areas of interest include, but are not limited to, the following:

- **Spectrum utilization efficiency**
- **Spectrum resilience and assured access for critical mission applications and passive scientific observation**
- **Dynamic spectrum access and management**
- **Spectrum situational awareness at scale**
- **Automatic and rapid mitigation of interference problems**
- **Modeling for coexistence analysis**

Topics relevant to each of the above include, but are not limited to, the following:

- **Technical methods, designs, and processes**
- **Economic-, market-, social-, and human-centric concerns**
- **Business and economic models**
- **Protection of citizen privacy, sensitive government missions, and business proprietary data**
- **Cost-effective hardware supporting more dynamic spectrum usage**
- **Use of artificial intelligence and machine learning techniques**
- **Testbed development**
- **Assessment and certification of advanced systems**

Use of AI/ML techniques for improving spectrum utilization and testing these approaches in real world environments is very critical. While cognitive radio and dynamic spectrum access have been researched by now for over two decades, it is rare to find real-world deployments of these technologies. The main reason is that the practical propagation constraints, hardware impairments, protocol and waveform aspects, among other factors, are commonly overlooked. Hence, approaches that may work great in simulations end up being impractical when they are tested in the real world. Valuable funding, as well as precious research and development resources, may be lost due to unrealistic modeling assumptions[2] that prevent deploying research ideas in real-world environments. To this end, investing in realistic digital twins that integrate real-world hardware and software constraints for the initial development and testing of DSS concepts carries a critical importance. Once the AI/ML-based DSS concepts are developed/tested in such digital twins, they can then be tested in their physical twin for real-world performance evaluation.

In Fig. 1, we explain the overall workflow for canonical experiments in the NSF AERPAW platform, which can be used for any DSS and spectrum monitoring experiments using real-world, open-source radio and vehicle (e.g. UAV) control software. AERPAW hosts various sample experiments that can serve as starting points for developing spectrum-related experiments in the digital twin. Experimenters can develop their experiments exclusively in a virtual environment, without having to visit the AERPAW platform in person, and AERPAW operations team deploys the experiments after the development is finished in the digital twin.

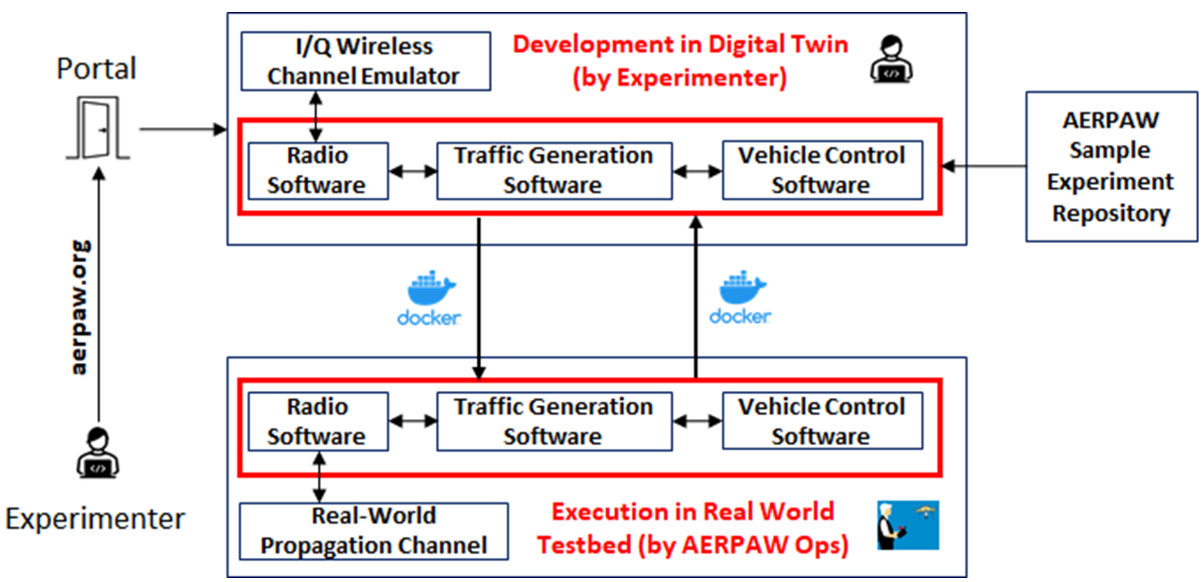

Figure 1: *AERPAW experiment workflow in development and testbed environments. Initially, an experimenter uses the digital twin to develop an experiment, then transfers the experiment to the outdoor testbed; the results are then returned to the digital twin.*

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts. Such problems have the following characteristics:

[2] "All models are wrong. Some models are useful." G. E. P. Box, British Statistician.

- **The goal can be concisely articulated to stakeholders outside the field**
- **Success or failure is clear**
- **Achieving success requires advancing the state-of-the-art in multiple areas**

As discussed above, in our view, the development and validation of high-fidelity digital twins for spectrum-sharing applications (forming a tightly coupled pair with their outdoor physical twins) is one of the key grand challenges. If this grand challenge can be addressed, such digital twins can serve as shared development environments available to the broader spectrum research community for validating their AI/ML approaches, and seamlessly moving them to real-world testbeds. The success criteria for such digital twins is that if the same software experiment is executed in the digital twin and the corresponding physical testbed, observed system performance (e.g., spectrum sharing performance that can be characterized in various different ways) should be very comparable. AERPAW's outdoor testbed (physical twin) with locations of five towers and the corresponding flying field are shown in Fig. 2 and Fig. 3, respectively. The corresponding digital twin includes virtualized versions of these environments, including vehicles, radios, towers, and propagation conditions.

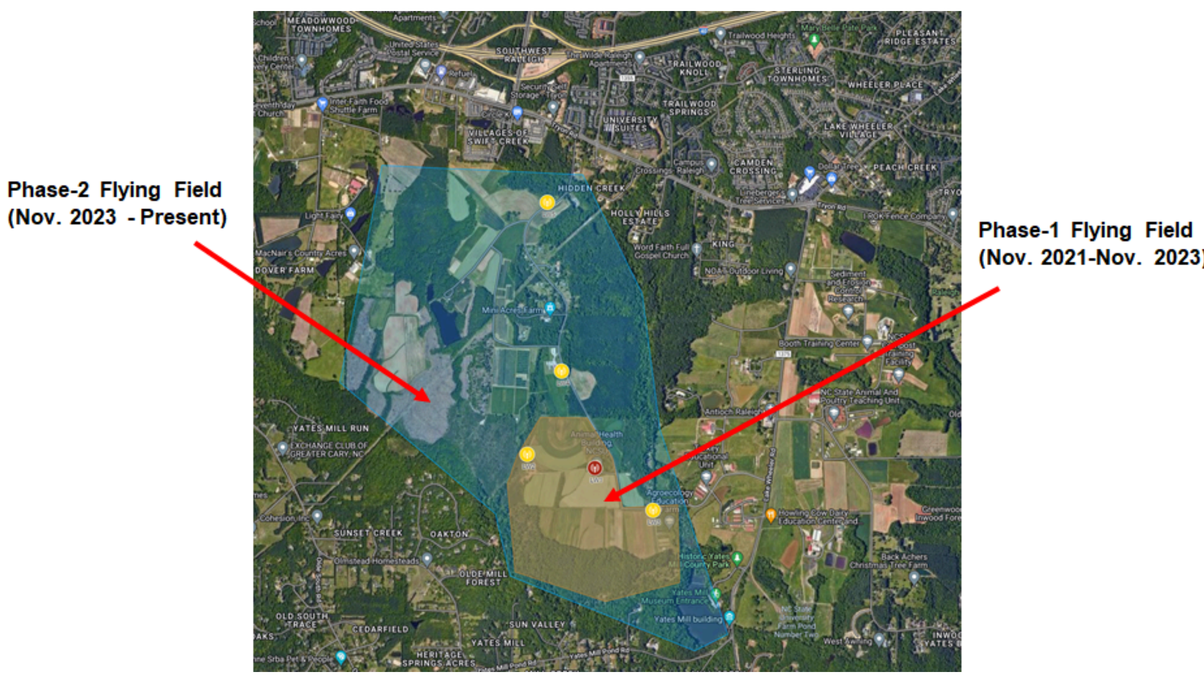

Figure 2: *AERPAW's UAV flying field in Lake Wheeler Field Farms, including Phase-2 extension of the flying field. The five radio towers provide radio coverage of the flying field using software defined radios. One of the towers is equipped with an Ericsson 4G/5G base station, while four of the towers include Keysight N6841A RF Sensors for real-time spectrum monitoring, signal classification, and signal source localization/tracking experiments.*

A major challenge to minimize the gap between the digital twin and the real-world testbed is to model the propagation conditions realistically in the digital twin, e.g. using ray tracing simulations. While the information about buildings can be downloaded and utilized from public websites such as OpenStreetMaps, and used in ray tracing simulations, other scatterers such as trees are not available in OpenStreetMaps and very difficult to model in a virtual environment. Such environments may require the use of Lidar scans to capture the information about all the scatterers, and scattered may vary across a year due to seasonal changes (e.g. due to presence/absence of leaves), changes in the environment (e.g. crops and farming equipment variations in the field), among other factors. To our knowledge, there are still major challenges in the effective integration of Lidar point clouds into ray tracing simulations for realistically modeling real-world environments in digital twins.

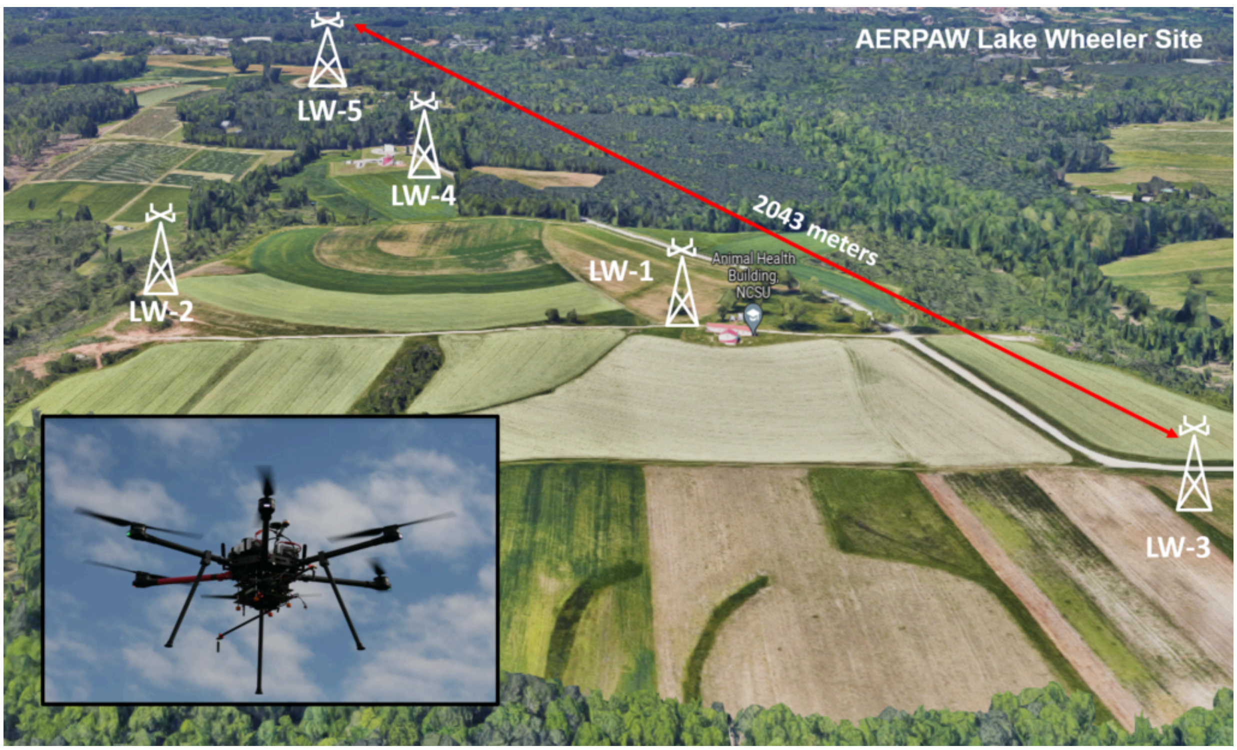

Figure 3: *AERPAW's UAV flying field in Lake Wheeler Field Farms and the five tower locations.*

4. Recommendations on spectrum R&D accelerators such as the following:

- **Shared public datasets**
- **Open-source software/projects**
- **Cost-effective flexible radio platforms**
- **Benchmarks and competitions**
- **Testbeds, research infrastructure, and collaboration support**

All these aspects are extremely important for minimizing duplication and enabling a shared development environment for the research community. As we have already commented earlier on the matter of open-source software projects, radio platforms, and testbeds, here, we will only comment on the critical need for public datasets, benchmarks, and competitions.

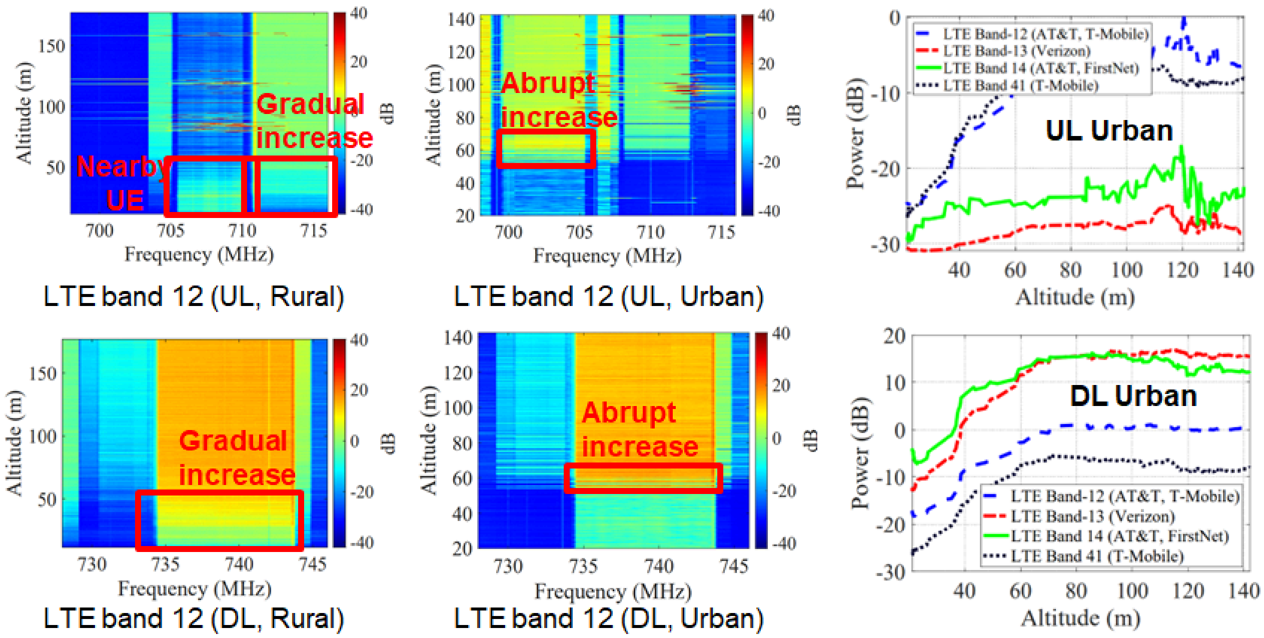

Figure 4: *Representative spectrum occupancy results versus altitude at LTE band 12 from one of the AERPAW datasets, considering both uplink (UL) and downlink (DL) in rural and urban environments. Similar datasets are available for all sub-6 GHz bands.*

Availability of public datasets in meaningful DSS environments is very important since they require a considerable expenditure of time and money (for equipment), as well as expertise not easily available. Making such datasets available, with detailed metadata and related post-processing scripts, will help the researchers with expertise in AI/ML techniques to test their DSS related ideas on real-world data rather than relying on over-simplified simulation tools. To give an example, spectrum measurements at a drone may rely on not only the 3D coordinates of the drone, but also the roll, yaw, and pitch of the drone (see Fig. 6), as well as the sensitivity of the spectrum sensor used at the drone. As such, knowing all this information in addition to the drone's 3D location can help develop not only more meaningful propagation and spectrum models but also more meaningful techniques for sharing the spectrum. There are already several publicly available spectrum data repositories, e.g. RF Data Factory as well as the datasets posted on the websites of individual PAWR platforms (see e.g. spectrum datasets by POWDER and AERPAW[3]). Identifying and addressing gaps in these datasets would be very beneficial for the research community. Fig. 4 shows example results based on the spectrum measurement datasets available on AERPAW's website.

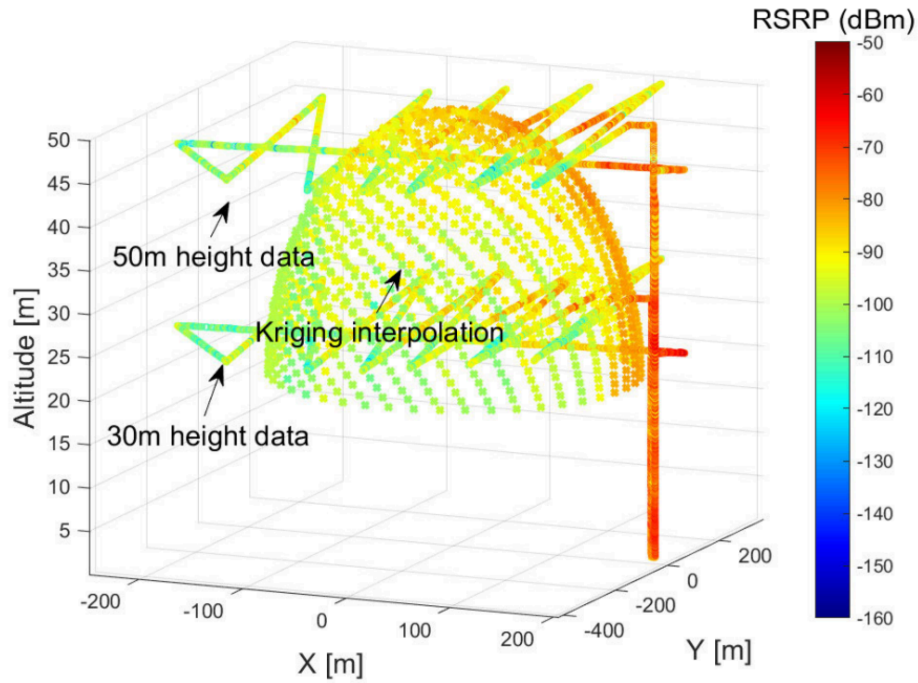

Figure 5: *3D spectrum mapping and interpolation using data collected at a UAV. Propagation data (or similarly, spectrum occupancy) at various UAV measurement locations can be interpolated across the 3D space, taking advantage of complex 3D correlation characteristics of such data, influenced by antenna factors, propagation conditions, and more[4]. It is worth to emphasize here that AERPAW platform (both the physical testbed and its digital twin) has unique ability to set in 3D space any configuration we want and hold it there for measurements: for example three transmitters on three drones at A,B,C and two receivers at D and E with certain antenna patterns on each of them.*

Competitions are also critical for coalescing the research community around a major problem. Competitions may be developed based on real-world datasets described earlier. Based on the data available on AERPAW's website, example dataset competitions that can be easily developed include: 1) 3D interpolation of spectrum occupancy or propagation measurements at UAVs using AI/ML techniques (see e.g. the results in Fig. 5 based on data collected from AERPAW environment); 2) localization of

[3] https://aerpaw.org/experiments/datasets/

[4] S. J. Maeng, O. Ozdemir, İ. Güvenç and M. L. Sichitiu, "Kriging-Based 3-D Spectrum Awareness for Radio Dynamic Zones Using Aerial Spectrum Sensors," in *IEEE Sensors Journal*, vol. 24, no. 6, pp. 9044-9058, Mar. 2024.

radio sources (e.g. jammers) based on measurements at a UAV; 3) classification of different types of UAVs and radio controllers based on radio recordings of the signals. Other competitions that may evaluate DSS techniques can also be developed but may require the data to be augmented with computer-generated data in space and time.

Wolfpack (NC State University) | **Deadalic Wings (NC State University)** | **SunLab (University of Georgia)** | **Eagles (University of North Texas)** | **NYU Wireless (NYU)**

Figure 6: *Representative UAV trajectories from five AERPAW AFAR challenge teams, based experiments that are exclusively developed at AERPAW's digital twin. These trajectories are decided online by the UAV during the testbed execution based on signal strength measurements observed from the UGV.*

In addition to competitions that may rely solely on datasets, competitions that involve the development and testing of DSS software in digital twin and testbed environments can also be developed. This may e.g. include the development of AI/ML techniques for DSS with autonomous vehicles. A recent related competition organized by the NSF AERPAW platform is the AERPAW Find-a-Rover (AFAR) challenge[5]. In this competition, the goal for the competitors was to develop their AI/ML software for localizing an unmanned ground vehicle (UGV) in the development environment, where the trajectory of the UAV could be controlled dynamically based on signal observations from the UGV. Five different representative trajectories, each from a different team, are illustrated in Fig. 6, which show how the UAV can take different trajectory strategies for localizing the UGV based on the AI logic developed by the experimenters in the digital twin. After the experiment was developed and tested in the digital twin, it was subsequently deployed in the real-world testbed (the software containers are moved seamlessly, without changes, to the physical twin testbed).

Due to the difference between propagation environments in the digital and physical twins, the localization accuracy in the digital twin was more favorable in the AFAR competition when compared to that observed in the real-world testbed. Representative real-world measurements at UAV from one of the teams are shown in Fig. 7 for two different locations of the UGV, which show that the signal strength does not only depend on the location of the UAV, but also the relative orientation and tilt of the UAV among other factors, which should be characterized in a digital twin implementation. Careful

[5] https://aerpaw.org/aerpaw-afar-challenge/

observation of the results shows that the signal strength at the diagonal trajectory of the UAV is lower compared to the signal strength at the spiral trajectory for the first location of the UGV, while this behavior is reversed when the UGV location is relatively at a different direction as shown in the second figure. Such effects can be thoroughly characterized and calibrated.

As we commented earlier, closing gaps between the real world and digital environment, including (but not limited to) the effects similar to that described above, can be a grand challenge for the research community. This will not only provide more realistic performance observations in the digital twin, but it will also allow training of AI/ML algorithms in the digital twin based on realistic data before they get deployed in the real-world scenario.

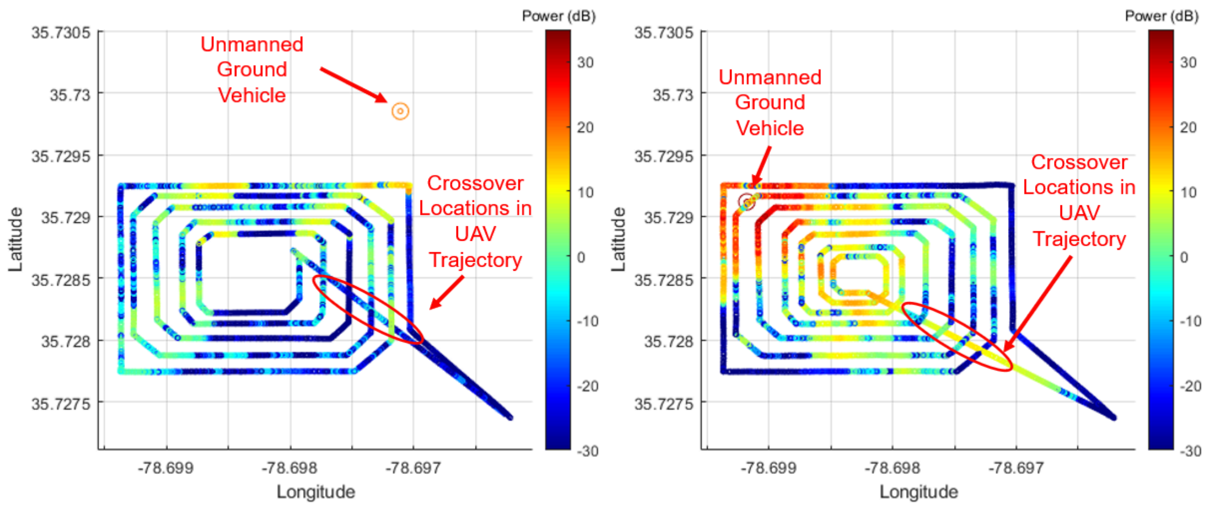

Figure 7: *Signal strength from two different unmanned ground vehicle (UGV) locations observed at a UAV's trajectory. The signal strength at cross-over locations are seen to be substantially different based on the direction, tilt, and relative position/orientation of the UAV with respect to the UGV.*

Similar to AFAR challenge experiment, various different DSS competitions can be developed in a digital twin, where experimenters can develop their DSS ideas first in the virtualized environment using real-world, open-source radio and autonomous vehicle software, and these experiments can then be seamlessly moved and tested in outdoor testbeds that are the physical twins of the development environment. Doing such competitions in a real testbed will ensure that none of the subtle details of communication protocols, waveforms, propagation conditions, vehicle trajectory control software, among other factors, are ignored, as may often happen in computer simulations or theoretical analysis.

5. Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

The federal government can: 1) invest in competitions in real-world testbed platforms to bring novel ideas from concept to reality; 2) invest in spectrum datasets, to identify what datasets are available and what are the gaps, and support efforts on generating specific datasets with rigorously documented metadata for enabling fundamental research by the broader community; 3) invest in developing high-fidelity digital twins that are specifically tailored to support AI/ML based spectrum sharing research and experimentation in diverse virtual and physical environments; 4) invest in research and development efforts that test DSS techniques in high-fidelity digital twins and their physical-twin testbeds.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

AERPAW team believes that seeking periodic (e.g., annual) feedback from the spectrum research community, similar to the process followed through this RFI, can help refine and enhance the R&D plan on an ongoing basis.

7. Terminology and definitions relevant for spectrum R&D.

- **One term of interest is "Dynamic Spectrum Sharing" which is a focus of the National Spectrum Strategy but was not defined.**

The concept of a "digital twin" should be defined rigorously for the DSS context, maybe including many of its variations. For the purpose of this document, we consider a digital twin to be a "development environment" where real-world software is programmed, e.g. radio software and drone software, in software containers. Many such software containers interact with each other by communicating through an I/Q channel emulator, in a fully virtualized environment. Such software can then be seamlessly moved to a testbed environment by moving the containers from the virtual environments to the computers at fixed towers and/or drones. There are other contexts where the term "digital twin" is used, e.g., not for development purposes, but in a real-time manner with an ongoing experiment, where each user equipment and base station may be connected to a digital twin to evaluate/predict network conditions and adapt their parameter configurations based on the conditions in the digital twin. There may be a need to define various aspects of "dynamic spectrum sharing" as it applies to experiment development in such a digital twin environment as well, such that the spectrum occupancy patterns resemble those in real-world environments.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Andreas F. Molisch

Response to "Request for Information on the National Spectrum Research and Development Plan"

Andreas F. Molisch
University of Southern California
Chair IEEE P1944 Standardization Group

Abstract: The one-line summary of this comment is: *efficient spectrum usage needs more research on wireless propagation channels*. This will serve to provide flexible and generalizable insights into spectrum planning, and allow to incorporate both currently existing, as well as future (and maybe not even yet conceived) systems into the spectral planning.

1. Two ways of modeling interference

There are fundamentally two ways of measuring and modeling interference. The first one is what one could call the "direct" method: the engineers measure or simulate the amount of interference power arriving at a victim receiver, and how this interference impacts the reception quality (e.g., bit error probability) at the receiver. Models for the number and location of both transmitters and receivers, the transmit power spectral density and direction, and the interference rejection capability of the receivers, are usually an inherent part of this approach. A number of simulations establish a cumulative distribution function of the interference level and/or reception quality, from which further conclusions can be drawn. Importantly, a change in the considered system requires a completely new simulation.

An alternative is what I will call the "composite" approach. In this method, we first establish a *double-directional* channel model, i.e., it describes (for a given transmitter and receiver location), the power, angle of departure, and angle of arrival of each multipath component (MPC). Such double-directional models can be deterministic (as obtained from ray tracing), stochastic, or mixed geometric-stochastic. In any case, these models and the channel descriptions that they entail, are independent of the particular system operating over the channel. This allows to use them in a flexible manner, because they can be combined with arbitrary systems – it does not matter whether the transmitter has directional or omnidirectional antennas, whether the receiver filter and transmitter filter are identical or have only a narrow overlap, etc. , as well as independent of the transmitter and receiver spatial density and distribution. They furthermore allow to easily determine which system parameters need to change to avoid excessive interference – for example, in the recent discussion about interference from cellular links to airplane altimeters, they could have easily shown (without further experimentation) how the altimeter receive filters need to be changed (or how the transmit beams at the cellular base stations need to be shaped). They also allow to test various methods for reducing interference under fair and reproducible circumstances – while the transmitted spectrum and directions might change, the channels remain the same; this is also what happens in nature.

While the composite simulation method is clearly superior in its flexibility and accuracy, the direct method is still more widely used. This is partly due to historic reasons, but also partly because for a number of situations, suitable channel models are still missing. This latter statement sounds surprising, and will therefore be elaborated in the next section.

2. Gaps in existing channel models.

Propagation channels have been measured and modeled for some 100 years, and the statement seems surprising that there are significant gaps that need to be filled. This is caused by the fact that channel models differ with the configurations (frequency range, the environment, as well with the spectral (bandwidth) and spatial (antennas/directions) degrees of freedom) for which the measurements are done. The past 15 years have seen the emergence of a number of systems with configurations that were previously overlooked, such as

* millimeter-wave and sub-THz communications systems. An important example is the potential interference of 24 GHz cellular systems to water-sensing satellites - a problem that essentially reduces to the question of the double-directional channel between base stations and satellites (or handsets and satellites). In particular, how much of the potential interference can be suppressed by suitable beamforming? The double-directional channel would give the answer.

* non-terrestrial networks: interference from ground stations to drones, from drones to ground stations, from both to satellites, and so on. With a few exceptions, double-directional characteristics are hardly known. Thus, while the properties of the desired signal for these links have been explored, those for the interfering channels are hardly known.

* upper midband: while several frequency ranges between 6 and 18 GHz are being assigned to cellular communications, double-directional models for these bands currently do not exist.

… and many more.

It must be stressed that in many situations where a model exists for the *desired* channel, the modeling of *interfering* channels is much less developed. One might ask: "the channel is the channel – it does not know whether it carries desired signal or interference". This is true, but there are numerous *aspects* of channels that are relevant only for interference, but which are not measured because no measurement unlimited range and accuracy. For example, the channels of a cellular signal at distances considerably larger than the cell radius are typically not carefully measured/modeled, because they are irrelevant for the coverage prediction, and are furthermore more difficult to measure because they are weak – yet they do play a major role for interference prediction.

3. The 3GPP models

It is often claimed that the 3GPP channel models are valid over 0.5-100 GHz, and cover a wide range of situations. However, these models are not suitable for interference assessment for a variety of reasons:

1. They are designed to allow a fair comparison of different *systems*, not to give an exact description/prediction of wireless propagation channels. They are based on a small number of measurements, in a set of narrow bands, in a limited number of environments.
2. They are mostly based on measurements in the 2-6 GHz frequency range (with a few sample measurements above and below), and the validity over a larger frequency range is simply postulated instead of being based on actual measurements.
3. They contain a number of simplifications that were done in the context of 3G systems in the early 2000s, and carried forward through the need of backward compatibility, not because they are actually valid.

I state these points as somebody who has contributed to the 3GPP model since its inception in 2002.....

4. **What is needed**

In light of all of this, there should be a concerted national effort to create better channel models, for a wide variety of situations, and in particular for those aspects that affect the propagation of potential interference signals. These efforts should encompass both deterministic prediction methods (ray tracing/launching) and measurements. Ray tracing/launching is well suited to creating large sets of data from which more reliable statistics could be extracted, while measurements are the "gold standard" of any scientific investigation, and are needed to calibrate and validate ray tracing.

Based on the input from the stakeholders about which scenarios are currently, and likely in the future, the ones where coexistence problems could most likely occur, an extensive program of channel measurements and modeling should be funded.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

ARA PAWR Rural Wireless Living Lab and Iowa State University Center for Wireless, Communities and Innovation (WiCI)

arawireless.org

Before the
NITRD National Coordination Office
National Science Foundation

In the Matter of)
)
National Spectrum R&D Plan)

Spectrum Research and Development for and by Rural America[1]

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Iowa State University
[redacted]

February 21, 2024

About ARA PAWR Rural Wireless Living Lab

The National Science Foundation Platforms for Advanced Wireless Research (NSF PAWR) program has been supporting the development and operation of the ARA rural wireless living lab to enable research, education, and innovation in agriculture- and rural-focused wireless technologies and applications. ARA is committed to the development and deployment of 5G-and-beyond technologies for rural America, and it is led by the Iowa State University (ISU) Center for Wireless, Communities and Innovation (WiCI). The mission of WiCI is to advance the frontiers of wireless systems and applications while addressing the broadband gap between rural and urban regions at the same time. To this end, WiCI has been collaborating with 65+ public-private partners from industry, academia, government, and communities to drive ARA-enabled wireless and applications technology development, deployment, and adoption, and it serves as a neutral entity in wireless research, education, and innovation. WiCI is a member of the O-RAN Alliance and Next G Alliance, and it has led the establishment of the ARA O-RAN Open Testing and Integration Center (ARA OTIC) to focus on Open RAN for rural America.

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ARA deploys advanced wireless, edge, and cloud equipment across the Iowa State University (ISU) campus, City of Ames (where ISU resides), and surrounding research and producer farms as well as rural communities in central Iowa, spanning hundreds of square miles of rural area [1]. Wireless platforms featured by ARA have demonstrated promising performance so far, for instance, up to 3Gbps wireless access throughput, up to 10km (about 6.21 mi) effective cell radius, and close to 10Gbps throughput across a wireless backhaul link of over 10km.

Spectrum innovation is a core focus area of ARA and WiCI, and WiCI is a member of the National Spectrum Consortium. Building upon ARA, WiCI is leading the ARA National Radio Dynamic Zone (ARA-NRDZ) project to focus on spectrum sharing and innovation for rural America.

More information about ARA and WiCI can be found at arawireless.org and wici.iastate.edu respectively, and inquires can be emailed to e2@arawireless.org.

Input on National Spectrum Research and Development Plan: Perspectives from Rural America

World-leading spectrum R&D is an integral element of the National Spectrum Strategy, and it is critical to the science, engineering, and technology foundation needed to modernize the U.S. spectrum policy and to make the most efficient use of this national spectrum resource. As we develop the national spectrum R&D plan, it is important to pay attention to the unique needs of diverse communities and sectors. In particular, ***rural America presents unique needs for spectrum policy and technology innovation, and it provides unique use cases to advance the state of the art in spectrum policy and practice.*** For instance, community- and non-profit-led rural wireless is expected to serve as a key enabler for rural broadband, if affordable spectrum access can be enabled for rural communities/ non-profits [1]. In addition, agriculture farms and rural America in general can serve as important test grounds for wireless spectrum innovation to support safe-critical wireless applications such as the use of Unmanned Aircraft Systems (UAS) in precision agriculture and telehealth [1].

Therefore, it is critical that the National Spectrum R&D Plan keeps in mind the unique needs and opportunities provided by rural America, with a special focus on spectrum needs, use cases, policy and technology innovation, as well as rural ecosystem engagement and workforce development.

1. Strategy for Spectrum R&D. Given that dynamic spectrum sharing and using advanced wireless as a key rural broadband solution are new fields of innovation and practice, rural-focused technology and policy innovation is critical, which in turn calls for *the* engagement of rural telecom ecosystem and rural-focused workforce development and innovation capacity building. There are over 800 rural telcos across U.S., and over 130 rural telcos in Iowa alone.

Deeply embedded into the rural communities and industries (e.g., agriculture) around them, these rural telcos have first-hand insight into the unique spectrum needs and use cases in rural America. Therefore, it is important to engage these rural telcos and related stakeholder communities in the nation spectrum R&D process in terms of problem formulation, application pilot, technology adoption.

Given that existing rural telcos are not as familiar with emerging spectrum access paradigms and have limited resources for deep engagement with progresses in spectrum R&D, it is important for the National Spectrum R&D Plan to pay attention to the need for workforce development, align spectrum R&D with community and capacity building, and engage rural stakeholders including research and education organizations (e.g., WiCI) and their partners. Specific action areas include 1) developing innovation capacity within the rural regions so that rural-focused spectrum and wireless innovations progress in parallel with urban-focused innovations, and 2) engaging and empowering rural-regions in spectrum and wireless innovations such as those related to dynamic spectrum sharing, Open RAN, and rural-focused massive MIMO.

2. Priority Areas of Spectrum R&D. Given the relatively sparse population/user-equipment density and the relatively large geographic space in rural America, spectrum R&D in lower frequency bands and the frequency bands suitable for non-terrestrial wireless networks (e.g., LEO satellite communications) will be critical to wireless connectivity in rural America. In particular, the lower 3 GHz band (3.1 - 3.45 GHz) as well as the bands of 7.125 - 8.4 GHz, 12.2 - 13.25 GHz, and 18.1 - 18.6 GHz as mentioned in the National Spectrum Strategy will be invaluable for rural America, and how to effectively use them for rural-focused massive MIMO as well as integrated terrestrial and non-terrestrial wireless systems will be important R&D directions.

In addition, Unmanned Aircraft Systems (UAS) are expected to be applied in diverse rural applications such as precision agriculture, infrastructure monitoring, and telemedicine, and the open space in rural America (e.g., agriculture farms) facilitates the development, testing, and early adoption of UAS in real-world settings [1]. Therefore, the spectrum and applications R&D in UAS CNPC band of 5.03 – 5.091 GHz is of particular interest to rural America too, both as users and as participants in research and innovation.

Given the expected adoption of Open RAN in rural America, the National Spectrum R&D shall also align with our country's R&D plan in Open RAN. Open RAN represents one major development in 5G-and-beyond systems, and it is poised to promote wireless network security while driving innovation, lowering costs, increasing vendor diversity and supply chain robustness, and enabling more flexible network architectures. Open RAN is of particular interest to rural America, not only because it can potentially reduce cost, but also because it reduces barrier to innovation and can enable rural-focused wireless technology development and deployment, including those on spectrum innovation. Leading Open RAN architectures such as O-RAN also have built-in mechanisms for supporting spectrum innovation, and spectrum R&D shall leverage such synergies.

3. Grand Challenges for Spectrum R&D. Unlike large commercial carriers in urban regions, many rural communities and non-profits (e.g., farmer cooperatives) are expected to operate rural wireless systems. One reason why most rural community carriers have not adopted fixed wireless (and wireless in general) for rural broadband is due to the lack of access to spectrum. To facilitate the adoption of rural wireless broadband solutions, we need to remove the barrier of spectrum access by rural communities and non-profits. To this end, we need to develop new spectrum policies and technologies that are conducive to community- and non-profit wireless network operations [1], as well as spectrum sharing between wireless carriers (e.g., between national and local community carriers) and between wireless communications and non-communications (e.g., radar) users.

Besides typical wireless use cases that need connectivity most of the time, rural America features unique use cases that only need spectrum access and connectivity on-demand and likely in confined geographic areas. For instance, spectrum use in crop farms tends to be seasonal, and it mainly needs spectrum access from spring to fall. In addition, even in the seasons when crop farms need spectrum access, it may only need access when certain ground and aerial vehicles need to operate in the field, thus posing on-demand, mobile spectrum access at confined geographic space where the agriculture vehicles operate. Therefore, these spectrum use cases in crop farms pose unique requirements for real-time, on-demand, and mobile spectrum slicing not feasible today, and they call for both technology and policy innovations in spectrum access. In addition, many rural wireless use cases such as UAS for precision agriculture are safety-critical, thus calling for innovations in dynamic spectrum sharing for safety-critical wireless systems.

4. Spectrum R&D Accelerators. Given that we are still at the early stage of research and practice in dynamic spectrum sharing and that a wide range of policy and technology innovations need to be nurtured and field-tested before their adoption in practice, the National Spectrum R&D shall leverage rural-focused, real-world testbeds such as the ARA PAWR wireless living lab*.* ARA PAWR provides an at-scale, real-world environment for testing both novel spectrum policies and technologies [2-4] with diverse stakeholder communities ranging from researchers to application developers, agriculture and rural users, as well as local and state government agencies, and it can serve as a platform for bringing together diverse stakeholder communities in collaborative R&D efforts towards shared spectrum data, models, and open-source software systems.

To support collaborative efforts across rural-focused spectrum and Open RAN R&D, the the ARA O-RAN Open Testing and Integration Center (ARA OTIC) can be leveraged to support integrative research, testing, and integration activities for innovative spectrum management strategies in the Open RAN framework.

References

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[3] G. Zu *et al.*, "AraHaul: Multi-Modal Wireless X-Haul Living Lab for Long-Distance, High-Capacity Communications," in *IEEE Future Networks World Forum (FNWF)*, 2023.

[4] T. Zhang *et al.*, "Exploring Wireless Channels in Rural Areas: A Comprehensive Measurement Study," in *IEEE Future Networks World Forum (FNWF)*, 2023.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

AT&T

Before the
NATIONAL SCIENCE FOUNDATION
Alexandria, VA 22134

In the Matter of	)	
	)	Docket No. 2024-03400
Request for Information on the National	)	
Spectrum Research and Development Plan	)	

COMMENTS OF AT&T, INC. ON THE NATIONAL SPECTRUM RESEARCH AND DEVELOPMENT PLAN

INTRODUCTION

AT&T appreciates the opportunity to provide input to the development of the National Spectrum Research and Development Plan (R&D Plan) in support of the National Spectrum Strategy (NSS) and its implementation. Given the many technical challenges facing the nation in optimizing its spectrum allocations and use to meet a wide range of needs, R&D will play a vital role in achieving the strategic objectives articulated in the NSS. R&D is also crucial to advancing the United States' leadership in spectrum dependent technologies across multiple domains—including in the global competition for leadership in deploying 5G and Next G networks.

In what follows, AT&T provides responses to topics 1, 2, and 7 of those posed in the Request for Information issued by the Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO) within the National Science Foundation (NSF), on behalf of the White House's Office of Science and Technology Policy.[1] We hope the NITRD Wireless Spectrum Research and Development Interagency Working Group (WSRD IWG) finds this information helpful toward its development of the R&D Plan and we look forward to continued collaboration with the NSF, other agencies, and other stakeholders in support of both the R&D Plan and NSS.

[1] Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO), National Science Foundation, "Request for Information on the National Spectrum Research and Development Plan," 89 FR 12871, February 20, 2024. https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan.

I. Topic 1: Strategies for Spectrum Research

The RFI seeks recommendations on spectrum research strategies that minimize duplication, provide sufficient research coverage of needed issues, and advance the state of spectrum science and engineering.[2] Several ways to achieve these ends are offered below.

Coordinated R&D Investment. The R&D Plan should encourage and provide guidance on mechanisms to facilitate joint research efforts and information sharing across the R&D communities resident in academia, government, and the private sector. Two existing mechanisms that could be leveraged more extensively include:

1. **Enhanced and Expanded use of Cooperative Research and Development Agreements (CRADAs) and Other Transaction Authority (OTA).**
   CRADAs are instruments frequently used to facilitate joint research work between federal and non-federal parties.[3] OTAs are another instrument authorized for the Department of Defense (DoD) to engage non-federal parties for research, prototype, or production work outside of the standard defense acquisitions requirements.[4] Both instruments already play important roles in spectrum R&D.[5] The R&D Plan should enhance this by coordinating, consolidating, and clarifying the use of both CRADAs and Research OTAs in support of the National Spectrum Strategy. For example, the R&D Plan could provide a playbook for the relevant agencies to use to align the right instruments to the right spectrum research projects and partners—both linked to specific NSS Implementation Plan activities and more generally—and streamline the process for the federal and non-federal parties.

2. **Expanded funding opportunities for private sector researchers.**
   For better or worse, in the modern, highly competitive telecommunications industry, industry's privately funded R&D efforts will be oriented on topics and issues expected to have a sufficient financial return on investment. Much of the research of greatest importance

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[2] RFI Topic 1. https://www.federalregister.gov/d/2024-03400/p-15.

[3] 15 USC §3710a.

[4] 10 USC §4021-4022.

[5] For example, the DoD and the National Spectrum Consortium have established a structure and process around OTA for connecting a broad range of private sector companies engaged in spectrum research and engineering to DoD solicitations. However, the primary orientation of the NSC's activities and DoD's solicitations through it have, naturally, been on serving DoD's requirements rather than the broader national spectrum objectives delineated in the National Spectrum Strategy.

to the National Spectrum Strategy lacks a clear business case for the private sector to fund with shareholders' money but falls in research areas where the private sector has the greatest relevant practical knowledge and expertise. This leads to potential misalignments in R&D activity, funding, and execution that could be redressed by providing increased access to federal funding for private corporations to engage in research aligned to the National Spectrum Strategy. And, while some federally funded research proposals are open to for-profit corporations, most crucial programs are not. For example, for-profit corporations are eligible for NSF's recent "Ideas Lab: Breaking the Low Latency Barrier for Verticals in Next-G Wireless Networks" (NSF 24-545) solicitation but they are *not* eligible for NSF's "Next Era of Wireless and Spectrum" (NSF 24-549) solicitation.[6] Of note, solicitation 24-549 is explicitly linked to the National Spectrum Strategy and encompasses research into topics in which private, licensed-spectrum holders are key stakeholders—though there is not necessarily a compelling business case to warrant significant private investment into the kinds of research called for by this solicitation. Conversely, solicitation 24-545—which, again, *is open* to for-profit corporations—falls in a research area in which a clearer potential business case can be made, and it is more plausible that private sector research would be (or is being) pursued for commercial purposes. The R&D Plan should rationalize the determination of eligibility for federally funded research projects of for-profit corporations to assure better coordination of public and private spectrum research.

Structural and Process Improvements. Information sharing across research communities is core to both advancing R&D and ensuring sufficient and non-duplicative research efforts. Given the significance of the role of the DoD as both the dominant federal spectrum user and conducting and in funding significant R&D work, the R&D Plan should lay out means by which an expanded set of private sector and academic researchers can access spectrum-relevant research findings and reports controlled by DoD, while still appropriately protecting Controlled Unclassified Information, Controlled Technical Information, and other categorizations of unclassified research. This would help improve national R&D coordination and reduce duplicative research by bridging the information asymmetry that often exists between the

[6] NSF 24-545: https://new.nsf.gov/funding/opportunities/ideas-lab-breaking-low-latency-barrier-verticals/nsf24-545/solicitation; NSF 24-549: https://new.nsf.gov/funding/opportunities/next-era-wireless-spectrum-newspectrum/nsf24-549/solicitation.

military spectrum research community and the academic and private sector spectrum research communities.

For example, the Defense Technical Information Center (DTIC) is a large repository of research conducted or funded by the DoD that is available to:

- "Authorized U.S. DoD/military employees
- "Authorized U.S. Government employees
- "Authorized U.S. Government Contractors and Subcontractors"[7]

While some limited portion of relevant spectrum related research and/or reports available in the DTIC repository may also be available to the public in the National Technical Information Service's (NTIS) National Technical Reports Library (NTRL) or other publicly available sources, certainly not all of it is. Per DoD policy, only reports categorized and marked as "Distribution Statement A. Approved for public release: distribution is unlimited" may be released to the public, as is the case for research reports in the NTRL. DoD documents, including DoD or DoD-contracted R&D with other distribution statements are increasingly restricted as to whom those documents can be released—even for unclassified information.[8] DoD policy for distribution of technical information states that "The DoD will pursue a coordinated and comprehensive program to promote *sharing technical information to the maximum extent possible to facilitate the efficient use of resources* in accordance with safeguarding requirements as specified in national and DoD information and operations security policies, procurement regulations, policies, and procedures…"[9] (*emphasis added*). While that policy is specifically applicable only to DoD, the objective of facilitating "efficient use of resources" is equally important in the context of the National Spectrum Strategy that has as one of its key objectives assuring sufficient federal and DoD access to spectrum domestically. Accordingly, the R&D Plan should identify ways to make unclassified DoD research available to a broader set of spectrum R&D entities and researchers while comporting with both DoD requirements and policy and the requirements of 42 USC Subchapter III, Part D.

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[7] Department of Defense, Defense Technical Information Center (DTIC), DTIC Registration Information, available at: https://discover.dtic.mil/dtic-registration-benefits/dtic-registration/.

[8] Department of Defense, DoD Instruction 5230.24, "Distribution Statement on DoD Technical Information," January 10, 2023. Distribution Statement A is only applicable to unclassified information; Distribution Statements B, C, D, E, and F can be applied to both unclassified and classified information. The discussion here only pertains to unclassified research.

[9] *Ibid*.

One simple and specific way to do so would be to provide a streamlined means for enabling appropriate entities and individuals—both academic and private sector—to access the DTIC repository. The R&D Plan could designate a Government Approving Official to facilitate authorizing the issuance of the External Certification Authority or Personal Identity Verification cards to appropriately validated and relevant spectrum researchers not otherwise affiliated with DoD, whether in academia or the private sector. For the purposes of the R&D Plan, this Government Approving Official could be the NSF Chief of Research Security, or an appropriate designee.[10] At the very least, the R&D Plan could direct that all spectrum-relevant research published in DTIC's repository that has a Distribution A categorization, and that is not already included in the NTRL, be posted there as well.

In the classified information domain, improved means of enabling private sector access to relevant classified research would help support the objectives of the R&D Plan and the National Spectrum Strategy. Classified research is obviously even more challenging to share while protecting national security than unclassified research. The DoD's Partnership for Advancing Trusted and Holistic Spectrum Sharing-Classified (PATHSS-C) subgroup, formed under the auspices of the National Spectrum Consortium to inform DoD's Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) study of the 3.1-3.45 GHz band took on this challenge and successfully demonstrated the viability of classified information sharing on spectrum topics with industry and academia outside of traditional mechanisms. To further the National Spectrum Strategy, this kind of classified information sharing, and particularly greater sharing of classified research work, needs to be sustained, routinized, and expanded. The R&D Plan should: (1) identify the kinds of classified research that are relevant to supporting the National Spectrum Strategy, (2) assess the relevant research communities that do not typically have access to these kinds of classified research, and (3) make recommendations on processes and forums for facilitating improved sharing of classified research across the relevant research community.

II. Topic 2: Recommended Priority Areas for Spectrum R&D

Spectrum utilization efficiency. Commercial spectrum licensees have very strong financial incentives to maximize the efficient use of the spectrum in which they have invested

[10] 42 USC §19032.

significant capital through both auctions *and* purchase and deployment of network equipment. Much of the research leading to 3GPP standards has focused on maximizing spectral efficiency within communications channels. These research trends will persist through the industry's continued evolution and advancement of the standards. However, for many federal spectrum users, 'spectrum utilization efficiency' is a more challenging notion to define or quantify. For example, many federal systems are necessarily designed to prize flexibility, agility, and mission effectiveness across large bandwidths over "efficiency." Research into ways to characterize risk-based frameworks associated with federal spectrum users' missions would be fruitful for helping assess federal spectrum utilization and identifying ways to productively increase overall spectrum utilization. For example, there is spectrum inefficiency when spectrum is reserved solely for federal use, but that use is merely episodic and then only sometimes for what could accurately be characterized as a truly critical mission, in terms of time-sensitivity and severity of consequence to the nation of interference leading to mission failure. The R&D Plan should incorporate this as a key research issue to explore.

Spectrum resilience and assured access for critical mission applications. This research area has the highest relevance to federal, and specifically military, systems and aligns well to the DoD's Electromagnetic Superiority Strategy's call for "revolutionary, leap-ahead technology and capabilities" for its electromagnetic systems that "should be flexible and access spectrum through frequency agility, frequency diversity, and wide tuning ranges."[11] It is reasonable to assume that DoD continues to pursue R&D into these capabilities, though likely that much of the most substantive research and findings will be controlled unclassified and classified. However, as part of the R&D Plan, DoD's research in this area should be coordinated through other federal agencies with parallel streams of research to determine how DoD's nascent spectral resilience and agility capabilities can be used to enhance coexistence with non-federal use of shared spectrum. Also, this issue is intimately related to the discussion above of federal users' spectrum utilization and the recommendation for research into risk-based frameworks and federal mission analysis.

For commercial licensed spectrum users, whose mobile networks represent important elements of the nation's critical infrastructure, the R&D Plan should support research efforts into

[11] Department of Defense, *Electromagnetic Superiority Strategy*, October 2020, p. 7.

resilience of spectrum dependent systems and networks from natural and manmade electromagnetic pulse (EMP) hazards. As has been repeatedly noted, there is a certain EMP risk posed by natural events (i.e., solar flares) and, in an era of increasing global instability and great power competition, there is a concomitant and renewed risk of manmade EMP attacks. Research areas here should include resilience, recovery, and restoration. This area is also particularly ripe for close coordination between the federal government and private industry in the conduct of research, development, testing, and deployment.

Automatic and rapid mitigation of interference problems. While much discussion of dynamic spectrum sharing has centered on controlling spectrum access to prevent any interference altogether,[12] another potentially more efficient solution set for some coexistence scenarios lies in rapid and automated mitigation of instances of interference. Margins of decibels, Hertz, geography, or time built-in to regimes for spectrum access management with the intent of preempting *any* interference necessarily leave more spectrum fallow and/or underutilized than necessary if and when two incompatible uses of spectrum can (1) tolerate some small degree of transitory interference and (2) have a method for mitigating or resolving it quickly. The R&D Plan should incorporate research into this area, such as identifying spectrum uses, federal and non-federal alike, that could tolerate transitory interference and supporting research into automated interference mitigations. For example, for mobile network coexistence with federal systems, this could include research into RAN-based sensing and response mechanisms and analysis of federal systems missions and interference resilience.

Modeling for coexistence analysis. AT&T's recent experiences with coexistence modeling efforts in the 3 GHz band, both as a 3.45-3.55 GHz licensee and as a participant in the PATHSS Task Group informing DoD's conduct of its EMBRSS study of the 3.1-3.45 GHz band, suggest that research into continued improvements in coexistence modeling is greatly needed. In developing spectrum sharing regimes, modeling often undergirds the baseline scoping of the coexistence challenge, e.g, determining the geographies where coexistence techniques are needed. Modeling also then informs decisions on the sharing mechanisms or coexistence techniques to apply. However, AT&T has found significant differences between its own internal network modeling, its measured, real-world network coverage and performance, and what

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[12] See response to Topic 7 below for further discussion.

several different government models of 3 GHz band 5G networks predict with regard to 5G interference into federal systems at given locations. While AT&T and other industry members are working directly with various U.S. government entities to reduce the significant over-prediction of interference in the government models, this is a valid and valuable area of research to establish a common understanding and set of norms for modeling that can better support the aims of the National Spectrum Strategy. Importantly, this R&D work needs to be informed by real-world and large-scale measurements; reliance solely on laboratory testing or small-scale field tests cannot provide sufficient insights on which to base spectrum policy decisions. Failure to accurately understand and scope the coexistence challenges leads government and industry to try to solve coexistence problems that may not be extant or as significant in the real-world as current models predict.

III. Topic 7: Terminology and Definitions Relevant for Spectrum R&D

Dynamic Spectrum Sharing (DSS). As this RFI notes, the term "Dynamic Spectrum Sharing" is indeed a focus of the National Spectrum Strategy but was not formally or explicitly defined. AT&T offered the following proposed definition in our response to the RFC on the National Spectrum Strategy Implementation Plan: "a sharing mechanism that allows for spectrum access to the same frequency band by two dissimilar spectrum users that varies in near-real time across one or more other dimensions of spectrum use: geography, frequency, time, or power[,]" with the additional explanation that "power" should be understood as "received power at a given location and time"[13] vice transmitted power. The Implementation Plan subsequently offered a description of DSS that begins to approximate a definition, stating: "dynamic spectrum sharing (DSS) involves the operation of independent systems close enough together (in frequency, space, or time) that dynamic access methods are required to prevent harmful interference."[14] While AT&T still recommends establishing an explicit definition of DSS for the National Spectrum Strategy and its implementation work streams (including the R&D Plan)—preferably one that closely tracks what AT&T has suggested—conduct of R&D into DSS should be characterized by:

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[13] AT&T, Inc., "Comments of AT&T, Inc. on the Implementation of the National Spectrum Strategy," NTIA Docket No. 230308-0068, January 2, 2024, p. 12.

[14] Implementation Plan, p. 19

- Examination of full-power licensed use;
- Development of a basis for predictable times and/or geographies in which dynamically shared spectrum can be used;
- Examination of a full range of interference mitigation techniques—not restricting R&D in mere 'on/off' spectrum *access* controls;
- Establishment of an objective timescale of dynamism that is non-arbitrary and relevant to the services/uses/missions sharing spectrum;
- Examination of varied architectures and/or loci of control for the sharing mechanisms: e.g., centralized, distributed, peer-to-peer, etc.;
- Seeking to define co-channel and adjacent channel interference environments to incorporate into network design and operation.

Already, research funded by NSF through the Spectrum Innovation Initiative-National Radio Dynamic Zones (SII-NRDZ) program touches on some of these areas.[15] The R&D Plan should ensure that R&D into DSS conducted under the auspices of the NSS and supported by the range of involved federal entities (e.g., DoD and NTIA) take a similarly broad conception of DSS rather than prematurely and narrowly focusing on simply evolving the current Spectrum Access System or Automated Frequency Coordination constructs.

CONCLUSIONS

Facilitating and coordinating spectrum research across government, academia, and multiple relevant private sector industries is a great challenge—one that is vitally important to meet the nation's current and future spectrum needs. The R&D Plan can aid this effort by:

- identifying and streamlining the effective use of mechanisms to enable cooperative research between industry and government in support of the NSS, such as CRADAs and OTAs;
- increasing the eligibility of for-profit corporations to relevant research funding opportunities in support of the NSS;
- improving the sharing of government research, particularly that conducted by DoD, with relevant private sector and academic researchers.

The R&D Plan can also help achieve the technical objectives of the NSS by orienting the research community on developing novel solutions to our spectrum challenges, including improved and commonly accepted coexistence modeling approaches, interference mitigation techniques beyond simple spectrum access or transmit power controls, and developing resilient

[15] See, e.g., https://www.nsf.gov/awardsearch/advancedSearchResult?ProgEleCode=151Y&BooleanElement=Any&BooleanRef=Any&ActiveAwards=true#results.

spectrum systems. Lastly, given the emphasis the NSS places on DSS, the R&D Plan should ensure that R&D efforts do not hone in too quickly on pre-determined approaches to DSS—leaving unexamined techniques and approaches that may prove more effective over the long-run, even if less readily available now. We look forward to continuing to work with NSF, the WSRD IWG, and the broader research community to drive advancement of the most effective use of the nation's spectrum through research and development.

Respectfully submitted,

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March 21, 2024

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Request for Information on the National Spectrum Research and Development Plan

Ben Wu and Kevin Gifford

Interference Tracking and Categorization for National Radio Dynamic Zones

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1. Motivation and Objectives

1.1 Motivation

Real-time spectrum sensing plays a key role for spectral resource allocation in national radio dynamic zones (NRDZ). The resource allocation problem can be summarized as enabling the usage of radio frequency spectrum for multiple systems at different (1) times, (2) frequencies, and (3) locations in space. Real-time spectrum sensing addresses the cognition of spectrum usage in time and frequency [1], [2]. In this proposed research, we will present a sensing system that accurately measures the location of an interference source (Fig. 1). With comprehensive cognition of time, frequency, and location, dynamic and efficient spectral allocation can be achieved in NRDZ*.

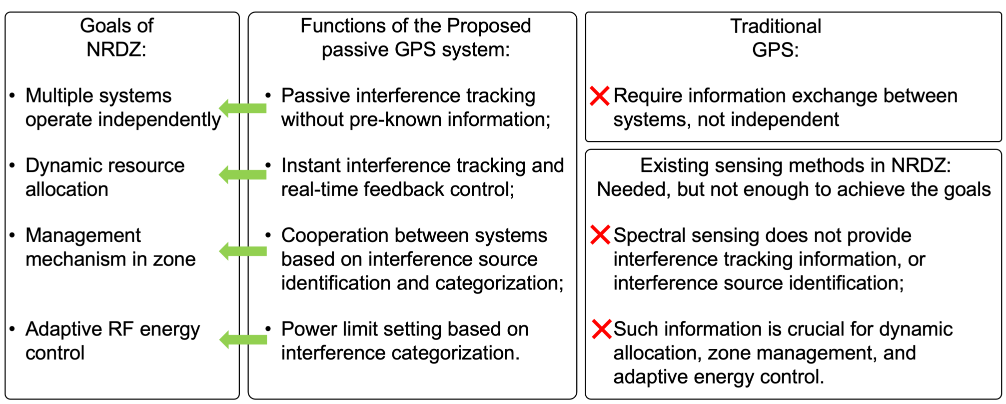

Fig. 1 Functions of the proposed system and how the functions meet the goals of NRDZ.

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This proposed research addresses "priority areas for spectrum research and development" in "Request for Information Notice", especially areas of "spectrum resilience", "dynamic spectrum access and management", and "spectrum situational awareness at scale".

The existing method for tracking interference sources is based on pre-known information shared or published by the spectrum users. For example, low earth orbit satellites generate interference to a radio telescope array, and the tracking information for low earth orbit satellites is shared to the radio telescope array. This does not meet the ultimate goal of independent operation in NRDZ. The goal of independent operation achieves ideal system robustness, so an NRDZ can manage any type of interference without pre-known information. In this proposed research, the sensors in NRDZ passively track the locations of the interference sources with neither pre-known information about the sources nor communication with the sources, which achieves complete independence.

1.2 Objective

The comprehensive information of time, frequency, and location of the interference source enable efficient use of all the possible resources of the radio frequency spectrum. The goal of this proposed research is to locate the interference source in sub-meter resolution and track the movement of the interference source. With accurate measurement of interference source locations, a receiver such as a radio telescope array can coordinate based on the location information. More importantly, tracking of movement of interference sources can provide key information to infer what type of system is generating the interference, such as a pedestrian, car, satellite, or drone, as well as the communication protocols they are using. The inference information will guide the receiver to coordinate future usage of the spectrum with the interference sources.

2. Method and Research Plan

2.1 Interference Tracking with a Passive GPS Model

In this proposed research, we developed a passive GPS model to accurately measure the location of an interference source. The Global Positioning System (GPS) has been deployed to provide geolocation information with sub-meter resolution [3]; however, the traditional GPS technology cannot be directly used for interference source tracking in NRDZ. With traditional GPS technology, satellites send signals to the target to measure the distance between satellite and the target (Fig. 2 left). To track an interference source in NRDZ, the behavior of sending measurement signals from the sensors to the interference source would generate additional interference which is unwanted in spectrum-controlled areas, such as observatories with radio telescope arrays.

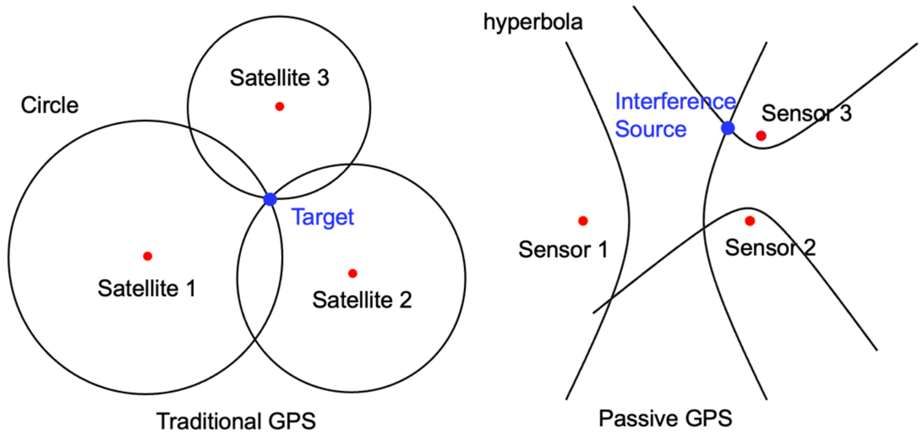

Fig. 2 Comparison between traditional GPS (left) and passive GPS in this proposed research (right)

To accurately measure the location of an interference source without sending signals from the sensors, we developed a passive GPS method (Fig. 2 right). In this method, all the sensors passively receive signals. At time t, interference source sends a signal. At time t_{m1}, sensor 1 measures the arrival time of the signal and it takes t_1 for the signal to transmit from the interference source to the sensor 1. With n sensors, we can have n different arrival times:

$$t - t_{m1} = t_1$$

$$t - t_{m2} = t_2$$

$$t - t_{mn} = t_n$$

Although t and t_1 are unknown, the difference of arrival times between two sensors can be measured with t_{m1} and t_{m2}, and calculated as:

$$t_1 - t_2 = t_{m2} - t_{m1}$$

With a known $t_1 - t_2$, the interference source should be in a hyperbola curve defined by the two sensors, where the two sensors are located at the two focus points of the hyperbola. The distance between the two sensors can be measured and are defined as $2C$. The arrival time difference ($t_1 - t_2$) defines the distance between two vertices for the hyperbola:

$$2A = (t_1 - t_2)\times c = (t_{m2} - t_{m1})\times c$$

Where c is the speed of light. The coordinate of the interference source (x, y) is determined by the hyperbola curve:

$$\frac{x^2}{A^2} - \frac{y^2}{B^2} = 1$$

Where $B^2 = C^2 - A^2$. Note: we use lower case c to represent the speed of light and upper case C to represent the focal length of the hyperbola.

With another pair of sensors (sensor 2 and sensor 3 in Fig. 2), another hyperbola curve is obtained, and the interference source is located at the intersection point between the two hyperbola curves. This method is similar to the traditional GPS in terms of finding intersection point between curves. The difference is that in traditional GPS, the satellites actively send signals, and measure the distances between satellites and the target. The location of the target is determined by the intersection of multiple round curves defined by the several distances. In this proposed method, the sensors passively receive signals, and the location is determined by the intersection of hyperbola curves. This is why we name our method “passive GPS”.

Although the two-dimensional case is discussed, this method can easily be expanded to three dimensions by adding another pair of sensors. With three-dimensional information, interference sources that are not on the surface of the Earth, such as satellites, drones, etc., can be located. In a three-dimensional application, a minimum of three pairs of sensors are needed (sensor 1 and 2; sensors 2 and 3; sensors 3 and 4).

2.2 Interference Identification

The passive GPS system provides location information and tracks the movement of the interference source. With the location information and movement speed/pattern, and by using deep learning, interference identification and categorization can be achieved. Interference will be categorized as originating from a pedestrian, motor vehicle, drone, satellite, etc. The interference categorization provides (1) instructive information for NRDZ to allocate spectrum resources and (2) feedback information to the passive GPS system about modulation format, which will further improve the resolution of the interference tracking.

3. Preliminary Results with Prototype System

In this section, we demonstrate a prototype system that locates the coordinate of the interference source with centimeter resolution based on the method presented in Section 2.1.

3.1 Experimental Setup

Fig. 3 shows the experimental setup of the prototype system. The system includes an interference source and 3 sensors. The interference signal is transmitted and received with antennas. The transmitting antenna sends out amplitude modulated pulses (Fig. 4 (a)) with carrier frequency of 863MHz (Fig. 4 (b)). The pulse repetition rate is 1MHz and pulse width is 200ns. The 3 sensors are synchronized to measure the difference in signal arrival time.

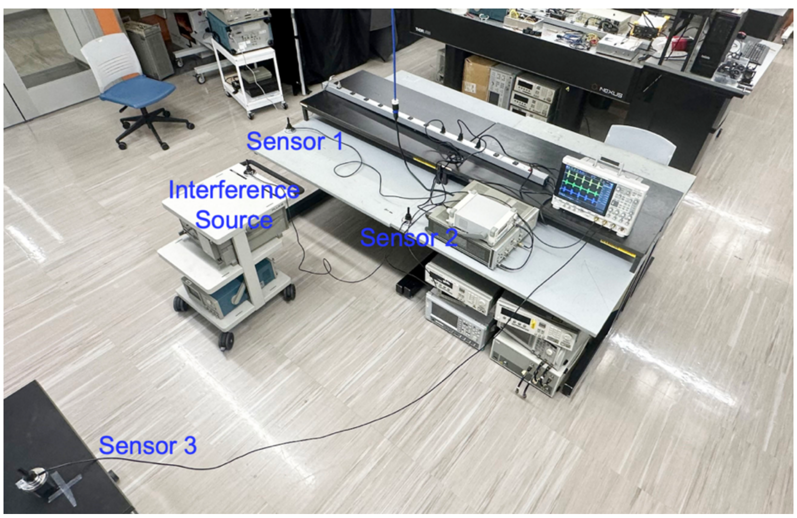

Fig. 3 Experimental setup of the passive GPS system.

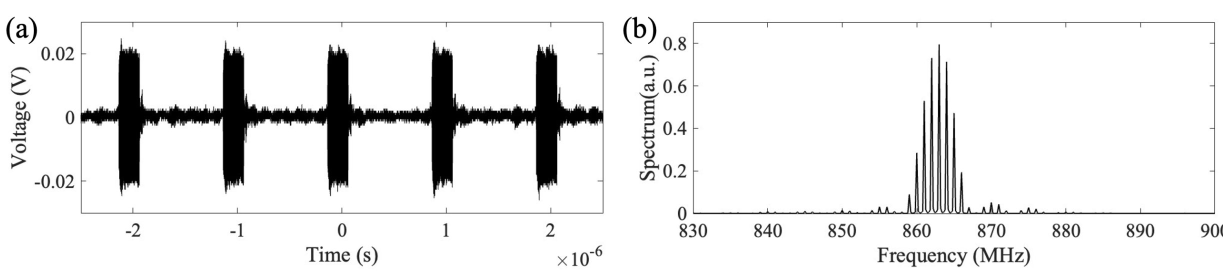

Fig. 4 Signal received from sensor 1 (a) Time domain signal (b) Spectrum of the signal.

3.2 Experimental Results and Analysis

The synchronized sensors measure the differences in signal arrival time between each sensor pair (Fig. 5). In this experiment, all the sensors are connected to the same oscilloscope, and signals from sensors are recorded by separate channels of the oscilloscope. In the field test, all the sensors are connected with optical fibers and synchronized with the same clock. Fig. 5 shows differences of signal arrival time (delay). The delay difference between Sensor 1 and Sensor 2, which is t_1- t_2, is measured as $1.6ns$, and the delay difference between Sensor 2 and Sensor 3, which is t_2- t_3, is measured as $2.7ns$.

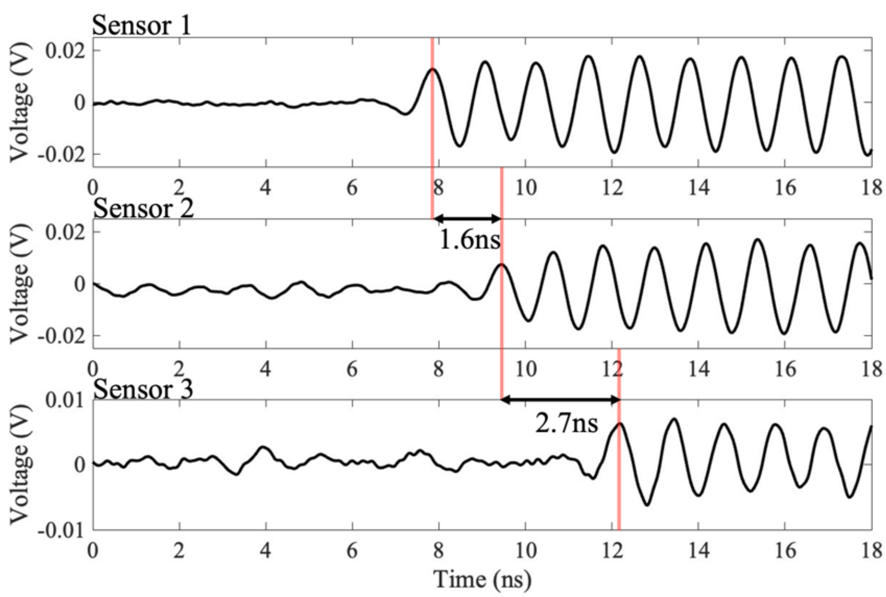

Fig. 5 Delay differences between 3 sensors.

With the delay differences and according to the theory in Section 2.1, the location of the interference source is determined by the intersection point of the hyperbola defined by Sensor 1 and Sensor 2 and the other hyperbola defined by Sensor 2 and Sensor 3 (Fig. 6 (a)). The red dots show the locations of the sensors. The blue dot shows the actual location of the interference source, measured by a tape ruler. Fig. 6 (a) shows that the intersection point of the two hyperbola curves overlaps with the blue dot, which means **the location of the interference source measured by the passive GPS method is the same as its actual location**. Fig. 6 (b) is an enlarged view of Fig. 6 (b) and demonstrates the accuracy of the measurement. The measurement result is 2cm from the actual location, which means the system achieves resolution in cm level.

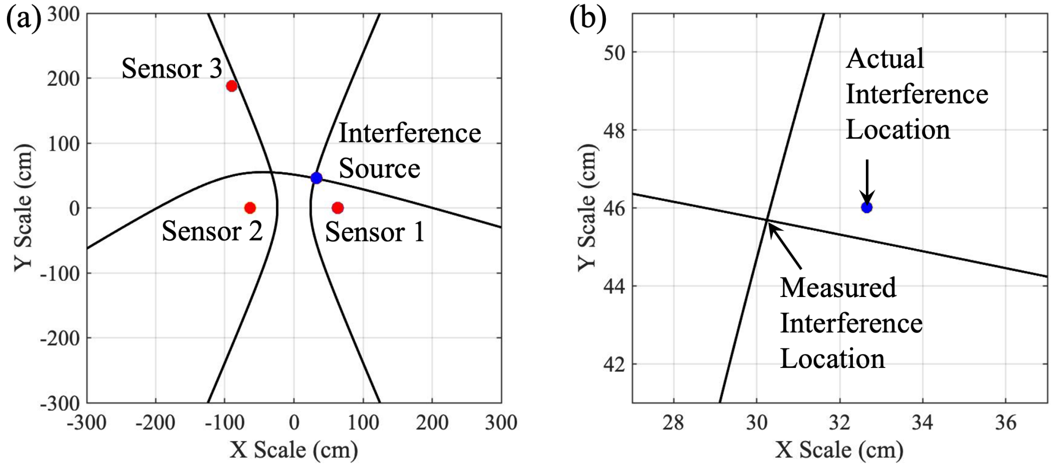

Fig. 6 Experimental measurement of the interference source location (b) is a zoomed-in view of (a)

Future work, which will be discussed with more details in Section 4, includes evaluating the passive GPS system in a larger geographical scale and distance. The scale of distance between the interference source and the sensors will meet the requirements of NRDZ. Longer distance decreases the signal to noise ratio (SNR) of the sensor receivers, which can be compensated for by (1) Applying an RF amplifier at the receiver. The current system uses a 10mW transmitter as the interference source without using any RF amplifier at the sensor receiver. (2) Leveraging the redundancy of the prototype system. The current system achieves cm resolution. Meter level resolution is enough to achieve the goal of interference tracking and identification, as discussed in Section 2.2. This means the prototype system has 2 orders of magnitude in terms of resolution redundancy. With this redundancy, the tracking system is functional at meter level resolution when the SNR drops by 10-20 dBm. (3) Adding more sensors. 3 pairs of sensors to is the minimum number of sensors to solve a three-dimensional problem. By adding more sensor pairs, the extra sensor will improve the resolution. This is very similar to traditional GPS, where 5-6 satellites are used for ideal resolution.

4. Implementation Plan

The implementation plan includes three steps: (1) Proof of concept, demonstrating that the passive GPS system works in the lab. **This step is finished as preliminary results**

in Section 3. (2) Outdoor test to evaluate the signal power and distance resolution of the system in a larger scale. The distance between sensors and interference generators will be in the range of hundreds of meters to kilometers. Software defined radios with portable power supplies will be used to perform the test. We will use free space optical communication links to provide a synchronization clock. PI Wu has built a test bed for free space optical communication links [4]. Fig. 7 shows the ongoing test system built by PI teams. This step will take about 3-6 months to finish.

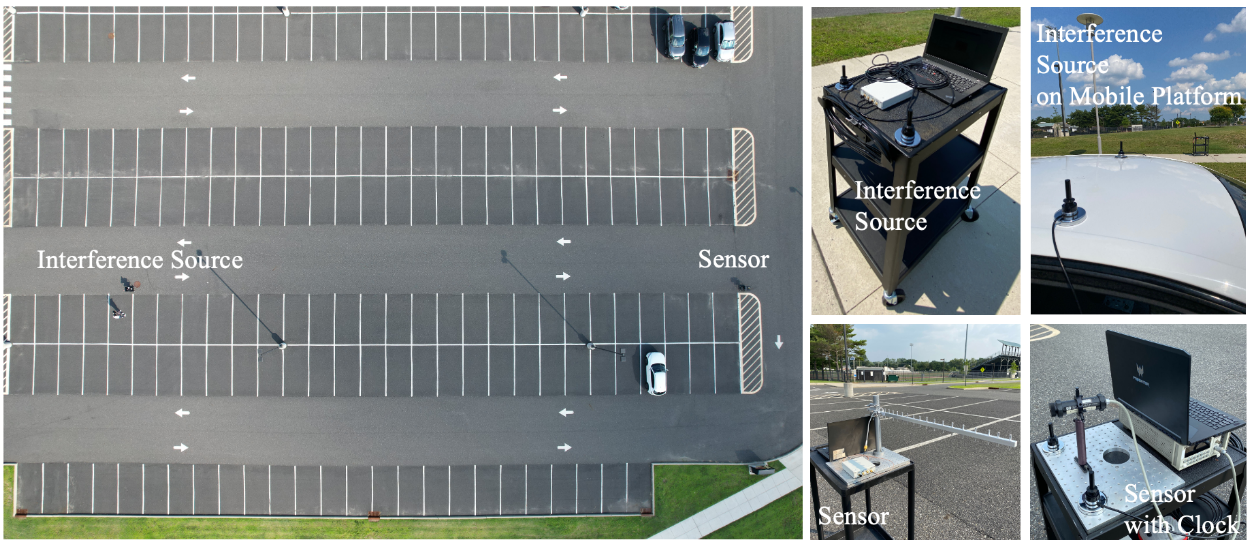

Fig. 7 Outdoor test bed of the passive GPS system that PIs have built.

(3) Field test at Hat Creek Radio Observatory. PI Kevin Gifford has built a sensor array at Hat Creek Radio Observatory [5]. The sensors use software defined radios, and have been tested to be able to measure the interference in both time and frequency domain. Fig. 8 shows the geographical location of five sensors. All the sensors are connected with optical fibers, which means that they can be synchronized with the same clock for accurate time delay measurement. We will test our passive GPS method with the sensor array at Hat Creek Radio Observatory. This step will take about 6-12 months to finish.

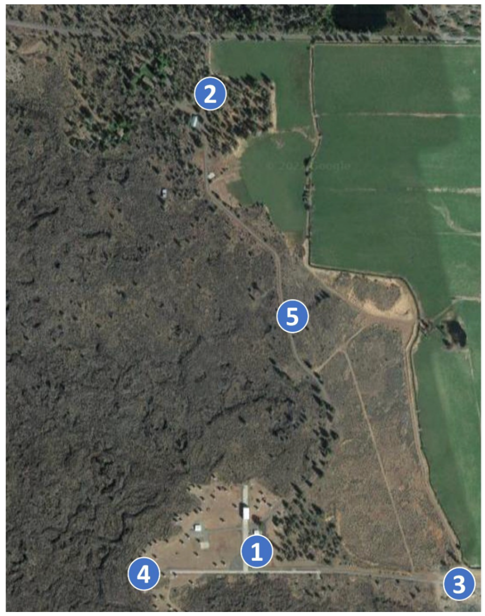

Fig. 8 Sensor array system in Hat Creek Radio Observatory that PI Gifford has built [5]. 5 sensors are shown with labels. Hat Creek Radio Observatory is located at the bottom of the figure.

5. Resources and Facilities

Our team has diverse expertise to secure the successful implementation of the proposed method and to perform field test within the planned time frame. PI Wu is an expert in interference management and has an active project from NSF Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program. Project title: Collaborative Research: SWIFT: Wideband Spectrum Coexistence Enabled by Photonic Circuits: Cross-Layer Design and Implementation, with recent publications [6]–[8]. PI Wu has built a prototype system of the proposed method in his lab, and the functions of the system meet the goal of interference localization (Figs. 3-6). PI Gifford has multiple active projects for NRDZ and spectrum resources allocation [5], [9], [10], and has built an interference sensor system at Hat Creek Radio Observatory which is a key milestone for the field test of this planned research (Fig. 8).

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Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

CableLabs

CableLabs

March 21, 2023

Networking and Information Technology Research
and Development National Coordination Office
National Science Foundation
2415 Eisenhower Avenue
Alexandria, VA 22314

Re: *Request for Information on the National Spectrum Research and Development Plan*

CableLabs appreciates the opportunity to provide input to the Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO), National Science Foundation on the National Spectrum Research and Development Plan (R&D Plan). CableLabs, as the non-profit research and development lab for the broadband industry, is heavily invested in research and development (R&D) regarding spectrum and innovative uses.

We look forward to the recommendations made in the R&D plan for government investments in spectrum-related research covering critical innovation areas necessary to advance the United States' leadership in efficient and diverse uses of spectrum to benefit consumers and national security and address the questions posed in the Request for Information in the order presented.

1. **Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering.**

CableLabs recommends that the federal government balance R&D funding among private sector interested parties including academia, non-profit R&D organizations, and the diverse set of wireless entities serving users via spectrum. CableLabs further recommends allocating spectrum R&D funding to non-Department of Defense agencies in order to increase the accessibility of funding by small or non-profit organizations and encourage R&D that advances consumer focused spectrum uses in addition to the unique DoD spectrum uses.

To encourage new R&D instead of repetitive R&D, a shared repository or database of R&D findings, measurements, and underlying data is key. This would not only avoid duplicative R&D but would enable a diverse set of stakeholders to identify new problems and R&D focus areas in a timely manner.

As discussed in the National Spectrum Strategy Implementation Plan and in our comments below, public access to data regarding spectrum usage (including across time, frequency, geographic location, and power levels) by Federal and non-Federal users is foundational to spectrum sharing and innovation R&D. Understanding the baseline of any spectrum band and the existing users is necessary to develop measurable advancements such as efficient and effective sharing mechanisms and new solutions for existing users to increase efficient use of spectrum.

2. **Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas.**

CableLabs recommends the following areas in order of priority for research and development in the near term:

- **Dynamic spectrum access and management** are integral to implementing innovative sharing frameworks and enabling quicker deployment of non-Federal uses in the bands identified in the National Spectrum Strategy. In particular, the 3.1 GHz and 7/8 GHz bands identified in the National Spectrum Strategy represent good candidate bands for dynamic spectrum access and management systems to protect mission critical DoD systems while allowing co-existence of new non-Federal uses to benefit consumers. Following best practices for any spectrum band study, co-existence should always be studied in parallel to other proposed options.

  Dynamic spectrum access and management R&D work is already underway in the development of systems such as incumbent informing capabilities and further evolution to spectrum access systems (such as those used in the 3.5 GHz band) or contention-based protocols. By prioritizing improvements to these existing systems, the Federal government will enable results-based R&D that leads to real-world deployments of innovative spectrum use. This focus area should also include R&D to enable automatic and rapid mitigation of harmful interference problems as this is a core task of dynamic spectrum management systems.

  Dynamic spectrum access and management systems, including those with near-real time mitigation of harmful interference, can benefit from the use of artificial intelligence and machine learning. These tools can enable finely tuned propagation and protection models based on the local environment and the ability to consistently update and learn about changing factors.

- **Spectrum situational awareness at scale** does not exist today, creating a significant gap between those with access to certain information and those without access. Spectrum situational awareness is often unavailable to the private sector and the Federal government. There is no one data source that provides accurate information regarding the time, location, and frequency of spectrum use by existing users, nor technical parameters of deployments. This information is key to creating a baseline for focused modeling of sharing frameworks and efficiency improvements. We support the efforts detailed in the National Spectrum Strategy Implementation plan to close this gap with appropriate protections for classified information, with the request that as much information as possible is shared with non-Federal R&D participants and future spectrum access and management organizations.

- **Modeling for coexistence analysis** is key to sharing spectrum. As stated by the Department of Defense and the National Spectrum Strategy, sharing spectrum is the way forward. Modeling needs to be updated to reflect real world parameters and usage, including: spectrum situational awareness, less conservative propagation models that reflect advances in the understanding of signal propagation, clutter, and diverse use cases. Deployment of new uses in the 6 GHz and 3.5 GHz bands revealed the importance of accurate modeling based on accurate data and the need to model innovative use cases, not the well-known standard high-power deployments. R&D exploring and implementing the lessons learned from these bands should be a priority in modeling.

- **Spectrum utilization efficiency** is a frequently identified concern. Certain spectrum use technology is reaching the end of its life cycle and spectrum users will only benefit from adoption of technological advances in spectrum utilization. Studies of efficiency of use are critical to determining sharing frameworks, modeling, new solutions, and could identify spectrum users who need federal funding to update spectrum use technology. This should include R&D for tools or techniques that allow existing or new spectrum use systems to become more resilient to interference from various sources. As detailed in the National Spectrum Strategy, the RF environment is currently crowded with only an increasing demand for additional spectrum to be shared for new uses leading to the need for these tools and techniques.

3. Recommendations on grand challenge problems for spectrum R&D.

As detailed above, the underlying issue creating significant barriers to all spectrum R&D is lack of information about existing spectrum use. Access to accurate and detailed information regarding current spectrum usage, including time, location, frequency, and technical parameters of deployments will be a game changer in multiple areas of spectrum research, a building block for creating new spectrum access and management systems, interference mitigation techniques, and enabling access to spectrum by new users more quickly.

Success or failure in this area is easy to measure and progress can be measured by data available for each band. Gathering and providing access to this information, in a system that protects classified information and allows real time updates by spectrum users requires a state-of-the-art solution.

4. Recommendations on spectrum R&D accelerators.

Shared public datasets are key to any future spectrum R&D projects. As we mentioned above, data regarding current spectrum utilization is critical not only to future spectrum sharing frameworks in specific bands, but also innovative technology solutions that will enable more efficient use of spectrum. The National Spectrum Strategy Implementation Plan focuses on collecting information from Federal spectrum users, but licensed private sector users should also be required to update spectrum usage and deployment data, whether through the Federal Communications Commission's Universal Licensing System or a new database that can host and provide information about all users in a particular band.

Benchmarks and competitions are a source of inspiration to the R&D community and eventual real-world spectrum users. These tools set expectations and goals that are measurable along with incentives to solving problems that may not warrant priority attention. CableLabs' experience hosting NTIA's 5G Challenge showed that competition participants are willing to reach stretch goals, work in a collaborative manner, and contribute to the maturity of an ecosystem because they were provided a platform, technical support, and monetary incentives. Through the 5G Challenge, competitors participated in the first successful proof of an end-to-end mobility connection on a multi-vendor Open RAN system. Outside the 5G Challenge, these vendors had no reason to put resources into interoperability with other vendors or the goal of an end-to-end mobility connection. Similar achievements can be reached in the areas of dynamic spectrum sharing, access, management, and harmful interference mitigation if the proper tools, technical support, and incentives are provided to participants.

Testbeds, research infrastructure, and collaboration support can provide a similar incentive to parties to reach significant state-of-the-art successes in the area of spectrum R&D. Neutral testbeds that provide a platform and resources without bias towards a particular use case give the community an opportunity that individual parties may not have. This also directly leads to support for collaboration and ongoing coordination. Spectrum R&D projects do not cease at the end of a grant or contract. Instead, the lessons learned and protocols or technologies developed are to be shared with the larger ecosystem to advance new, efficient, and diverse uses of spectrum.

5. Recommendations on near-term Federal activities.

All of the recommendations above require significant resources, including funding, information technology infrastructure, process development, collaboration guidelines, and input from various stakeholders. Near-term the government can focus on providing accessible funding for R&D in priority areas as recommended by commenters and evaluated by NITRD NCO.

Collection of information from Federal agencies, as detailed in the National Spectrum Strategy Implementation Plan, and updates of private sector data can be accomplished in the near-term as well.

Setting up guidelines and infrastructure for coordination between Federal and non-Federal spectrum users and R&D organizations, with considerations of diversity of interests and the necessary protection of classified information is a near-term achievable task. The National Spectrum Strategy Implementation Plan proposes a structure that may limit the participation of interested stakeholders and that structure may need to be updated to encourage and facilitate R&D.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

Spectrum R&D, including problem statements and solutions, is incredibly dynamic. Therefore, the R&D Plan will need to be equally nimble to keep up with the new technologies and use cases released every year. We hope to see the R&D plan impact the spectrum R&D ecosystem early, thus we recommended seeking comment again in 18 months with the goal of updating the plan in 2 years, and on a regular schedule moving forward. The targeted questions in this RFI are a constructive framework for gathering information and the next round of comments could also focus on successes, failures, and lessons learned.

7. Proposed definition of "Dynamic Spectrum Sharing."

Spectrum sharing comes in many varieties, not all of which would be considered dynamic, but all bring an increased value to the use of spectrum and should be deployed based on the characteristics of each specific band and the nature of the critical incumbencies in that band. We recommend that a key component of "dynamic spectrum sharing" is the ability to accept and process data and make decisions in near real time and propose this definition:

> Coexistence of multiple use cases by distinct users in a particular band managed by a system with the information and authority to react near real time to the needs of priority users and mitigate harmful interference and can onboard new users in a timely manner.

Examples of dynamic spectrum sharing under this definition include incumbent informing capabilities with near real-time data inputs provided by sensing, or time, location, and frequency priority use reservation inputs; real-time sensing of spectrum usage; contention-based protocols; and any combination of those sharing mechanisms with a proper management system or management protocol.

Conclusion

CableLabs looks forward to the National Spectrum Strategy R&D Plan and the inspiring innovative results of future R&D in this area.

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Respectfully submitted,

/s Mark Walker
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Vice President, Technology Policy
CableLabs
[redacted]

/s Jessica Almond
Jessica Almond
Director, Technology Policy
CableLabs
[redacted]

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Cellular Telecommunications and Internet Association (CTIA)

Before the
NATIONAL SCIENCE FOUNDATION
NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT NATIONAL COORDINATION OFFICE
Alexandria, VA 22314

In the Matter of	)
	)
Request for Information on the National Spectrum Research and Development Plan	)
	)

COMMENTS OF CTIA

CTIA[1] submits this response to the National Science Foundation ("NSF")'s Request for Information on establishing a national spectrum research and development plan ("R&D Plan").[2]

I. INTRODUCTION.

Spectrum R&D is critical to maintaining U.S. global leadership in wireless and enhancing use of spectrum for our nation's economic and national security. The commercial wireless industry has made substantial investments in technology advancements that improve spectrum utilization, enhance service quality, and lower deployment costs. Examples include spectrum refarming, massive multiple-input multiple-output technologies, carrier aggregation, RF front-end design, Open Radio Access Networks, network slicing, and artificial intelligence-enabled network management.[3] During the 4G decade alone, U.S. wireless providers increased their spectrum efficiency by a factor of 42, when measured on a MBs/MHz basis.[4]

These advances—the result of R&D investments—yield innovations and growth in the form of new products, services, and business models that benefit American consumers and U.S.

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[1] CTIA – The Wireless Association® ("CTIA") (www.ctia.org) represents the U.S. wireless communications industry and the companies throughout the mobile ecosystem that enable Americans to lead a 21st century connected life. The association's members include wireless providers, device manufacturers, suppliers as well as apps and content companies. CTIA vigorously advocates at all levels of government for policies that foster continued wireless innovation and investment. The association also coordinates the industry's voluntary best practices, hosts educational events that promote the wireless industry and co-produces the industry's leading wireless tradeshow. CTIA was founded in 1984 and is based in Washington, D.C.

[2] Request for Information on the National Spectrum Research and Development Plan, 89 Fed. Reg. 12871 (Feb. 20, 2024) ("R&D Plan RFI" or "RFI"). This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

[3] *See*, *e.g.*, Comments of CTIA, GN Docket No. 22-203, at 18-25 (filed July 1, 2022).

[4] *Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum*, CTIA (July 2019), https://www.ctia.org/news/smarter-and-more-efficient-how-americas-wireless-industry-maximizes-its-spectrum.

enterprises alike. Among others, this includes new competitive broadband options through 5G Home and localized industrial and manufacturing use cases, along with new consumer-oriented sectors such as ride sharing and third-party food and grocery delivery. The U.S. wireless industry is also advancing our national security through innovation and wide-area deployments, both by enabling use of next-generation commercial technologies and networks to support federal missions and by supporting prototyping and testbeds for use of advanced wireless technologies at military installations.

As NSF develops the R&D Plan, we urge it to apply three guiding principles: orient spectrum research toward improving private sector investment and commercially viable deployment; ensure all potential spectrum research areas are explored, including commercial access for full-power spectrum; and promote equitable transparency and access to technical information in stakeholder engagements. These principles will help ensure that R&D will improve lives, enhance our economy, help the nation maintain its global standing while enhancing national security, especially relative to competitors like China, and create well-paying U.S. jobs.

Today, there is an immediate need to evaluate federal spectrum use, transparently with federal and non-federal stakeholders, to better understand opportunities for more intensive and efficient operations. The R&D Plan can help improve spectrum decision making by adding important context about the capacity needs of federal users, operation of federal missions in other countries, and proven sharing techniques.

The U.S. will be able to maintain its leadership role in spectrum only if R&D efforts are connected to marketplace realities—on the commercial front, if the R&D Plan is out of sync with the speed of business, or strays too far into "industrial policy," our nation risks smothering commercial innovation and growth. NSF should strive to avoid arbitrary limitations in terms of vision, scope, or policies in the R&D Plan that could keep the U.S. from achieving vital national goals, and it should pull from lessons learned from prior spectrum evaluations in the process.

Finally, as the National Spectrum Strategy ("Strategy") sets out, there is an immediate need to make additional mid-band spectrum available for commercial use,[5] which will support expanded and enhanced mobile and fixed wireless broadband and is necessary for progress on

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[5] *See National Spectrum Strategy*, The White House, at 6-7 (Nov. 13, 2023) ("Strategy").

Open RAN and other network and technology innovations. R&D is, naturally, a longer-term initiative, and it should not slow progress on high-priority spectrum bands under near-term evaluation as part of the Strategy's spectrum pipeline.[6]

II. U.S. GLOBAL LEADERSHIP IN WIRELESS AND THE U.S. WIRELESS ECONOMY ARE BUILT ON FULL-POWER, WIDE-AREA COMMERCIAL NETWORKS WITH PREDICTABLE ACCESS, AND THE R&D PLAN SHOULD EXPLORE WAYS TO ADVANCE SUCH OPPORTUNITIES.

The U.S. relies on full-power spectrum to support wide-area commercial deployments that promote innovation and bring the benefits of new technologies to all Americans—it is the foundation of the wireless ecosystem.[7] It would be imprudent to ignore this reality as NSF launches the R&D Plan. There are multiple actions the R&D Plan can initiate to meet this grand challenge.[8]

A. The R&D Plan Should Promote Research on Enhancing Opportunities for Full-Power, Wide-Area Spectrum Use.

CTIA agrees with the RFI that strategies for conducting research must "ensure[] that all essential spectrum research areas are sufficiently explored," which should include access for additional full-power spectrum, and must recognize that economic factors are relevant to identifying priority areas for spectrum R&D.[9] This comports with the President's directive that the Strategy underlying the R&D Plan include "plans to optimize United States spectrum management" by considering the benefits of exclusive-use licensing as a spectrum access model.[10] And it is consistent with the Strategy's Implementation Plan, which calls for spectrum modeling that includes consideration of economic factors associated with spectrum allocation.[11]

Licensed, full-power spectrum offers the predictable access required for the massive investment necessary to deploy wide-area networks on the scale needed for new wireless

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[6] *See* Comments of CTIA on Implementation of the Strategy, at 12-18 (filed Jan. 2, 2024), https://www.ctia.org/positions/documents/nss-implementation-plan-rfi-comments-of-ctia ("CTIA Strategy Implementation Comments").

[7] *Id*. at 5-12; *see also* Comments of CTIA, Docket No. NTIA-2023-0003, at 11-14 (filed Apr. 17, 2023), https://www.ctia.org/positions/documents/comments-of-ctia-before-ntia-in-the-matter-of-development-of-a-national-spectrum-strategy ("CTIA Strategy Comments").

[8] *See* R&D Plan RFI, 89 Fed. Reg. at 12872, Question 3.

[9] *Id*. at Questions 1, 2.

[10] *See Memorandum on Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy*, The White House, at Sec. 3(c) (Nov. 13, 2023).

[11] *See National Spectrum Strategy Implementation Plan*, NTIA, at 12, Outcome 2.2(a) (Mar. 12, 2024) ("Strategy Implementation Plan").

innovations such as 5G Home broadband.[12] The U.S. wireless industry is at the forefront of the nation's economic success, with licensed, full-power spectrum contributing more than $5 trillion to the U.S. economy in the last decade, and providers investing a historic $39 billion in 2022 alone on network capacity and coverage expansion.[13] Yet a deficit of licensed spectrum exists as compared to other nations' commitment to licensed use.[14] Absent action to make additional full-power spectrum available for commercial use, this deficit could impede innovation, upend the ability to meet consumer and enterprise demands, and impair non-federal mission-critical use cases such as public safety and critical infrastructure uses, which rely on commercial networks and require predictable, secure spectrum access. It would also hinder the ability of secure, licensed spectrum deployments to support federal missions, including defense capabilities.[15]

Additionally, while NSF seeks input on a definition of "dynamic spectrum sharing" ("DSS"), it should promote research opportunities for proven sharing techniques. Specifically, it should recognize "spectrum sharing" more broadly for R&D purposes and define it to include repacking, relocation, and compression, which can enable full-power, wide-area deployments.[16]

B. NSF Should Explore Efficient Utilization to Enhance Spectrum Opportunities.

The RFI highlights the need for strategies that consider spectrum utilization, efficiency, and resilience.[17] In this regard, and consistent with the approach outlined in the Strategy's spectrum band studies,[18] the R&D Plan should study new means to advance the proven strategies of repacking, relocation, and compression, which have enabled shared commercial access to federal spectrum while enhancing the federal mission. Indeed, there is a long tradition of making

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[12] *See, e.g.*, CTIA Strategy Implementation Comments at 19; CTIA Strategy Comments at 19-21.

[13] *See* CTIA Strategy Comments at 11-14.

[14] *See id*. at 8.

[15] *See*, *e.g.*, *Modernizing Communications for the Air and Space Forces*, AT&T BLOG (Mar. 8, 2023), https://about.att.com/blogs/2023/5g-buckley-space-force-base.html; *5G and technological innovation help the Department of Defense explore new frontiers*, VERIZON (Sept. 2021), https://papers.govtech.com/Moving-to-Agile-100758.html/5G-and-Technological-Innovation-Help-the-Department-of-Defense-Explore-New-Frontiers-139930.html; Press Release, T-Mobile, *T-Mobile and Oceus Team Up to Bring 5G Advanced Network Solutions to U.S. Government* (June 14, 2022), https://www.t-mobile.com/news/business/t-mobile-and-oceus-team-up-to-bring-5g-advanced-network-solutions-to-u-s-government.

[16] *See* R&D Plan RFI, 89 Fed. Reg. at 12872, Question 7.

[17] *Id*. at Question 2.

[18] *See* Strategy Implementation Plan at 6, Outcome 1.2(a); *id*. at A-3 (stating the lower 3 GHz and 7/8 GHz spectrum sharing analyses will include various spectrum management mechanisms, including "spectrum sharing, repacking, relocation, and compression of Federal systems, as well as co-existence via variations in frequency usage, operating locations, time of use, and power levels–for both the Federal and commercial systems") (citations omitted).

spectrum available for shared use under pre-defined or static sharing mechanisms that leverage auction revenues to pay for relocation, repacking, compression, or upgrading federal incumbent users as appropriate, while providing predictable commercial access.[19] Information will be necessary to optimize any coexistence requirements to ensure predictable access to the spectrum.

More efficient federal use will further enable these sharing strategies, and as a first step the R&D Plan should promote evaluation of whether federal agencies are making efficient use of spectrum and help identify the capacity needs of federal users. Ever-increasing spectral efficiency has been a hallmark of licensed users,[20] spurred in part by the unyielding incentive to maximize the return on their investments in spectrum acquisition via auctions. Given the lack of such market incentives among federal users, NSF should encourage research into actual federal spectrum usage, not just allocations, as the Implementation Plan directs.[21] As the Strategy highlights, "[d]ata about current real-world usage, the purpose and type of use (active or passive), as well as occupancy in the time, frequency, and geography domains, is needed as the basis for assessing the potential for increased capacity."[22] Stakeholders need to know where incumbents are located and when and how they are operating. Information on how much bandwidth is required for federal operations, as opposed to how much spectrum they occupy, is an important step. As are technical specifics such as transmit power, duty cycles, antenna and pulse characteristics, and interference margin and mitigation capabilities, which can inform discussion of co-channel and adjacent-channel protection criteria and coexistence.[23]

At the same time, CTIA recognizes that federal users may require evolving spectrum access to meet mission objectives, but a baseline understanding of their current spectrum use is critical to informing future discussions regarding our nation's airwaves. NSF has an opportunity here to promote the collection of such information, which can be populated into a comprehensive system to better facilitate spectrum access for commercial and federal operations alike.

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[19] *See* CTIA Strategy Comments at 21-27.

[20] *See supra* at 1 and n.4.

[21] *See* Strategy Implementation Plan at 8, Outcome 1.3(a); *see also id*. at 4-6, Outcomes 1.1(a), (b); *id*. at 15, Outcome 3.1(a).

[22] Strategy at 12.

[23] *See* CTIA Strategy Implementation Comments at 20-23; *see also* NTIA Commerce Spectrum Management Advisory Committee ("CSMAC"), *Spectrum Efficiency Subcommittee Report*, at 4, 11 (July 2018), https://www.ntia.gov/sites/default/files/publications/csmac_spectrum_efficiency_subcommittee_report_0.pdf ("CSMAC 2018 Spectrum Efficiency Report").

Another area of research could be the extent of inter-agency sharing that is occurring within federal allocations, as well as opportunities for greater government-to-government sharing to free up bandwidth for commercial use.[24] Research should also be encouraged regarding whether mission requirements can be met by migrating functions from federal systems to commercial networks or other mediums such as fiber, as the Implementation Plan directs.[25]

The R&D Plan should also promote research on federal receiver performance in targeted bands.[26] This enhanced understanding would provide meaningful information for future reallocations, including as the interference environment evolves, safeguard against approaches that may unnecessarily inhibit other potential uses in a band, and better ensure affected parties disclose relevant information before spectrum policy decisions are made.[27]

Finally, the R&D Plan should leverage resources within the FCC and NTIA's Institute for Telecommunication Sciences to facilitate the U.S. Government's understanding of 5G and future wireless technologies for purposes of evaluating bands and coordination with federal users. This will enable more refined conversations about the practical realities of wireless broadband deployment, which can better inform discussions on spectrum repurposing and sharing.

C. The R&D Plan Should Promote Transparency in Spectrum Evaluations to Facilitate Informed and Effective Spectrum Sharing and Coordination.

The R&D Plan should promote development of information sharing policies for use during spectrum investigations, as effective policies can only be achieved when all interested stakeholders can meaningfully engage in and benefit from the discussion.[28] A variety of spectrum stakeholders, including the Department of Defense ("DoD") and industries, will be seeking access to information to enable shared use. Unfortunately, history has shown there is likely to be an imbalance in terms of which stakeholders receive access to relevant data—in particular, to sensitive or classified information. In the context of the Partnering to Advance Trusted and Holistic Spectrum Solutions ("PATHSS") Task Group and Emerging Mid-Band

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[24] *See* CSMAC 2018 Spectrum Efficiency Report at 11.

[25] *See* Strategy Implementation Plan at 5-6, Outcome 1.1(b); *see also* Department of Defense Research & Engineering Enterprise, FutureG Office, https://rt.cto.mil/futureg-home/ (last visited Mar. 18, 2024).

[26] *See*, *e.g.*, Strategy Implementation Plan at 16, Outcome 3.1(c).

[27] *See* Comments of CTIA, ET Docket No. 22-137, at 10 (filed June 27, 2022); *see also* Expanding America's Leadership in Wireless Innovation, 78 Fed. Reg. 37431, 37434, Sec. 5 (June 14, 2013) (strongly encouraging the FCC to develop a program of performance criteria for radio receivers and requiring NTIA to provide information regarding federal receiver standards and agency practices to facilitate the same).

[28] *See*, *e.g.*, Strategy Implementation Plan at 8, Outcome 1.3(a); *id.* at 10-11, Outcome 2.1(a).

Radar Spectrum Sharing ("EMBRSS") initiative, for instance, coexistence dialogue and discussions of accommodating federal and commercial users were constrained and would have been enhanced if there had been additional transparency on the inputs and assumptions being modeled, including the domestic usage and expected service life of the relevant DoD systems.

As the National Security Telecommunications Advisory Committee ("NSTAC") stated: "Incumbent federal systems users should be as transparent as possible to enable meaningful evaluation of the spectrum for commercial use."[29] The R&D Plan should facilitate development of a mechanism for all relevant stakeholders to meaningfully engage with usage, testbed, and technical data. This could build off and enhance solutions used in the PATHSS/EMBRSS and Advanced Wireless Services processes for classified and controlled unclassified information.[30]

The R&D Plan should also promote development of a roadmap for *ex ante* coordination processes that are transparent and that hold both new entrants and incumbent federal operators accountable for the commitments that are made and relied on regarding spectrum repurposing and sharing. Such initiatives should not, however, duplicate any principles for spectrum management/coordination developed by NTIA and the Interagency Spectrum Advisory Council.

D. NSF Should Explore Global Harmonization and International Coexistence with Military Radars to Inform Domestic Policy Considerations.

The R&D Plan should promote research on the benefits of spectrum harmonization and economies of scale for wireless equipment. Harmonizing spectrum for substantially similar use worldwide helps minimize the threat of other countries seeking to dominate bands for 5G and beyond, while benefitting consumers through economies of scale in infrastructure, devices, and chipsets. It is thus in our national interest to participate in global spectrum harmonization, rather than having the U.S. on a spectrum island.[31] Failing to leverage global allocations leads to lost innovation and productivity and higher costs, which put at risk the estimated $200 billion in economic benefits that spectrum harmonization can bring to the U.S. over the next decade.[32]

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[29] Letter from Scott Charney, NSTAC Chair, to President Joseph R. Biden, at 5 (2024), https://www.cisa.gov/sites/default/files/2024-02/2024.02.26-DRAFT_NSTAC_Letter_to_the_President_on_Dynamic_Spectrum_Sharing-508c.pdf ("NSTAC Letter"); Howard Buskirk, *NSTAC: Balance Industry and Federal Interests in Spectrum Strategy*, COMM. DAILY (Mar. 8, 2024).

[30] *See* CTIA Strategy Implementation Comments at 24; *see also* Strategy Implementation Plan at 8, Outcome 1.3(a).

[31] *See* CTIA Strategy Implementation Comments at 15; CTIA Strategy Comments at 31-32; NSTAC Letter at 8; *see also* Strategy Implementation Plan at 16, Outcome 3.1(e).

[32] *Advancing US Wireless Excellence: The Case for Global Spectrum Harmonization*, ACCENTURE, at 8 (Feb. 2024), https://www.ctia.org/news/advancing-u-s-wireless-excellence-the-case-for-global-spectrum-harmonization.

In this regard, research would be useful on the demonstrated ability of dozens of nations to deploy 5G without compromising military radar systems, including the type utilized by DoD in the U.S. and abroad, for example in the 3 GHz band.[33] Such information would be beneficial to discussions on the transition of similar spectrum here in the U.S. and could inform opportunities for upgrades to, or replacement of, outdated federal equipment to better support defense missions while enabling commercial access.

III. IN STUDYING DSS, THE R&D PLAN SHOULD INCORPORATE LESSONS LEARNED AND RECOGNIZE CHALLENGES.

Novel spectrum sharing technologies are worthy of exploration, and the "technical demonstration platform" envisioned by the Strategy may prove informative for future spectrum repurposing discussions. The R&D Plan should acknowledge, however, that DSS is, at present, a potential complement to commercial, full-power, exclusive-use licensing, not a replacement.

Additionally, as NSF explores strategies for DSS R&D, it should ensure any DSS testbeds are not conducted in mid-band frequencies identified for near-term study. If NSF believes a testbed is appropriate for the bands identified in the Strategy for near-term use, it should consider testing in the 37.0-37.6 GHz band and in the non-3GPP standardized portion of the lower 3 GHz band (*i.e.*, 3.1-3.3 GHz).

The R&D Plan should recognize that DSS need only include sharing across a single dimension (*e.g.*, geography, frequency, time, power) at one time. In this way, R&D strategies can consider the widest array of options and focus on a broad range of spectrum access needs, including full-power opportunities, even as DSS is explored. To that end, DSS should be viewed more broadly than any single implementation, such as the Citizens Broadband Radio Service ("CBRS"). Rather, it should be defined as a sharing mechanism that allows for spectrum access to the same frequency band by two dissimilar spectrum users that varies in near-real time across one or more other dimensions of spectrum use: geography, frequency, time, or power. Such definition should be revisited over time as the landscape evolves.

In any research on DSS, NSF should acknowledge and seek not to replicate the various challenges that have erupted in early spectrums sharing experiments, consistent with the

[33] The n77 and n78 bands from 3.3-3.8/4.2 GHz are being used by nearly 50 countries for 5G, many of which have U.S. or allied radar systems that coexist or will need to coexist in the future with widely deployed 5G networks. *See Successful Military Radar and 5G Coexistence in the Lower 3 GHz Band: Evidence from Around the World*, CTIA (Aug. 15, 2023), https://www.ctia.org/news/successful-military-radar-and-5g-coexistence-in-the-lower-3-ghz-band-evidence-from-around-the-world.

Implementation Plan's call for assessing past spectrum allocation challenges and successes.[34] We identify three key issues below.

First, it is widely recognized that the CBRS framework has a number of limitations and has resulted in over-protection of federal incumbents in the band.[35] Indeed, NTIA has directed that further study of the 3.1-3.45 GHz band will address these shortcomings, highlighting that the effort for this band will focus on achievable outcomes that "substantially improve the efficiency of spectrum use as compared with current approaches to [DSS] (such as the [CBRS]) by leveraging new technologies and capabilities."[36] NSF should pursue realistic modeling assumptions as necessary to ensure federal incumbent systems are adequately, but not overly, protected by new commercial systems that share the same frequency band. Among other things, the following solutions could serve as a guide: (1) allowing use of clutter data, where appropriate; (2) relaxing highly conservative federal incumbent protection reliability, thereby making more spectrum available for commercial use without jeopardizing federal operations; (3) removing aggregate interference coordination calculations, which have been shown to be unnecessary and complex to efficiently implement in dynamic environments; and (4) more timely releasing spectrum after incumbent cessation of use.

Second, modeling and coordination areas must be grounded in real-world measurements and realistic system capabilities. For instance, measurements of commercial wireless systems show significant attenuation is provided by terrain, clutter, the curvature of the earth, antenna pointing, and time occupancy, but these and other factors were not accurately represented in the prior CBRS or PATHSS/EMBRSS processes. Incumbent systems are also often equipped with interference avoidance and rejection capabilities, which were likewise not considered in the PATHSS/EMBRSS or CBRS modeling. Moreover, the "whisper zones" around each CBRS Environmental Sensing Capability ("ESC") sensor cause CBRS devices to be shut down or operated at much lower power levels, a problem that is compounded by having multiple ESC providers. The CBRS and PATHSS/EMBRSS incumbent protection approaches also did not consider realistic operational settings, network laydowns, and capabilities of incumbent systems.

[34] *See* Strategy Implementation Plan at 12, Outcome 2.2(b).

[35] *See*, *e.g.*, NTIA, CSMAC, *Report of Subcommittee on CBRS*, at 6, 8, 10-11, 16-17 (Dec. 2023).

[36] Strategy Implementation Plan at 19, Outcome 3.2(f).

Third, the R&D Plan should promote robust, commercially viable service. The lack of investment in the CBRS band, as demonstrated by the low level of deployment and public statements to investors, underscores the need for spectrum access models that are scalable and incent necessary investment in large-scale spectrum use, with technical rules including full-power base stations to better align with the coverage of similar spectrum bands.[37] NSF correctly recognizes the importance of these considerations in seeking to ensure R&D projects consider economic, market, and business concerns and models,[38] and the R&D Plan should reflect this objective, consistent with the Strategy, Implementation Plan, and NSF's Directorate for Technology, Innovation and Partnerships.[39] To that end, certain guardrails should be established with any DSS regime developed to ensure commercially viable utilization of the relevant spectrum band by both incumbents and new licensees, including: (1) ensuring access for full-power licensed use; (2) establishing predictable times and/or geographies in which the spectrum can be utilized on an ongoing basis; (3) examining a full range of interference mitigation techniques and not just on/off spectrum access control or transmission power limitations; and (4) using defined co-channel and adjacent-channel interference environments to incorporate in network design and operation.

Finally, NSF should consider guidance on the use of modeling assumptions that play an important role in spectrum sharing proceedings, such as the 6 GHz band. These modeling assumptions could include, for example, building entry loss (including where real-world transmission testing is conducted inside a building), line-of-sight field testing, antenna orientations, bandwidth sizes, duty cycles, and activity factors.

IV. CONCLUSION.

CTIA and its members look forward to working with NSF and the U.S. Government to advance spectrum R&D efforts and the Strategy writ large. By taking steps as discussed herein, NSF can lay the foundation for research initiatives that promote investment and deployment, enhance transparency, and support the holistic needs of all users of our nation's airwaves.

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[37] *See*, *e.g.*, CTIA Strategy Comments at 28-30; Letter from Umair Javed, Senior Vice President, CTIA, to Scott Blake Harris, Senior Spectrum Advisor, NTIA, at 14-16 (dated Jan. 30, 2024) ("CTIA Strategy Implementation Reply Letter").

[38] *See* R&D Plan RFI, 89 Fed. Reg. at 12872, Question 3.

[39] *See* CTIA Strategy Implementation Reply Letter at 6-7; Strategy Implementation Plan at 15-16, Outcomes 3.1(b), (d); *see also* About TIP, NSF, https://new.nsf.gov/tip/about-tip (last visited Mar. 18, 2024).

Respectfully submitted,

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March 21, 2024

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

DeepSig Inc.

Before the
National Science Foundation
Alexandria, VA 22314

In the Matter of	)	
	)	
National Spectrum Research and Development Plan	)	
	)	
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Comment of DeepSig Inc.

DeepSig Inc. (“DeepSig”) appreciates the opportunity to submit comments to the National Science Foundation (“NSF”) Request for Information (“*RFI*”), *National Spectrum Strategy Research and Development Plan (“Plan”)*.[1]

I. INTRODUCTION AND BACKGROUND

The release of the *National Spectrum Strategy (“Strategy”)*[2] was an important step to ensure the United States remains the leader in global spectrum innovation. Wireless innovation is happening at unseen levels globally. A reliable pipeline of commercially available spectrum is critical to maintaining leadership and achievable with investment in efficient and effective technologies. The *Strategy* calls for the development of a National Spectrum Research and Development Plan to provide guidance for government investments in spectrum-focused research (and innovation, by extension).[3] In accordance with the instructions for the *RFI* to which this comment is in response, we respond to selected items listed in the *RFI* in order. This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

[1] *Fed. Reg.* 89:34 (Feb. 20, 2024)
[2] *National Spectrum Strategy*, The White House (Nov. 13, 2023), https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf (“Strategy”)
[3] *Id.* at 15

DeepSig Inc. is a product-centric company that develops wireless processing software solutions using machine learning techniques to transform 5G, edge sensing, and critical wireless applications. By weaving AI machine learning into radio signal processing functions, DeepSig develops solutions that inject intelligence into the network, creating efficient, autonomous, and affordable solutions for 5G and lays the foundation for 6G native AI enhancements. Open RAN allows for this transformation to occur by disaggregating and virtualizing the majority of 5G base station functionality on commercial servers or in the cloud. DeepSig's OmniSIG is an ML software offering real-time RF signal identification, classification, and localization for various radio systems, facilitating automated alerts and reactions with open-standards based signal activity descriptions.

II. RECOMMENDATIONS FOR EFFICIENT, THROUGH, AND EFFECTIVE RESEARCH

DeepSig understands that maximal spectrum efficiency is critical to a sustainable pipeline of commercially-available spectrum. Broadly, we propose a set of core objectives that, if adopted, will keep investment focused on achieving maximal efficiency: (i) real-time spectrum monitoring in a cost-sensitive and realistic manner; (ii) accurate spectrum sensing information is needed to optimize access, sharing, and scheduling of spectrum; (iii) architectures for future spectrum sharing and unlicensed spectrum band coordination should use the forms of intelligence in objectives I and II. Most importantly, NSF should fund technology R&D with a clear path to commercialization to ensure efficient use of research funds, with an emphasis on amplifying and accelerating market driven solutions.

A. Methods to increase coordinated investment in R&D between <u>all</u> stakeholders

The introduction of a federal fund-matching program will encourage private investment in spectrum technology. By providing federal funds to match private sector investment on a 1:1 basis or greater, the program would de-risk investment in nascent technologies while increasing the impact and potential return of private research and development ("R&D") expenditures, and could focus on accelerating the maturation and insertion of key technologies to enable spectrum sensing, spectrum sharing, dynamic spectrum optimization, maximization of spectrum efficiency, and other key enabling technologies.

Furthermore, creating incentives for large organizations (e.g. network operators and system integrators) to adopt and deploy new innovative technologies is essential for ensuring widespread adoption and real-world impact, and can serve to help de-risk early technology adoption costs. One way to accomplish this is through subsidies or requirements that tie the adoption of technologies to access of the newly-freed spectrum bands. These incentives can go beyond the private sector. Federal agencies should have access to emerging technologies without complex and time-consuming procurement processes. DeepSig stands ready to provide further suggestions for a smooth, spectrum-wide implementation

B. Realigning Spectrum R&D Towards Industry Application And Innovation

In advocating for a robust and future-proof National Spectrum R&D Plan, DeepSig Inc. posits that a recalibration of current structures and processes is imperative to maximize the return on investment and to ensure the deployment of practical spectrum solutions.

Structural and process improvements are necessitated within the organization and promotion of both Federal and non-Federal spectrum R&D initiatives. The National Science Foundation (NSF) has traditionally focused its efforts on university-centric basic research. While this is an important aspect, especially for fresh thinking and basic research foundations, we believe the maturation and commercialization of spectrum technologies, and investment to accelerate industry and small business efforts to realize these technologies is also critically important. Research, development, and product integration are essential to propel innovation from ideation to market-ready solutions, and to move new spectrum technologies into sustainable and valuable industries for the nation.

The current commendable coordination among agencies such as NSF, DOD-OUSD R&E, DOD CIO, and NTIA must evolve to include and even emphasize industry participation and commercial solutions, particularly for the development of mature solutions. This has not always been the case within past initiatives such as NSF RINGS, which focused exclusively on university basic research precluding our participation or information sharing despite private investment in directly related spectrum technologies. Collaboration across these stakeholders is crucial for aligning R&D with real-world applications and accelerating the commercialization adoption and deployment process.

To refine the R&D focus, a more diligent approach is necessary—one that prioritizes impact and maturation, minimizes redundancy, and fast-tracks mature solutions that promise substantial advances in network technology. Reducing duplicative efforts will streamline the R&D process, conserving resources for novel initiatives that demonstrate a clear trajectory toward marketplace success and sustainable economic models and accelerating and complementing rather than competing with private technology investment.

Lastly, industry-centric proof of concepts that synergize operators, network technologies, and new, commercially viable spectrum solutions are paramount. These proofs of concept should not only demonstrate technical feasibility but also the potential for rapid adoption, compliance with regulatory standards, and financial sustainability. Such a prioritization strategy ensures that R&D translates into tangible benefits for the spectrum industry and society at large, fostering an ecosystem where innovation flourishes and propels the United States to the forefront of the global spectrum arena.

III. RECOMMENDED PRIORITY AREAS FOR SPECTRUM RESEARCH

For sake of clarity, this section deviates from the standard format of this document to list our five priorities: enhancing MIMO and air-interface technology, creating OpenRAN solutions, a study of FR2 and FR3 bands, increased spectrum situational awareness, interference mitigation, and coexistence modeling.

Enhancing MIMO and air interface Technologies: Advancements in intelligent or AI-driven MIMO, Massive MIMO, distributed MIMO, and air interface technologies are essential. These technologies serve as the backbone for increasing capacity and should be prioritized for R&D. Accompanying these, technologies that support sensing, digital twinning for spectrum mapping, wireless propagation modeling, and spatial/beam control to optimize co-occupancy of the spectrum are critical. Such technologies ensure that existing and new systems can coexist more efficiently and interoperably. Particularly in consideration of next-G air interface technologies, research and development of AI-Native air interface technologies, leveraging MIMO, offers possibilities to better share, re-use, and exploit spectrum within and between networks and technologies more efficiently, and is a key technology where the US must obtain and maintain leadership.

OpenRAN Solutions: The promotion of commercially viable OpenRAN-based solutions and platforms is vital. These solutions offer a pragmatic approach to transitioning from basic research to solutions that have a real-world impact. OpenRAN architectures facilitate the prototyping and maturation of advanced wireless technologies, enabling a more agile and cost-effective ecosystem for innovation, allowing US innovations and research to reach the market more easily and achieve impact and value creation. OpenRAN offers a strong platform on which to build, prototype, and deploy key spectrum optimization technologies, and to rapidly deploy new technologies and spectrum sharing models effectively across diverse vendors and network operators.

Reevaluation of Spectrum Utilization: A continuous reevaluation of spectrum utilization is needed to improve efficiency. Studies focusing on the FR2 and FR3 bands should explore the potential for more relaxed licensing models, including fully unlicensed utilization, to enhance spatial re-use and densification and diversity of solutions and operators where feasible. Such an approach could allow multiple entities to efficiently share and reuse spectrum, and combination with MIMO and beam-steering technologies can help to mitigate interference between users effectively in these deployments. Studies looking at more dynamic spectrum sharing in mid-band and FR1 as well should be considered as well, but likely need a more structured approach for instance a new CBRS-like generation which leverages more pervasive sensing and information sharing to efficiently allocate spectrum between users.

Spectrum Situational Awareness: Achieving spectrum situational awareness at scale is fundamental to the ability to effectively allocate, share, and maximize the utility of spectrum. It necessitates the deployment of efficient edge sensing and intelligence solutions, such as DeepSig's AI-based OmniSIG signal classifier, which can be implemented at a low incremental cost through deployment alongside existing devices and infrastructure, reducing the need for deployment, maintenance and operation of dedicated sensors akin to ESCs. By embedding sensing capabilities at scale within the network, ideally within the actual radio units (RU's), and enabling new information sharing interfaces between in-network sensors and inter-network orchestration services such as a next generation SAS, a real time operating picture of spectrum usage may be built and sustained, allowing for pervasive and real time understanding of spectrum usage which can be used to ensure efficient allocation and usage between vendors, and maximizing the value of spectrum for everyone.

Interference Mitigation: The rapid and automated mitigation of interference issues is closely tied to situational awareness and the ability to re-allocate and maximize the usage, value, and density of spectrum. By utilizing intelligent sensing at the network's edge, technologies like

OmniSIG can swiftly and effectively identify and address interference and facilitate adjacent spectrum usage with the knowledge that interference can be detected and mitigated rapidly and in automated means, and that spectrum need not lay vacant based on overly "safe" assumptions about occupancy, usage, and propagation – leading to greatly improved dynamic spectrum sharing.

Coexistence Modeling: The development of real-time AI-driven and data-driven propagation models, combined with sensing and information sharing from infrastructure, potentially within a RAN Digital Twin framework, represents a significant opportunity. Improved models for spectrum propagation are envisaged as enablers for more sophisticated coexistence analysis, facilitating better spectrum reuse and allocation, especially in complex and dense urban environments with the highest spectrum needs. Coordinated network information and data-informed decisions are essential to lay the groundwork for a next-generation Spectrum Access System (SAS) and to lay the foundations for a sharing-native 6G service which makes the most out of our finite and valuable spectrum resources for the maximum number of users .

IV. FEEDBACK ON SPECTRUM R&D ACCELERATORS

DeepSig recognizes the imperative need for strategic alignment and resource optimization in spectrum R&D activities. In the sphere of public datasets (in fact we have published several widely known public open datasets in the area for the greater good, and we have also invested significant resources in the development of non-open datasets in order to provide competitive products), it is crucial that such data collections are not treated as ends in themselves. The creation of datasets and open datasets can be valuable, but must serve clearly defined roles within broader R&D objectives, thus ensuring they provide actionable insights and true utility rather than standing as resource-intensive pursuits with limited applicability or clearly defined objective or purpose.

Turning to the realm of open-source software and projects, while these resources can indeed serve as powerful enablers of innovation, their primary role should not be misconstrued as the ultimate goal. The promotion of open-source should be carefully calibrated to foster an environment where sustainable products, solutions, and intellectual property rights (IPR) are developed—assets that carry intrinsic commercial viability and longevity and sustainable economic models to drive industry growth and job creation. Investment and R&D should weigh the benefits of open source for commoditized capabilities which serve a common good, while allowing the creation of not-completely open solutions which offer differentiation and unique innovative value in the ecosystem. This mirrors the guidance of the leading economists in the open source economic modeling. Utilizing open platforms and interfaces, notably OpenRAN, should be strongly encouraged to expedite the integration and interoperability of diverse and innovative solutions into a cohesive system that support rapid industry evolution, as opposed to the hitherto approach which has led to less diverse, less nimble and more centralized ecosystems.

In the context of flexible radio platforms, affordability and practicality must anchor the deployment of wireless infrastructure. The R&D undertaken in this sector must not only validate the societal value through enhanced spectrum utility but also must present a realistic adoption curve. By forming synergies with international hardware developers and concentrating on high-volume, commercially-oriented radio systems rather than on high-cost, specialized equipment, we can foster broad and impactful advancements in spectrum utilization which will visibly see wide scale deployment and adoption without significant costs to vendors or operators.

The track record of benchmarks and competitions in the field highlights the necessity for these initiatives to be carefully orchestrated and adequately funded. Unfortunately, we have had several negative experiences participating in spectrum centric data competitions run by USG which were poorly planned and executed, with erroneous data, implementation, or evaluation leading to significant time investment with no positive outcome for either party - and even the silent discontinuation of the competition by the organizers at one point. For benchmarks to be truly valuable, they must be founded upon concrete real-world scenarios, with rigorous and sufficiently resourced implementation, and measured against universally accepted performance metrics, ensuring relevance and actionable outcomes, and well executed with sufficient planned outcomes and incentive for competitors.

Lastly, while investments in testbeds are commendable, they must be astutely directed to ensure that the focus remains squarely on the key issues confronting spectrum utilization. Encouraging collaborations between industry and operators to validate and refine approaches in practical settings is paramount. Such partnerships are instrumental in propelling mature Proof of Concepts (PoCs) that showcase viable spectrum optimization models, therefore, advancing the national R&D agenda in a manner that is both effective and attuned to the market realities.

V. DYNAMIC SPECTRUM SHARING DEFINED

We propose the following definition for the term "Dynamic Spectrum Sharing" as applied from its use in the *National Spectrum Strategy*:

> A system which shares spectrum allocations dynamically based on demand, current usage, prioritization, spectrum user requirements, and the ability to deconflict interference between them. There are several forms of this, including CBRS style DSS between networks and other spectrum users – within-network DSS e.g. for spectrum sharing between 4G,5G and other technologies – and future-CBRS style DSS which may employ more sensing and information sharing regarding spectrum usage and requirements to enable more dense and efficient spectrum re-use and assignment through DSS.

VI. CONCLUSION

Access to new spectrum is critical to enable technology innovations for government and commercial stakeholders alike. DeepSig looks forward to working with NSF and other spectrum stakeholders to foster efficient use of spectrum for years to come. DeepSig is well-positioned as a leader in the wireless ecosystem and will continue to invest in key spectrum technologies.

DeepSig applauds the swift action of the NSF and NSF's investment in critical next generation wireless and spectrum technologies. We look forward to working with NSF and other spectrum stakeholders to foster and accelerate the spectrum R&D ecosystem and next generation wireless technologies.

Respectfully submitted,

DeepSig Inc

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Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Dynamic Spectrum Alliance (DSA)

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March 21, 2024

Ms. Mallory Hinks
National Science Foundation
2415 Eisenhower Avenue
Alexandria, VA 22314
USA

Re: Request for Information on the National Spectrum Research and Development Plan

Dear Ms. Hinks -

The Dynamic Spectrum Alliance (DSA)[1] respectfully submits these comments[2] in response to the Request for Information (RFI) issued by the National Science Foundation (NSF) on the National Spectrum Strategy Research and Development Plan (NSS R&D Plan). We appreciate the opportunity to offer our perspectives on key innovation areas for spectrum research, particularly as related to Dynamic Spectrum Sharing (DSS) - an area in which our members have significant knowledge and experience particularly in designing, developing, implementing, and operating dynamic spectrum management solutions (DSMS).

Responses to RFI Questions

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering.

In order to ensure that spectrum research minimizes duplication, while also achieving measurable results, the DSA encourages NSF to recognize in the NSS R&D Plan the existence of proven innovative licensing frameworks and DSMS tools and technologies, including the solutions that have made spectrum sharing a success in the Citizens Broadband Radio Service (CBRS) and 6 GHz bands. Given the historical success of the variety of spectrum sharing

[1] The DSA is a global, cross-industry, not for profit organization advocating for laws, regulations, and economic best practices that will lead to more efficient utilization of spectrum, fostering innovation and affordable connectivity for all. Our membership spans multinationals, small-and medium-sized enterprises, as well as academic, research and other organizations from around the world all working to create innovative solutions that will benefit consumers and businesses alike by making spectrum abundant through dynamic spectrum sharing. A full list of DSA members is available on the DSA's website at dynamicspetrumalliance.org/members.

[2] This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

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techniques in different bands designed to protect different incumbents, the DSA is of the view that there is no one size fits all solution to spectrum sharing. On the contrary, better results are achieved when sharing mechanisms are tailored to the characteristics and deployment conditions of the federal and commercial incumbents of each band.

The DSA recommends that the NSS R&D Plan focus on iterating on, enhancing, and optimizing dynamic spectrum access and management by using, as a starting point, existing DSMS tools and solutions, including the CBRS Spectrum Access Systems (SAS), the 6 GHz Automated Frequency Coordination (AFC), and the TV White Spaces databases – all of which have proven to protect incumbent systems from harmful interference while significantly increasing spectrum availability for a wide range of new broadband services. These existing DSMS solutions can be enhanced through additional research and development – for instance, by updating the propagation models used, automating sharing mechanisms, such as incumbent notification systems, and use of active Radio Access Network (RAN) technology together with machine learning to better assess RF environments. By focusing initially on enhancements of existing, proven solutions, the NSS R&D Plan can avoid duplication and achieve measurable advancement more expeditiously.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas.

The DSA strongly supports the research areas listed as priorities in the RFI. Spectrum efficiency, dynamic spectrum access and management, automated interference mitigation, and co-existence modeling are all areas in which the DSA and our members have keen interest and extensive experience. Further research and development in these critical areas will have meaningful impact on the achievement of the objectives articulated in the National Spectrum Strategy. We also fully support efforts to study the economic-, market-, social-, and human-centric aspects of increasing spectrum access. Testbeds are an effective way to assess these aspects in addition to the more traditional hardware and software components of spectrum management techniques.

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts.

No comment.

4. Recommendations on spectrum R&D accelerators.

No comment

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5. Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

As mentioned above, the DSA recommends that the Federal agencies focus near-term efforts on updating propagation models, developing automated sharing capabilities, such as incumbent notification systems, and establishing real-world, data-driven protection criteria for incumbent Federal systems.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

No comment.

7. Terminology and definitions relevant for spectrum R&D. One term of interest is ''Dynamic Spectrum Sharing'' which is a focus of the National Spectrum Strategy but was not defined.

The DSA defines Dynamic Spectrum Sharing as the use of both innovative licensing frameworks, such as those that enable opportunistic access, and automated dynamic spectrum management tools to coordinate spectrum assignments, increase spectrum efficiency, and expand spectrum access for a wide range of new users while also protecting incumbent operations.

The DSA and our members are available to discuss these comments and provide any additional information and insights on dynamic spectrum management and its role in the implementation of the NSS R&D Plan.

Respectfully submitted,

/s/ Martha SUAREZ
President
Dynamic Spectrum Alliance

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Ericsson

Ericsson Response: Request for Information on the National Spectrum Research and Development Plan

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Introduction

As a leading global mobile networks vendor, and a clear leader in the United States, Ericsson appreciates the initiative of the US Government in creating this opportunity to respond to the request for information on the nation's R&D plan for spectrum.

Our response to the RFI will be guided by our perspective as a mobile network vendor: we view spectrum as the critical means to an end, which is the successful deployment of competitive nationwide scale networks. As we continue to expand the reach of 5G into so many spheres of society and industry and prepare to transition to the next generation, a comprehensive approach to identifying a spectrum pipeline for mobile services remains important.

The key to successful deployment in any spectrum band is competitive and cost-effective performance in terms of capacity, coverage, service continuity, and quality of experience. The service expectations of end users, the operators' customers, are the same regardless of spectrum band or operational mode or regulation and will only get higher. Since the introduction of digital cellular communication technologies in the early 90s, traffic on commercial mobile networks has grown exponentially. This growth is aided by a value chain which benefits from a virtuous cycle that encompasses regulators, technology developers, service providers, and end-users.[1] Digital communication has enormous benefits for economic productivity in a variety of sectors of society and industry. The humble mobile telephone network has evolved into an extension of the Internet, spanning economic sectors such as entertainment, industry, telecommunications, finance. Mobile technologies are well along the way in assuming critical functions that impact public safety,

[1] The term "technology developers" includes participants such as chipset vendors, equipment providers, hyperscale cloud providers, and application or content developers. Service providers likewise includes connectivity providers and application service providers such as media distribution companies, web services, telecommunications operators, etc.

peacekeeping, utilities, automation, and transportation. Our business and that of the mobile telecommunications industry in much of the world depends on the regulatory and policy mechanisms that can free up spectrum for mobile services.

Demand for mobile services grows unabated, and more spectrum is needed in the UHF and centimetric ranges between 3.1-8.5 GHz in the nearer term in the 5G era, and within the 7-15 GHz ranges in the longer term to secure success in the 6G era and beyond. We expect that radio spectrum will be made available under a variety of regulatory regimes, including ones that require sharing, and in a variety of bands that preferably are concentrated mostly in the centimetric wave bands below 8.5 GHz, but also include suitable bands extending beyond 8.5 GHz into the millimeter wave regions. Indeed, there is academic interest in studying even sub-THz spectrum above 100 GHz; fundamental technologies and use cases must however mature further.

Successful deployment in a band validates the business case of our operator customers for deploying in it, and their investment in spectrum licenses and in equipment. It also means good business for us as a network vendor, and our own investment into technology, products, and services to support the deployment. The same holds true for the terminal side. In addition, end user demand is satisfied with the right expectations. At the same time, successful deployment translates into high utilization of precious spectrum, which is a scarce national resource. Thus, there is alignment of incentives among the end user, the operator, the network vendors, terminal vendors, and the government, which is a clear start for ultimate success.

1 Q1: Strategies for conducting spectrum research

Innovation in spectrum sharing technologies is driven by conflicting demands placed on spectrum by multiple services, all of which have availed of greenfield spectrum in the past. It is natural that the search for spectrum for mobile services will seek bargains from other services already assigned to a band of interest, often to federal users. The NTIA National Spectrum Strategy (NSS) prescribes consideration of dynamic spectrum sharing to improve the efficiency of use of spectrum among wireless networks and other services. A definition for dynamic spectrum sharing appears at the end of this paper.

Ideally, the sharing regime should maintain the performance of licensed spectrum with full-power and wide-area coverage, offer global scale to products, and follow standardized solutions. The presence of mobile networks in a band will involve some interference to other services sharing the band; co-existence studies should reach reasonable accommodation on the noise rise to those users. If necessary, sharing must include a plan to upgrade those users with poor receiver immunity specifications. At a high level, research should address the requirements to be met by all services.

We assume that the primary motivation behind sharing is to provide shared access to spectrum to commercial mobile networks and one other or more Radio Service(s), e.g. commercial mobile network and satellite, fixed services, earth exploration/space services, radiolocation, or radionavigation. Often, sharing of spectrum may involve granting priority to one service or the other and may require protection of one or more services separated by frequency, space, or time of use. This is the essence of the dynamic behavior sought.

In our view, a fundamental challenge is how we may maximize network performance subject to those constraints without compromising the mission of other services that may be interfered by network operation. This challenge will be answered differently in the shorter term and longer term.

1.1 Near-term Approach: The Mobile Network is already very capable

One of the first actions to support spectrum R&D decision making is the necessity to quantify current spectrum usage to determine the extent to which the spectrum is being used through surveys and/or analyses. R&D plans should consider whether incumbents plan to upgrade or can be upgraded and ensure that incumbent systems use commercial partners and standards where possible. Spectrum R&D should also consider investing in and promoting incumbent technology advancements in spectrum utilization as appropriate. Assessments should also examine the possibility of improving cost-effective spectrum access by existing services by looking at the potential of band segmentation or relocation.

Ericsson recommends R&D decisions that incorporate the capabilities of mobile technologies to the utmost. 5G NR has been developed with a host of features that can be configured and repurposed in novel ways to build efficient solutions that can be deployed quickly. One strength of mobile technologies is the ability to operate over multiple bands using dual connectivity or carrier aggregation. Combining shared spectrum with one or more exclusively licensed bands is a quick way of implementing services by offering the network a way of gracefully accepting degraded capacity without outage to customers. Transmit power control, antenna tilt adjustments, or powering off sectors or sites allows higher priority users protection through coordination. Many of these features may be implemented without changes to mobile standards and with a cost that the industry is willing to assume.

As an immediate step, the spectrum R&D plan should expediently consider the reduction of Dynamic Protection Areas in CBRS band and Cooperative Planning Areas in the AMBIT band with better methods for coordination with incumbent systems.

1.2 Long term approach: Innovative spectrum sharing solutions

In the longer term, basic academic and industrial research can be matured to the point where its outcomes can be adopted in standards, be industrialized into viable products, and eventually deployed. We hope that the shorter-term solutions will provide a solid foundation for later advances. This incremental approach has served mobile networks very well.

We foresee exciting possibilities for research. We believe that spectrum sharing modes and the technologies to enable sharing go hand in hand. In terms of spectrum, we look forward to new sharing modes that blur the differences in performance between shared and unshared spectrum and offer the benefits of both. New information sharing mechanisms between the network and the other services can be developed. Revolutionary changes to the network's higher and lower layers, including transmit and receive techniques can be adopted.

1.3 Sharing Conditions

We believe the pressing need is for sharing spectrum between a network and an incumbent system under specific conditions. The industry seeks to prioritize operation with high power. Spectrum sharing becomes necessary when previously allocated services cannot be relocated or decommissioned. Consequently, there are inevitable constraints on the network to protect the incumbent, compared to exclusive licensing of the same spectrum. In our view, a fundamental challenge is how to maximize network performance subject to those constraints.

Ideally, the sharing regime should maintain the performance of licensed spectrum with full-power and wide-area coverage, offer global scale to products, and follow standardized solutions. At a high level, research should address the requirements to be met by all services with a level of information sharing that engenders trust and confidence between the participants in a sharing regime.

1.4 US research and development funding

At Ericsson, we have generally had distinct approaches to government-funded research and to government-funded development. We are very comfortable with collaborative research, where the open exchange of ideas is an existential need. We provide funding and equipment to a number of US research programs and university collaborations. We may consider programs where we receive small amounts of funding for our own research in the future.

We are cautious about funding for development, where we focus on building competitive products on a global scale. We thrive in open competitive markets, and indeed we are the clear leader in the US. We are wary of funding for development potentially creating product subsidies and market distortion.

1.5 US research organization

We are very encouraged by the resurgence of investment in wireless research in the US, which we view as highly overlapping with spectrum research. In the big picture, we do not see a need to fundamentally change the way research is organized in the US. Our position is to find opportunities which match our interests and engage with them on their own terms.

Ericsson is highly active in the US research community with the broad goal of energizing research towards 6G and beyond. To that end we have multiple strategic engagements with government, academia and industry that all build towards that goal. We have a number of ongoing bilateral university research collaborations, including UT Austin, MIT, Stanford, NYU, UC Berkeley, Rutgers, and most recently Princeton. We are partners in several NSF programs, where we provide funding and equipment: NSF RINGS program, the NSF FuSe program, and its follow-up in planning, FuSe2; and PAWR, where we provide network equipment to the ARA and AERPAW testbeds. We are participating in several project proposals under the DoD MEC hub program. We are part of a team that won an award for an Open RAN testing lab from the NTIA Public Wireless Supply Chain Innovation Fund. We served on the advisory board of the DARPA spectrum sharing challenge. We are very active in ATIS NGA, including leadership positions and contributions to many activities.

1.6 Spectrum research and standards

Along with its renewed interest in wireless and spectrum, the US Government has also highlighted the need for increased participation in standards. The National Standards Strategy for critical and emerging technology was issued in 2023, with communications and networking technologies listed first among eight focus areas. It follows naturally that one desired outcome of spectrum R&D is to influence future standards. The work towards 6G is in its early stages in bodies such as ITU-R and 3GPP, with full specifications expected around 2028 and first deployments around 2030. While standards evolve over several releases within a mobile generation, including 6G, there is some urgency to engage in spectrum R&D now to reach actionable results that can impact future standards in a few years.

2 Q2: Recommended priority areas for spectrum R&D

2.1 Spectrum Utility

This is not just a measure of how many services can be allocated in the same frequency band but must include an economic understanding of associated business models for network services and of incentives for investment under various options for utilizing spectrum.

2.2 Automatic and rapid interference mitigation

When spectrum sharing is considered, studies will have to consider dependencies that cannot be codified in a single systematic solution. Instead, unique sharing criteria will need to be researched and developed. In general, sharing will depend on a framework that requires two major facilities:

1. Information exchange interfaces that can provide situational awareness of the environment based on location, time, frequency band, and transmission characteristics of any signal relative to the impacted receivers. Information exchange can be slow, such as from geolocation-aided policy servers, or fast, such as with sensors located at the network edge.
2. Functional ability to alter the behavior of one radio service in order to share spectrum with another radio service, and additionally to mitigate the effects of mutual interference.

2.3 Modeling for coexistence analysis

Every use case is unique and the quality of information about another radio service will determine the effectiveness of the methods possible. Information sharing between stakeholders is critical. Co-existence studies should reach reasonable accommodation on the noise rise to each service and consider upgrading those users that have poor receiver immunity. Studies should aim to maximize spectral efficiency and ensure that spectrum is used to its highest degree by all stakeholders.

2.4 Sharing Scenarios

Many bands will require sharing with satellite communications. The graphics in **Error! Reference source not found.** illustrate typical approaches to sharing that may be employed in a variety of binary sharing scenarios; often, the sharing needed is based on mere geographic separation of services. Temporal adaptivity may be considered under rare circumstances.[2]

Some sharing situations of interest involve compatibility with fixed services or radiolocation. It is noteworthy that radiolocation alone among the above examples is where real-time agility in dynamic adaptation of spectrum use by the mobile network may be imagined. Notification

[2] Consider combating the effects of temporal propagation changes that may occur due to atmospheric changes that alter long signal paths, e.g. through ducting.

between such radars and mobile systems is a recommended priority area for advancing the art and for implementation in a testbed.

Research should clearly identify all situations that benefit from dynamic spectrum sharing and then whether real-time dynamic adaptation in networks offers a cost-effective method of sharing spectrum at scale. In the case of terrestrial radar, the network may be designed to adapt to the cadence and duty cycle of some classes of radars. In the case of mobile radar platforms, dynamic approaches may need to adapt to radar platform mobility as well. Research should consider the practicality of homogeneous behavior in equipment versus whether adaptation will have many flavors. Lastly, studies should adopt a mission-oriented systems approach to network design and develop interference mitigation strategies to provide reliable connectivity.

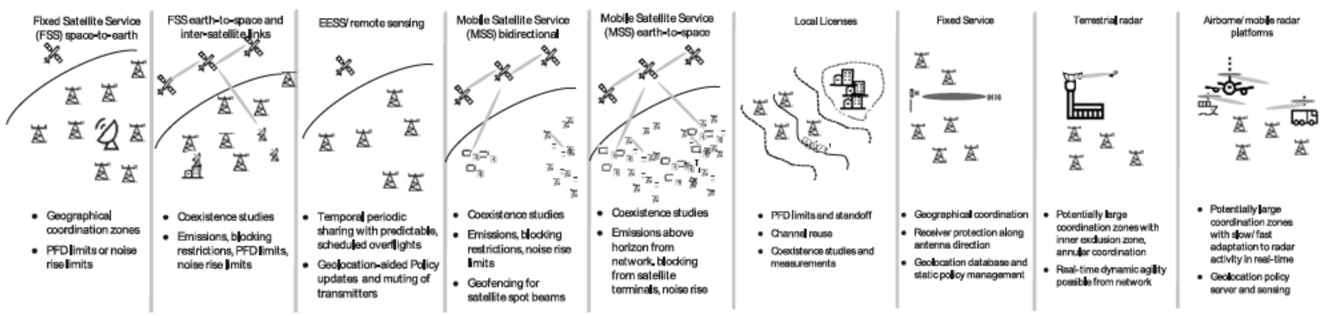

Figure 1 Sharing spectrum in diverse situations with potential mitigation approaches; the provided scenarios are representative and not comprehensive.

3 Q3: Grand challenge problems for spectrum R&D

Ericsson supports grand challenges focused on dynamic spectrum sharing between a mobile network and several types of incumbent systems. The demand for spectrum is increasing and, in some cases, dynamic spectrum sharing could permit balanced access to spectrum by the incumbent and mobile networks. In a multi-year challenge, the degree of difficulty could be ratcheted up every year. For instance, better modeling of the dynamism of the incumbent system could be considered. Understanding the relationship between the granularity of information exchange between the services and the corresponding performance benefit is key to the ultimate success of spectrum sharing.[3]

We see such a grand challenge as one important component in an overall concerted effort on spectrum research, as exemplified by our partnerships and collaborations in an earlier section.

Below are a few topics that can be investigated, e.g. in an NSF program, relating to spectrum and sharing in particular.

3.1 First Step: Network Management and dynamic spectrum sharing

Network management is most efficient in a steady state and needs relatively stable resource availability. Network management is also most effective over time frames that can maintain

[3] We note that information exchange was a part of SC2 but wasn't quite developed.

stability by moving users to stable alternative resources, reallocating policies across use cases, and accepting degraded performance without compromising service continuity. Fast-varying reconfiguration of resources may keep the network in an inefficient transient state.

Network management is currently designed to optimize performance given available resources. Sharing resources can vary in time more or less quickly. One research topic is to investigate how to evolve network management to be able to provide stable and effective operation with time-varying resources.

3.2 Further Efforts: Time dynamic sharing

In the case of periodic or intermittent dynamic incumbent activity, agility is needed in response while protecting the incumbent. The degree of dynamism of spectrum occupancy by the incumbent may be caused by physical motion, e.g. airborne or maritime radar and by its signal occupancy in time, frequency, or space, e.g. rotating radar beam.

Consider an airborne radar, with a sweep cycle of the order of seconds and a narrow beamwidth of a few degrees out of 360. A ground location is in the main lobe of the beam for the order of, say 100 ms out of 10 s. Given a rough timing of the incoming beam, and a safety window of e.g. 1 s, the network could operate there for 90% of the cycle. Carrier aggregation with one carrier in the shared band and one in a band exclusive to the network can maintain continuity of service with the exclusive carrier during the 1 s window.[4] In contrast, precise timing of the incoming beam for simultaneous operation on the shared carrier would require enormous complexity for little additional gain and no applicability in most bands.

Effective management of radio resources in wireless networks is best done with local action for rapid response and long-distance external information interfaces for policy and license management. This has the benefit of design aligned with the global market. External information interfaces can provide semantic data on imminent events and protection requirements that instruct local mitigation measures. Research should hew to those principles, thereby ensuring empowerment and autonomy of the network.

3.3 Incumbent physical motion

In the case of low earth orbiting satellites and mobile radar platforms like airborne radar, the motion of the platforms is relatively irrelevant at the time scale of the network, e.g. an airplane with a radar moves across 10 cm in the duration of a 5G NR scheduling slot. However, the lack of full-duplex capability can make detection of radar challenging at the base station in TDD bands. Antenna down-tilting reduces observability at or above the horizon. UE based sensing should be studied in the context of near- and long-term solutions. Satellites can move relative to the earth's surface as well but usually do so in a predictable and periodic manner.

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[4] Here we ignore the movement of the plane, which is very slow compared to the beam sweep. The speed of the plane affects the length of the radar event, which is of the order of 100's of seconds.

3.4 Modeling

While empirical propagation models are a great tool for understanding the potential of sharing, a statistical model does not match reality. Bias often occurs from risk-averse requirements and absence of customized modeling. These phenomena should be studied.

Research can consider how situational modeling of the observed environment can be blended with tools like ray tracing. Such techniques show great promise in considering actual performance in the field and can be subject to adaptive modeling and simulation. Additionally, it is important to model traffic in mobile networks realistically, recognizing the reality of sparse use of network resources as opposed to continuous loading of a channel with energy and its relation to interference.

3.5 Sensing

Sensing of interference is possible in situations where a service is capable of monitoring use of spectrum by another service. There are two possible approaches. Operation of services like radar may be amenable to sensing within the mobile network deployments; these abilities are a great fit for 6G integrated sensing functions. Receivers for satellite transmission might benefit from monitoring detectable increases in noise level at the site of their antennas. In the former case, systems should aim to get real-time notification from sensors integrated into network components or by sensor functionality that can interface with the RAN spectrum management function. Integrated sensors in base stations and user equipment are appealing for the reuse of the network components. External sensors may be near-term solution before the 6G timeframe. A sensing function like the ESC in CBRS would need time to convey information about measured interference that is worthy of network reconfiguration; action would be decidedly less agile in those cases. Research should also consider security implications of the use of sensors; mere sensing of energy at the network can be exploited by malicious actors.

4 Q4: Spectrum R&D accelerators

4.1 Data Management

The US Government should recreate an improved spectrum dashboard that clarifies actual use of spectrum bands wherever regulated radio services are in operation. Public data sets should be made available, including information about equipment in service, allowing for embargo of sensitive information.

4.2 Spectrum Competitions and Challenges

The Spectrum Challenges culminating in SC2 were an excellent approach to "gamification" of research efforts with the Colosseum testbed as a platform for comparative evaluation. The approach does have limitations; however, it is worth looking at rapid evaluation of competing approaches tuned to well-designed objectives.

4.3 Testbeds for Spectrum R&D

In addition to our support for the PAWR program mentioned earlier, we also support the OpenAirInterface Software Alliance (OSA) and serve on its board. Open-source stacks such as OAI allow researchers to delve deep into and modify network stacks at will. Testbeds that employ software defined radios show great promise but tend to be expensive to construct and operate.

Flexibility and visibility can also make it difficult to add complex functionality to testbeds. In PAWR, it has been a struggle to incorporate advanced beamforming and antenna arrays with flexible MIMO functionality. The Colosseum channel emulator also does not support large arrays. In-line emulation in digital twin environments offers good potential in conjunction with ray-tracing and advanced modeling as mentioned earlier.

In our opinion, it is better to aim testbeds towards the future, focusing on key experimental capabilities that facilitate the advancement of spectrum research, with all the flexibility and observability needed. A testbed focusing on current technology would have a hard time keeping up even with current commercial deployments.

We offer the following recommendations for future spectrum testbeds:

- Aim new testbeds towards the future, focusing on key experimental capabilities that facilitate the advancement of spectrum research. Dedicate new funding to focus on specific features that advance spectrum research.
- Reuse existing testbed infrastructure and strengthen its remote access capability. Proliferation of testbeds would dilute effort and slow progress.
- Build a new channel emulator that can scale with array size and number of nodes, relying on ray tracing techniques and digital twins of arrays.
- Adopt a common data model with detailed meta-data with associated software tools to facilitate usage by researchers in off-line experiments. Facilitate data collection with offline processing, rather than complete networks with real-time processing.

5 Q5: Immediate and near-term federal activities

The R&D plan should not stop the government from establishing a clear pipeline for spectrum availability for 5G and eventually for 6G. Apart from spectrum in the lower 3 GHz band, 7.125-8.5 GHz, and 12.7-15.35 GHz,[5] the government should also commit to examining the potential of the 4.4-4.94 GHz band. Near term activities are further detailed in Section 1.1.

6 Q6: Process to refine and enhance R&D plan

We recommend forming a committee composed from Industry, Academia, and Government representatives to review and further adjust the R&D plan. We emphasize the necessity to have industry involved.

7 Definition: Dynamic Spectrum Sharing

Dynamic Spectrum Sharing is the ability of two or more radio services operating across the same frequency range to adapt efficient utilization of that range in time, frequency, or space such that they can each provide their intended service in a cost-effective manner with minimal performance degradation or interference caused to other services in the range.

[5] This includes the recent FCC intentions to allot 12.7-13.25 GHz and potential spectrum in the 14 GHz range.

8 Conclusions

We reiterate that while the RFI addresses research and development, actions towards meeting immediate spectrum needs of the national telecommunication infrastructure should not be paused in anticipation of research outcomes. Academic work develops fundamental expertise, while testbeds expose possibilities that may be considered within standardized solutions.

Ericsson is a leader in its industry and devotes a substantial number of resources to R&D. Our expertise will be critical as the US considers new ways to access spectrum to meet traffic demand. The mobile industry depends on adequate spectrum availability to support cost-effective connectivity for all, including national imperatives around reliable public safety services and critical use cases supporting automation across major societal and industrial sectors. Securing a clear spectrum strategy that creates a pipeline of bands is an economic and national security imperative.

We have organized our recommendations into immediate, shorter term, and longer-term steps, and provided more details about the longer term, where R&D can be more ambitious and open ended. We expect shorter term solutions to be as simple as possible, exploiting the advanced features that already exist within mobile standards. Ericsson is committed to support the advancement of spectrum sharing as one solution to ensure a consistent and reliable access to spectrum.

ABBREVIATIONS

Abbrev.	Description	Abbrev.	Description
AERPAW	Aerial Experimentation and Research Platform for Advanced Wireless	NR	New Radio
AMBIT	America's Mid-Band Initiative Team (3.45-3.55 GHz)	NSS	National Spectrum Strategy
ARA	**A**gricultural and Ru**ra**l Communities	O-RAN	Open Radio Access network
CBRS	Citizens Broadband Radio Service	OAI	Open Air Interface
CISE	Computer and Information Science and Engineering	OSA	OpenAirInterface Software Alliance
DARPA	Defense Advanced Research Projects Agency	PAWR	Platforms for Advanced Wireless Research
EESS	Earth Exploration and Space Services	PFD	Power Flux Density
ESC	Environmental Sensing Component	R&D	Research and Development
FSS	Fixed Satellite Services	RF	Radio Frequency
FuSe	Future of Semiconductors	RFI	Request for Information
MIMO	Multi-Input Multi-Output (antenna)	RINGS	Resilient Intelligent Next Generation Systems
MSS	Mobile Satellite Service	SC2	Spectrum Challenge 2

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

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March 21, 2024

Ms. Mallory Hinks
National Science Foundation
2415 Eisenhower Avenue
Alexandria, VA 22314
USA

Re: Request for Information on the National Spectrum Research and Development Plan

Dear Ms. Hinks -

Federated Wireless, Inc. ("Federated Wireless"), the industry leader in the development and deployment of commercial dynamic spectrum management solutions ("DSMS"),[1] offers these comments[2] in response to the Request for Information ("RFI")[3] on the National Spectrum Research and Development Plan ("R&D Plan") issued by the National Science Foundation ("NSF") that seeks to "identify key innovation areas for spectrum research and development" that will achieve "measurable advancements in state-of-the-art spectrum science and engineering."[4]

We appreciate the opportunity to share our perspectives on this matter, which is of critical importance to the implementation of the National Spectrum Strategy ("NSS") and to sustained U.S. leadership in advanced wireless technologies and services. We hope our expertise in the development and deployment of groundbreaking DSMS technology and products will prove useful to NSF as it develops an R&D Plan that will identify priority areas and recommend productive directions to improve spectrum management and usage.

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[1] Federated Wireless is a certified Spectrum Access System ("SAS") administrator for the Citizens Broadband Radio Service ("CBRS") band and an approved Automated Frequency Coordination ("AFC") system operator for the 6 GHz band.

[2] This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

[3] National Science Foundation, Request for Information on the National Spectrum Research and Development Plan; *available a*t https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan ("RFI").

[4] RFI.

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1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering. This includes, but is not limited to, the following:

- ***Methods/approaches to increase coordinated investment in R&D amongst government agencies, academia, civil society, and the private sector***
- ***Structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D***

In order to assure that spectrum research results in measurable advancements, Federated Wireless recommends that the R&D Plan focus on 1) areas and projects that can be solved in the near-term; and 2) projects that include federal to federal, federal to commercial, and commercial to commercial sharing.

Furthermore, we strongly urge the federal government to refrain from "reinventing the wheel," particularly as it relates to DSMS technology and tools. There exist today commercial solutions that can and should be leveraged by the federal agencies to manage spectrum resources without the need for new federal development efforts. The commercial sector is willing and able to continue to invest in these DSMS capabilities and should be incentivized to do so. That being said, we recognize and encourage targeted federally funded research and development to enhance these capabilities as described in response to Question 2 below.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas. Areas of interest include, but are not limited to, the following:

- ***Spectrum utilization efficiency***
- ***Spectrum resilience and assured access for critical mission applications and passive scientific observation***
- ***Dynamic spectrum access and management***
- ***Spectrum situational awareness at scale***
- ***Automatic and rapid mitigation of interference problems***
- ***Modeling for coexistence analysis***
- ***Topics relevant to each of the above include, but are not limited to, the following:***
- ***Technical methods, designs, and processes***
- ***Economic-, market-, social-, and human-centric concerns***
- ***Business and economic models***
- ***Protection of citizen privacy, sensitive government missions, and business proprietary data***

- ***Cost-effective hardware supporting more dynamic spectrum usage***
- ***Use of artificial intelligence and machine learning techniques***
- ***Testbed development***
- ***Assessment and certification of advanced systems***

In addition to the list above, which is an excellent start, Federated Wireless recommends that the following research areas also be prioritized in the R&D Plan:

- Improvements to existing DSMS implementations, such as the CBRS SAS and 6 GHz AFC, to enable even greater spectrum efficiency. For example, today, the SAS manages commercial access to the band by listening for naval radar operations via a network of environmental sensing capability ("ESC") sensors, via an online scheduling portal, or through static exclusion zones. In many cases, commercial CBRS operations can be interrupted for longer periods of time or over larger geographic areas than necessary to protect actual incumbent use. The use of more real-time information, provided via automated notification, to manage access to frequencies and assign transmit power levels would improve shared spectrum access usage by commercial users. Similarly, the use of advanced propagation models would enable far more efficient use of available spectrum as compared to the outdated and overly conservative models that have been used historically. Finally, revision to incumbent protections requirements based on real-world measurements, rather than theoretical modelling, could greatly improve spectrum sharing and efficiency. Federal R&D funds should be targeted at these specific near-term improvement opportunities.

- Spectrum requirements and access challenges for non-traditional mobile network operators, including enterprises, municipalities, educational institutions, and other non-traditional operators.

- Virtualization of radio access network ("RAN") functions and a common, Open RAN Intelligent Controller ("RIC") with Service Management and Orchestration ("SMO") capability. Having a commercial-ready, common RIC/SMO platform will facilitate a wide community of developers to build applications to make more efficient use of 5G networks and spectrum on a massive scale and tailored to the use cases needs of various enterprises. Without such a platform, technology and solution development will remain hampered by the limitations associated with the closed, vendor-locked and preferred network configurations of large mobile network operators and their preferred suppliers.

- A common spectrum management platform for federal agencies to collect and analyze data about current real-world usage, while taking issues like cybersecurity into account. This platform could use cloud-based spectrum management, artificial intelligence/machine learning ("AI/ML"), advanced antenna technology, open and

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interoperable network architectures, cognitive transceiver technologies, advanced RF microelectronics, simultaneous transmit and receive, and edge intelligence.

- Improvements in workforce efficiency through use of autonomous vehicles, machine learning, and augmented/virtual reality applications.

- Low-rate initial production ("LRIP") of new software and hardware solutions aimed at Open RAN and spectrum management advancements.

- Spectrum sharing between terrestrial networks (3GPP, Wi-Fi) and non-terrestrial networks (LEOS, MEOs). Sharing/quasi non-cooperative and integrated operations should both be explored.

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts. Such problems have the following characteristics:

- ***The goal can be concisely articulated to stakeholders outside the field***
- ***Success or failure is clear***
- ***Achieving success requires advancing the state-of-the-art in multiple areas***

As described in response to the previous questions, Federated Wireless recommends that the government initiate R&D projects that, together with industry experts, can leverage cloud-computing and automation to maximize the efficiency of federal use, while also enabling more responsive, real-time sharing of spectrum between federal and non-federal users. With each iteration of DSMS technology, we have been able to greatly accelerate access to new spectrum bands. Rather than reinvent the wheel with each new band, however, we should build upon the successes of prior dynamic sharing frameworks and identify opportunities to iterate and improve.

We also recommend that market adoption challenges faced by small and medium-sized enterprises should be a focus area and that solutions developed through the R&D Plan should be able to be exported globally and become self-sustaining through commercial adoption. We recommend grant proposals contain statements on the project's relevance to commercial success and steps to transition from testbed to commercial operation. We also encourage the R&D Plan to include collaboration with organizations that can develop a statement of objectives and statement of work in a format agreed by a consortium or consensus of companies. Finally, non-traditional innovators should not be burdened by traditional federal acquisition regulation accounting or compliance processes, which will otherwise limit participation, especially by small and medium sized enterprises.

4. Recommendations on spectrum R&D accelerators such as the following:

- ***Shared public datasets***

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- ***Open-source software/projects***
- ***Cost-effective flexible radio platforms***
- ***Benchmarks and competitions***
- ***Testbeds, research infrastructure, and collaboration support***

To accelerate schedules and deliverables and leap ahead of global competition, it is important to ensure that access to funding is made available in the immediate future, rather than 8-10 years from now. To have meaningful impact on U.S. leadership in this space, we recommend that the R&D Plan endorses front-loading funding and prioritization of projects that have practical outcomes and a focus on commercial readiness.

Furthermore, the majority of the R&D Plan's support should go to small and medium enterprises to address operational and market adoption challenges, such as commercial readiness of development, security, and operations (DevSecOps), scale and availability, enterprise and security integration, monitoring and management, end-to-end testing, etc. Increasing and easing spectrum access for more enterprises to launch commercially relevant capabilities and supporting development of a common vendor-neutral RIC/SMO platform should be two areas that can be exported globally and become self-sustaining.

Federated Wireless encourages the R&D Plan to include Open Testing and Integration Centers ("OTICs") that can be operated over time and will support new product and application development and testing. While academic and government-run OTICs are important contributors, industry and use-case focused OTICs will be critical to ensure solutions make it to market and become self-sustaining.

We also recommend the R&D Plan expand existing Department of Defense ("DoD") investments in 5G testbeds to the surrounding communities for dual use commercial and military use cases. The NSC could provide industry consensus on prototype, trial and testbed approaches.

The R&D Plan should include the development of an open database of government research solicitations and corresponding results that can be input to a large language model ("LLM") and then queried by the public and government agencies. Such an approach will result in efficient coordination across the federal agencies and would significantly reduce the cost of understanding the state-of-the-art in spectrum research.

Open data sets (identified as an accelerator) are quite important for ML and were a key enabler for LLMs. However, if we want Large RF Models ("LRFMs") we need truly large, tagged, curated RF data sets, which is a significant undertaking and should be included in the R&D Plan. Furthermore, AI for RANs is a critical technology for 6G and would have overlapping data, but only partially. A similar initiative to establish a large open database of RAN metrics and operational data should be undertaken.

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NSF should take a more active lead in the development of open 3GPP and ORAN software repositories.

5. Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

Updating and improving propagation models and incumbent protection requirements should be top priorities for the R&D Plan.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

N/A

7. Terminology and definitions relevant for spectrum R&D.

- ***One term of interest is "Dynamic Spectrum Sharing" which is a focus of the National Spectrum Strategy but was not defined.***

Federated Wireless recommends that the terms "Dynamic Spectrum Sharing" and "Dynamic Spectrum Management Systems or Solutions" be defined as follows:

DSS (also referred to as Dynamic Spectrum Access or DSA) is the use of software, cloud-computing, automation, as well as alternative spectrum licensing approaches to enable more efficient use of spectrum by multiple network operators and/or end users.

DSMS are the technology and tools, including cognitive radios, spectrum sensing and environmental sensing technologies, spectrum access systems, and dynamic frequency coordinators, that together support DSS to dramatically improve spectrum utilization, increase the reach and reliability of wireless communication systems, and reduce the cost and complexity of deploying and managing wireless networks.

8. Other topics.

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Conclusion

Federated Wireless appreciates the opportunity to provide these comments on the NSS R&D Plan. Federated Wireless recommends that the R&D Plan focus initially on updating propagation models and fine-tuning incumbent protection requirements. We also encourage funds be directed towards projects that will solve spectrum access challenges by diverse users, invest in the development of open interfaces to manage network control, configurability, and optimization, and those that are focused on solving real-world commercial and operational challenges.

Respectfully submitted,

/s/ Jennifer M. McCarthy
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Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Idaho National Laboratory

INL Response to RFI on the National Spectrum Research and Development Plan

Introduction

Idaho National Laboratory (INL) addresses research and development needs that cannot be met as effectively by the federal government or the private sector alone. INL accomplishes missions by operating between federal government and private sector to maintain long-term competency on issues of national importance to develop and transfer technology to the private sector. INL maintains a high level of competency in advanced spectrum study and use as supported by our uniquely capable wireless testbed, development of state-of-the-art spectrum efficient waveforms, center for studying wireless security, and broad governmental support for spectrum topics. As such, INL strongly supports the new direction for the advancement of spectrum laid out by the National Spectrum Strategy and are encouraged to see the rapid development of the National Spectrum Research and Development Plan (R&D Plan)[1]. Identified herein are suggestions that aim to continue the excellent progress on the later.

Successful spectrum R&D plans should address three core areas: (1) approaches to drive innovation, (2) tools to support collaboration, and (3) methods to increase understanding. Each of these areas interacts to develop a spectrum R&D ecosystem based on collaboration that effectively realizes practical advancements. Together, these areas provide a conceptual framework for the R&D plan at large. Additional specific responses to topics raised in the RFI are detailed in the subsequent sections below.

Approaches to drive innovation focus on directly enabling innovative spectrum solutions in practical situations. Within this area, five concepts have been identified to underpin innovation in spectrum R&D: (1) diversity, (2) consistent funding, (3) clear transition pipelines, (4) workforce development, and (5) operational connection. The foundation of innovation is

[1] https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan

fostering a diversity of ideas that cover the full range of spectrum R&D. Thus, enabling innovation in spectrum R&D requires investigation of diverse models for spectrum sharing, diverse waveforms, diverse testbeds, diverse tools or systems for spectrum monitoring, and diverse spectrum bands. Harvesting the benefits of this diversity, requires some consistency in the approach to funding to avoid the cost of context switching; this consistency can be achieved either by employing several different funding sources or by establishing large umbrella funding programs, such as the NTIA Innovation fund. For the results of this funding to have practical impact, there must be a clear transition pipeline. This pipeline must span from more basic research as captured by academic publications, through establishing maturity through established testing frameworks, to commercial or governmental use assessments with relevant stakeholder involvement and awareness of relevant policy mechanisms throughout. Much of this transition also depends on having a workforce with the necessary skills and knowledge to leverage the developed innovations. Developing a new workforce, training the existing workforce, and providing the necessary reach-back support are important enabling elements of practical innovation. Finally, realizing the impact of innovation through transitioning technology depends on R&D that is well connected to potential operational uses. A spectrum R&D plan should consider mechanisms to address each of these elements to support spectrum innovation.

The broad scope of activities necessary for innovation in spectrum R&D requires collaboration. Developing the tools necessary to support collaboration is a critical element of spectrum R&D plan. Four categories of tools that should be considered are: (1) metrics to communicate value, (2) platforms for sharing, (3) mechanisms for idea exchange, and (4) methods for harvesting knowledge. A set of commonly used metrics provide the foundation for communication of the value of different spectrum technologies and are thus important to facilitate meaningful collaboration. Similarly, fostering broad collaboration requires some means to share data, results, and methods. For example, the combination of websites to host open publications (e.g., arXiv), websites to host open-source code (e.g. GitHub), and websites that connect the two (e.g., papers with code) have helped to foster broad collaboration in the area of machine learning. Beyond platforms to support sharing, mechanisms for idea exchanges, such as inclusive field trial events or regularly scheduled symposia, are necessary to enable collaboration. Finally, the development of methods to harvest knowledge from experimentation and experience underpins the content exchanged at such events or on sharing platforms. Together these tools provide a foundation for the collaboration necessary to develop a spectrum R&D ecosystem.

Finally, a spectrum R&D plan should promote and manage diverse research perspectives, including fostering understanding of spectrum uses and properties. Promoting diverse scientific, data driven approaches to spectrum assessment and technology development facilitates both the innovation and collaboration envisioned by the National Spectrum Strategy. This includes developing approaches to directly facilitate spectrum innovation through the use of band studies assessing Federal Agencies' mission needs compared with commercial and other special purpose needs. While the spectrum R&D plan ought to encourage a broad diversity of technologies, it must also facilitate comprehensive reviews of such innovations. Policy makers, including regulators (NTIA & FCC) as well as Agencies, must benefit from the spectrum R&D plan to inform well-designed national policies. Comprehensive band studies ought to specifically include: "out of band" interference detection and potential human health effects. The spectrum R&D plan ought to propose a process to mitigate identified challenges, in order to create a beneficial loop for future spectrum R&D and collaborative, innovative solutions. Based upon well-defined, scientific-based methodologies, the spectrum R&D plan should enable a culture shift in the management and use of spectrum to promote understanding of critical spectrum issues and then facilitate innovative solutions.

Spectrum Research Strategies

The R&D Plan should focus on practical, collaborative efforts that realize the impact of diverse innovations. This is perhaps most significant with regard to enabling research through the use of testbeds that offer a diverse range of capabilities. To this end, INL suggests the following points:

- There are a diverse set of test facilities available that should be leveraged, per Strategic Objective 3.2:
    - INL's testbed, POWDER, COSMOS, & Hat Creek Range Observatory each represent outdoor wireless testbeds with different characteristics to enable real-world measurements and field-testing of Dynamic Access Methods[2].
        - INL provides 890 square miles with broad access to RF spectrum and low ambient noise throughout nearly all bands. This facility is well suited to explore new concepts and validate approaches with minimal risk of interfering with incumbents.

[2] Dynamic Access Method is a rule or control system for spectrum access that depends on external conditions. It is an "if-then" statement to be executed at runtime (not design time) to enable a spectrum sharing model. This term defined by Dr. John Chapin (NSF) during NRDZCOM3 public event.

        - POWDER is situated within downtown Salt Lake City and provides the means to examine 5G and beyond in the context of an active city RF background.
        - COSMOS offers several software defined radio nodes interfaced to mobile edge computing functional in the heart of Manhattan for the purpose of exploring high bandwidth, low latency communications in an urban setting.
        - Hat Creek Range Observatory focuses on radio astronomy and provides a clear case of an especially sensitive incumbent user.
    - NSF's Spectrum X consortium offers a good model for facilitate experimentation-based collaborations.
    - NSF's RDZ concept directly examines stitching together the benefits of diverse testbeds through some overarching management and commonly available tools.
- The NSS testbed may be best realized as a coordination of existing resources
    - The R&D plan would be well served to investigate and leverage tools, for example:
        - Monitoring and RF control system, similar to OpenZMS as developed by the POWDER testbed and explored within the NSF RDZ efforts.
        - Experiment Management service to schedule and report test results to stakeholders.
        - Spectrum Management services to control spectrum sharing and manage risk of interference to operational systems.
        - Ability to properly monitor and store results of classified and unclassified tests.
        - Infrastructure to perform network administration and cyber-security monitoring.
    - If a single NSS testbed is envisioned, then it will still need to develop advanced monitoring systems to improve remote monitoring by research stakeholders and to enable Dynamic Access Methods.
    - If the NSS testbed is envisioned to be distributed and to leverage existing spectrum resource and testing stakeholders, then collaboration could be fostered through periodic stakeholder working meetings. Existing forums (NRDZCOM or WSRD) could be modified to include NSS testbed break-outs, or a new collaboration forum proposed. NTIA could use such meetings to provide status updates on spectrum sharing capabilities and challenges, and stakeholders

could present ideas to mitigate/resolve challenges or explore alternate spectrum sharing models.

Beyond enabling collaborative, experimentation-based research, the R&D Plan should champion science-based assessment of spectrum risk to inform policy. This should include methodology for identifying and managing the risk of interference generated by spectrum sharing disrupting ongoing operations. Activities associated with the research and development of spectrum sharing techniques must directly fold into the overarching science-based approach and risk management scheme. This implies important responsibilities such as:

- NSS Testbed should remain aware of nearby licensees and coordinate spectrum sharing research where required
- NSS Testbed research should be informed by ongoing Academic studies, as well as commercial or Agency mission needs. Stakeholder working meetings may be helpful.

Priority Areas for Spectrum R&D

As mentioned above, developing a diversity of RF techniques is a critical enabling factor for realizing a health spectrum R&D ecosystem. This includes examining the following elements:

- Robust RF prediction modeling tools capable of predicting out of band interference.
- Robust spectrum monitoring tools to manage interference risk; for example improve sensitivity to a changing RF environment, such as detecting arriving point to point antennas.
- Investigation of new kinds of spectrum sharing models (includes differentiating spectrum sharing models from spectrum sharing methods).
- Toolkit of waveform adaptations that could be employed to respond when interference is detected.

Given the broad potential impact of RF, spectrum security is an important cross-cutting consideration that must develop in tandem with all other topics. Spectrum sharing, in particular, will shift the security landscape of communications by opening large new attack surfaces and security considerations. The R&D Plan must set forth a means of addressing emerging security concerns as a foundation for trust in emerging uses of spectrum.

Further, INL has captured the following questions as significant obstacles to the realization of spectrum sharing research and development:

- What automation capabilities are necessary to enable "safe" spectrum sharing tests?
    - What is a minimum coverage of RF monitors during spectrum sharing research to confidently be aware of interference potential?
        - Consider "out of band" effects upon non-participating emitters
    - What opportunities exist to automate detection of potential interferers for Spectrum Managers?
- Under what conditions should spectrum authorizations not be limited to geographic area?
    - Consider a dynamic access method which completely operates as a secondary signal on a "not to interfere" basis with primary signals.
- What defines spectrum saturation in a spectrum sharing paradigm?
    - Is there a threshold of spectral efficiency (usage) above which spectrum should be classified as saturated?
    - What are the human effects of spectrum saturation? Are human effects equally significant for some individuals – and in particular frequency bands – based on continual low-level exposure as compared to overall power received?
    - Does "OOB" (out of bound) power increase with saturation?
    - Do non-linearities (e.g. accumulation of OOB energy) affect spectrum sharing effectiveness?
- How does a researcher confirm "not interfering"?
    - Consider limitations of passive sensing at a single point, as with Spectrum Access System (SAS), to detect interference to a Point-to-Point communications link, especially due to OOB interference.
    - How close is "too close" between a spectrum sharing experiment and the nearest point on a Point-to-Point communications link?

Grand Challenge Problems for Spectrum

The diverse nature of spectrum research suggests that the need for a Grand Challenge series with regular scheduled events to facilitate large scale collaboration and development on key spectrum issues. Given the objectives of the National Spectrum Sharing, a first focus area for such a series should likely be field trials of spectrum sharing technologies suitable for use in the 7 GHz band identified in the Strategy. While there are several specific use cases that could be examined in the 7 GHz band, sharing with significantly disadvantaged incumbents (e.g. MILSATCOM users) and geo-fencing based sharing systems with automated enforcement mechanisms seem to be the most pressing two use cases.

Whatever Grand Challenge Problem is actually set, events in the challenge series should set ambitious, quantifiable goals. Such an ambitious, quantifiable goal might balance the performance achieved by secondary users with the impact experienced by Primary users. For example,

> Dynamic access methods during this Grand Challenge should demonstrate operation with >6-sigma availability as a Secondary user without creating >50 ms downtime for any Primary user.

An appropriate outcome for a Grand Challenge event could demonstrate the reliability of new dynamic access methods in a operational environment. However, unexpected results and even failures from a Grand Challenge might reveal insights that provide a basis for subsequent challenge events.

Spectrum R&D Accelerators

INL identifies the following R&D accelerators as being significant:

- Diverse open access to testbeds, especially as enabled through the development of distributed testbed management systems.
- Training events that contribute to workforce development
- Platforms for sharing ideas and data
    - Data sharing must enabled by identifying the data models that should be supported for spectrum data
- Collaboration forums for spectrum sharing researchers
- Collaboration forums for testbed managers
- Events to facilitate hands-on experience for decision makers

Near-Term Federal Activities

INL identifies the following potential near-term Federal activities:

- Spectrum collaboration/showcase events that provide hands-on experience/observation of spectrum and spectrum technologies for existing Federal decision makers.
- 7-8 GHz field trial of spectrum sharing with incumbents aligned with Federal band study

Process for Ongoing R&D Plan Refinement

INL identifies the following mechanisms for ongoing R&D Plan refinement:

- Focus on ensuring that knowledge is harvested and disseminated through activities such as:
    - Encouraging academic publications or open publications where possible.
    - Augmenting planned events with lessons learned reports.
    - Holding seminar series from practitioners.
- Develop idea exchange mechanisms to review R&D approach. Existing forums like WSRD or Spectrum X meetings could be a starting point.
- Establish spectrum collaboration/showcase events as strategy meetings for decision-makers.
- Fund R&D through consist vehicles that establish long-term visions while maintaining the ability to leverage lessons learned. The NTIA Innovation Fund is an example of large-scale, well aligned, long-term funding umbrella.

Spectrum Terminology and Definitions

INL proposes the following important definitions and terminology updates:

- Dynamic Access Method: A rule or control system for spectrum access that depends on external conditions.
- Dynamic Spectrum Sharing (DSS): Operation of independent systems close enough together (in frequency, space, and time) that dynamic access methods are required to prevent harmful interference.
- Spectrum Sharing Model: An operational framework that defines roles and responsibilities of entities involved in dynamic spectrum sharing.
- 7.11.1.1 could specifically state that dynamic spectrum sharing tests/research is “authorized under this section” and that it’s distinct from electronic attack. Regardless of model.
- Discussion of interference should be refined to differentiate between acceptable (tolerable) and unacceptable (bad) interference.

Other Topics

The collaborative approach to research discussed above should extend beyond technology development and directly engage policy making. There are many emerging policy questions that would benefit from tighter collaboration with spectrum R&D activities. As examples of these questions, INL has identified the following:

- How often would regulators / policy-makers like to be informed of R&D results?
    - Continual monitoring from the Spectrum Monitoring system (or Zone Management System)?
    - Periodic briefings of major accomplishments, as at public idea exchange forums?
    - What metrics build regulators' trust that a dynamic access method is "safe" and "reliable"?
- Under what conditions should spectrum authorizations not be limited to geographic area?
    - Consider a dynamic access method which completely operates as a secondary signal on a "not to interfere" basis with primary signals.

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Request for Information on the National Spectrum Research and Development Plan

Jeffrey Reed (Virginia Tech), Nishith Tripathi (Virginia Tech), Vijay Shah (George Mason University), Vuk Marojevic (Mississippi State University)

Response to RFI on the National Spectrum Research and Development Plan[1]

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Below are recommendations in the NSF RFI on the National Spectrum Research and Development Plan.

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering. This includes, but is not limited to, the following:

- *Methods/approaches to increase coordinated investment in R&D amongst government agencies, academia, civil society, and the private sector*
- *Structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D*

Indeed, several agencies have conducted research into the more efficient use of spectrum, spectrum sharing, and policy behind spectrum sharing, and DoD and NSF appear to be the two leading agencies behind this research. Frankly, there is a slight overlap. NSF research

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tends to be more fundamental, and DoD research focuses on more applied research to improve spectrum sharing with radar systems. Furthermore, sometimes DoD efforts have ITAR or classification restrictions that are unacceptable to NSF and many universities. Nevertheless, while the research scope and TRL level are different, ensuring that both research camps know each other's efforts is valuable and needed. Some possible approaches to make sure of this knowledge transfer include:

1. Request from one agency to participate in PI meetings of another agency. To some extent, the ISART Conference run by the Institute for Telecommunications Sciences (ITS) of NTIA has helped with this role. Still, this conference could be shaped better to accommodate that knowledge transfer. An alternative to ISART is to use SpectrumX or other university organizations as a convener for technology transfer from key DoD and NSF projects.
2. Create webpage descriptions of the projects in both agencies to discriminate that knowledge. Projects from both DoD and NSF should be required to set up these pages and link them to a central website.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas. Areas of interest include, but are not limited to, the following:

- *Spectrum utilization efficiency*
- *Spectrum resilience and assured access for critical mission applications and passive scientific observation*
- *Dynamic spectrum access and management*
- *Spectrum situational awareness at scale*
- *Automatic and rapid mitigation of interference problems*
- *Modeling for coexistence analysis*

Topics relevant to each of the above include, but are not limited to, the following:

- *Technical methods, designs, and processes*
- *Economic-, market-, social-, and human-centric concerns*
- *Business and economic models*
- *Protection of citizen privacy, sensitive government missions, and business proprietary data*
- *Cost-effective hardware supporting more dynamic spectrum usage*
- *Use of artificial intelligence and machine learning techniques*
- *Testbed development*
- *Assessment and certification of advanced systems*

The key priority for research is described in recommendation 3. In addition, it is vital to remember that there are technologies, such as interference excision, that can significantly facilitate spectrum sharing. Understanding the theoretical capacity that intermit spectrum can provide (trunking gain) and the association of a value to that spectrum could increase the monetary value of this spectrum. Spectrum sharing, considering earth sensing, satellite-to-satellite communications, satellite-to-ground communications, and between space and non-space communications, will become a much bigger deal in the future with the proliferation of mega-satellite constellations. Optical links should be explored to support the necessary bandwidth for these systems and avoid interference with passive scientific uses of the spectrum.

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts. Such problems have the following characteristics:

- *The goal can be concisely articulated to stakeholders outside the field*
- *Success or failure is clear*
- *Achieving success requires advancing the state-of-the-art in multiple areas*

The most important outcome from the R&D initiative would be a spectrum-sharing framework that becomes internationally recognized through standards organizations, is widely applicable across bands, and fits within wireless service providers' business models/practices. Having international consistency on how spectrum is managed is critical to the success of spectrum sharing, allowing mass-market costing and minimization of international boundary conflicts. There are also potential advantages for the DoD in having an international spectrum-sharing regime for when international operations are needed. We are at a unique time when this is possible, and this opportunity should be embraced! For example, 6G is beginning to be defined by the 3GPP standards bodies. The O-RAN Alliance has established a framework for potential sharing using Open RAN (O-RAN) that resides on top of the 3GPP architecture.

While O-RAN is not perfect for spectrum sharing, it has many merits and can be modified as it evolves to be even more spectrum-sharing capable. It has features such as disaggregated components, AI provisioning, slicing, edge computing, and real-time control of base station parameters, and it can host various special applications (e.g., xApps and rApps). Leveraging the RAN Intelligent Controller (RIC) of O-RAN could allow bi-directional spectrum sharing and interference excision techniques. Crowd-sourcing techniques for spectrum awareness could also fit within the O-RAN framework.

There is much momentum internationally, especially in the US, to adopt O-RAN to enable a more competitive RAN infrastructure environment. Spectrum sharing is potentially the "killer app" for O-RAN, and if the US pursues this initiative, it could provide a competitive advantage. The combination of spectrum sharing and network sharing that O-RAN enables can be a potent combination for improving spectrum availability. The US has a major funded O-RAN R&D initiative that can immediately be leveraged to help address spectrum sharing and provide incentives for adopting O-RAN.

4. Recommendations on spectrum R&D accelerators such as the following:

- *Shared public datasets*
- *Open-source software/projects*
- *Cost-effective flexible radio platforms*
- *Benchmarks and competitions*
- *Testbeds, research infrastructure, and collaboration support*

One of the significant impediments in spectrum research is the inability to perform experiments at scale with cellular networks. While simply collecting datasets has benefits, they are limited. They cannot reflect the dynamics that occur when spectrum decisions and actions cause other things in the environment to change; for instance, a radar system changes its modes to deal with interference. Access to this testing type is difficult since service providers' networks are there to serve customers. One approach may be to leverage private 5G systems to perform these experiments, such as those 5G networks deployed on college campuses for experimentation. This way, dynamic behavior can be observed, and sufficient users in the network can exercise spectrum-sharing approaches.

Another approach would be to perform these experiments during or immediately after the deployment and testing of a service provider's "greenfield deployment," establishing new infrastructure in a new band before it is turned over to become a production network.

Another approach is to extend the Minimization of 3GPP mechanisms such as Drive Tests (MDT) and Network Data Analytics Function (NWDAF) to facilitate data collection intelligently and with minimum power consumption.

5. Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

In response to question 3, we suggest that O-RAN is a crucial enabler for spectrum sharing and that funds allocated for R&D be used to perfect this critical application of O-RAN. This could be done quickly with funds that are already appropriated.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

A long-term plan is needed for how the spectrum will be transitioned and for researchers to have enough time to apply their creativity to the bands in question. Each band is unique due to its legacy users and propagation characteristics. Developing a long-term framework for implementing spectrum sharing, such as using the O-RAN framework, will also quicken the pace and provide a platform for researchers to evaluate their innovations.

7. Terminology and definitions relevant for spectrum R&D.

NTIA should consider creating and publicizing a glossary of terms that represents the consensus of the research community.

8. Other topics.

Workforce training is important to ensure that spectrum is used and managed effectively. Many spectrum managers are reaching retirement age, and a new contingent of spectrum managers is needed. There should be an overlap between the new and older generations to be effective. This means that workforce development activities must commence as soon as possible. Typically, workforce development is NSF's responsibility, and while it can lead to such an effort, other agencies must be highly involved in it.

Acknowledgment: These comments are informed by NSF projects 2235139, 2120411, and 2128584.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

John Leibovitz

Implementation of the National Spectrum Strategy
Comments of John Leibovitz
January 2, 2024

The National Spectrum Strategy (NSS) released on November 13, 2023, states that "NTIA, working with Federal agencies, will continue to pursue development of an enduring, scalable mechanism to manage shared spectrum access, including through the development of a common spectrum management platform." NSS at 15. The concept of a common spectrum management platform is a key aspect of the NSS, because it creates the opportunities to take advantage of advances in technology, and to facilitate the achievement of other goals in the NSS, including the spectrum pipeline. Therefore, the development of an "enduring, scalable mechanism to managed shared spectrum access" should be a top priority in the Implementation Plan, and resources towards this effort should be front-loaded.

Spectrum sharing is by now well-enough developed that there are known elements that transcend bands and use cases. It should be possible to distill these elements into a common platform. A September 2021 paper I co-authored, *Taking Stock of Spectrum Sharing*, [1] included a basic framework with examples of different sharing systems that have been used:

Sharing Mechanism	**Centralized**	**Decentralized**
Coordinating (e.g., Database)	TVWS, AFC, SAS	Some CIRN systems
Sensing	ESC	LBT, DFS
Informing	IIC	Beaconing

Fig. 2: Basic Spectrum-Sharing Framework

A common spectrum sharing platform would accommodate these known use cases and anticipate others that might emerge. Its development should draw on past experiences with sharing between Federal and non-Federal users, among Federal agencies, and among commercial users. It will be important to understand stakeholders' experiences with different bands and different use cases and to anticipate the bands and use cases of the future. Expertise from both inside and outside the Federal government will be essential in this regard.

In developing the platform, NTIA should focus on three main components: (1) the architectural vision; (2) the implementing technology platform; and (3) the enabling regulatory framework.

(1) Architecture. NTIA should begin with a time-bound process to align on a common, high-level vision of the future spectrum-sharing architecture. As an output from this process, NTIA should develop a reference document that describes the key elements of the spectrum sharing architecture. This document need not be long or convoluted. In fact, given the need to accommodate change and evolution, an easily referenceable set of high-level diagrams is preferable to a weighty tome. This deliverable should become a living document with specific organizational units at NTIA and the FCC identified as its "keepers," similar to how the Table of Allocations has been managed for decades. The diagram below illustrates a high-level architecture concept.

[1] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3916386

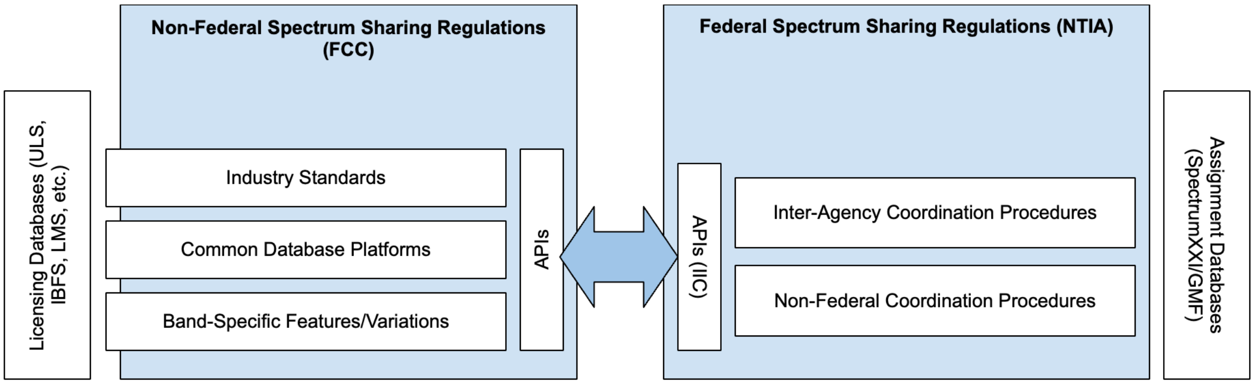

Fig. 1: Illustrative High-Level Spectrum Sharing Architecture

The visioning process described above would produce a more fleshed-out version of this diagram – or something similar – that could be used to drive alignment and a common vernacular among spectrum-sharing stakeholders.

(2) Technology Implementation. The implementing technology platform should use a definition of shared spectrum access that is broad enough to cover a wide range of evolving sharing scenarios and enabling technologies. The platform should encompass both dynamic (e.g., "CBRS-style") and slow-time (e.g., "AWS-3 style") sharing among different sets of constituent users both on the government side and the civilian side (e.g., carrier networks, private networks, hybrid networks). The eventual goal should be to replace manual frequency coordination with automated techniques. Modular design would provide flexibility to address sharing solutions tailored to specific bands and use cases, with the ability to upgrade components over time. On the Federal side, the technology platform may include the creation of a reusable, extensible system to facilitate automated sharing among Federal users that also interoperates with non-Federal sharing systems to facilitate commercial spectrum access. (The Incumbent Informing Capability would be one feature set of this system.) On the non-Federal side, modernization of enabling systems (e.g., the FCC's Universal Licensing System) would enable real-time information flows to spectrum-sharing infrastructure. Non-Federal sharing also benefits from development of industry standards (e.g., through standards bodies such as 3GPP) that encourage consistent, competitive implementations of sharing approaches across multiple bands and situations.

(3) Regulatory Framework. NTIA, working with FCC, should develop a modular, reusable, and extensible regulatory framework for spectrum sharing that mirrors its "digital twin", the model technology implementation. The development of spectrum sharing has been hindered by the tendency to develop all-new regulations for each band, rather than creating a generalized regulatory solution that can be reused and refined over time. One symptom of this tendency is the lack of common regulatory vernacular for similar concepts across multiple spectrum bands. The result has been an alphabet soup of acronyms for basically similar regulatory frameworks. For example: "TV White Spaces Database," "Spectrum Access System," and "Automated Frequency Coordination" all refer to essentially the same technology of using a database to deconflict different spectrum users. The better approach would be to establish a basic set of rules for the use of central databases to enable sharing. These rules would be codified in the FCC's regulations and in the NTIA Manual. Commonality should be embraced; any necessary band-specific differences could be accommodated as variations from the core rules.

As noted above, modularity is an especially important design principle. The architecture, technology platform, and regulatory framework might include "parallel" modules for various spectrum sharing scenarios (e.g., database coordination, sensing mechanisms, informing capabilities). Over time, other modules could be added (e.g., an Artificial Intelligence (AI) module to implement complex sharing procedures). These modules could be used individually or in combination to achieve the desired result. Once there is a common regulatory framework, it will be possible to determine which modules apply to which bands. Some bands may require only a subset of the overall system capabilities.

The effort to develop a common spectrum management platform will be best served by full alignment between NTIA and the FCC. Much of the discussion of mechanisms for sharing, especially in the context of the National Spectrum Strategy, has been focused on sharing between Federal government and commercial uses. But future spectrum sharing could potentially be architected in a way that is flexible enough to accommodate non-Federal sharing scenarios as well. Close cooperation between NTIA and the FCC will pay dividends by providing a roadmap to facilitate common technology platforms for sharing across different bands.

John Leibovitz is the principal of Jupiterra LLC. He was previously Deputy Chief of the Wireless Telecommunications Bureau and Special Advisor for Spectrum Policy to the Chairman at the Federal Communications Commission (2009-2015). The views expressed in these comments are solely those of the author.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Lockheed Martin Corporation

NSF RFI Response: National Spectrum R&D Plan

LOCKHEED MARTIN CORPORATION

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21 March 2024

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Contents

1. Introduction

Lockheed Martin Corporation ("Lockheed Martin") appreciates the opportunity to submit these comments to the Networking and Information Technology Research and Development ("NITRD") National Coordination Office's ("NCO"), National Science Foundation ("NSF") Request for Information ("*RFI*"), *Request for Information on the National Spectrum Research and Development Plan*.[1] Lockheed Martin commends the NSF for working to advance coordinated, focused, and sophisticated research and development ("R&D"), which the White House *National Spectrum Strategy* ("*NSS*")[2] recognizes as paramount to improving our collective understanding of spectrum—a critical step to developing the co-existence solutions necessary for optimizing the U.S.' spectrum governance regime for the 21st Century. Lockheed Martin has been a vocal public proponent of co-existence[3] and thus looks forward to working with the NITRD NCO to develop an R&D plan which ensures that *all* spectrum users across *all* access models (*e.g.* licensed, unlicensed, experimental) may continue benefitting from our scarce and increasingly congested spectrum resources.

Lockheed Martin is a global enterprise principally engaged in research, design, development, manufacture, and integration of next-generation spectrum-utilizing technology systems, products, and services for both commercial and government customers worldwide. Examples include, but are not limited to: the nearly 800 spacecraft Lockheed Martin has built for a wide range of government and commercial missions; critical national security space capabilities; radar platforms; and myriad fixed wing and rotary-wing aircraft relied upon by governments and private sector entities globally. Further, Lockheed Martin is also looking to leverage commercial 5G technologies for the terrestrial and non-terrestrial solutions it is developing for its customers.[4]

Lockheed Martin has previously partnered with the NSF on matters of critical scientific importance, and similarly intends to work with the NSF on the nationally significant issue of spectrum R&D. Further and notably, Lockheed Martin not only develops systems, products, and services which utilize Federal spectrum allocations, but is itself a Federal Communications Commission ("FCC") licensee. As a necessity, due to its own technology research, development, testing and evaluation ("RDT&E") and sustainment activity, Lockheed Martin routinely works with the National Telecommunications and Information Administration ("NTIA") and the FCC, and other spectrum stakeholders in government, academia, and the private sector, on important issues of spectrum engineering, policy, regulation, and governance.

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[1] NSF, *Request for Information on the National Spectrum Research and Development Plan* (rel. Feb. 20, 2024)

[2] The White House, *National Spectrum Strategy* (rel. Nov. 13, 2023), https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf.

[3] *See e.g.*, Comments of Lockheed Martin (Docket No. NTIA-2023-0003) (Apr. 17, 2023), https://www.ntia.gov/sites/default/files/publications/lockheed_martin.pdf; Supplemental comments of Lockheed Martin (Docket No. NTIA-2023-0003) (Jun. 28, 2023), https://www.ntia.gov/sites/default/files/2023-07/lockheed_martin_written_input.pdf; and Lockheed Martin comments to NSS Implementation Plan Request for Comment (Jan. 2, 2024), https://www.ntia.gov/sites/default/files/lockheed-martin-written-input.pdf.

[4] *See, e.g.*, Lockheed Martin, Lockheed Martin and Verizon to Advance 5G Innovation for U.S. Dept. of Defense (accessed Mar. 20, 2024), https://news.lockheedmartin.com/lockheed-martin-verizon-advance-5G-innovation-us-deptartment-defense.

Lockheed Martin emphasizes the importance of a national security-first R&D approach and the need to evolve R&D as a continuum model. Further, and whereas national security-first is an overarching concept to guide R&D, insofar as the development and deployment of specific technologies, Lockheed Martin ardently believes that dynamic spectrum sharing ("DSS") technologies must be the R&D Plan's primary priority. Our Nation's spectral environment is increasingly congested, with little to no greenfield spectrum left, thereby necessitating that increased spectrum demand be met through shared spectrum use—co-existence (*i.e.*, not compression, or forced Federal relocations, etc.). The need for DSS is made all the more necessary when one considers that mission critical national security technologies, such as radar, require access to very specific spectrum bands and the relocation of which could take decades and cost hundreds of billions of dollars—if suitable alternative spectrum even exists.[5] Despite this reality, policymakers have still displayed a keen interest in forcing national security systems to compress operations or relocate. This policy reality makes the need for DSS enabling true co-existence between national security systems and commercial new entrants all the more important.

2. Strategies for Conducting Spectrum R&D

2.1 A national security-first approach

The *RFI* seeks comment on structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D. Given our belief that spectrum co-existence must be the Plan's key objective, we recommend the adoption of a national security-first approach: the mission requirements of national security systems must serve as the bedrock for any spectrum R&D—requiring close coordination and collaboration with the Department of Defense ("DoD") and the Defense Industrial Base. The nature of these systems necessitates that commercial new entrants to bands already committed to these critical government functions conform to national security system needs, allowing DoD and other Federal users to meet the Nation's national security and other requirements. Further, national security systems often represent congressionally-approved multi-billion-dollar investments intended to remain operational for decades; it is likely less burdensome for national security technology considerations to drive development of commercial new entrant devices—which often have refresh periods on the order of months or a few years—as opposed to, for instance, requiring the Nation's ballistic missile defense system to conform to the needs of such commercial new entrant devices.

While DSS R&D considerations are discussed in-depth below, the following provides an example of the national security-first approach. Federal bands are the sole subject of *NSS* efforts to identify more spectrum for the spectrum pipeline,[6] thus (pending a major policy change)[7] the most likely spectrum reallocation scenarios are those where commercial entities gain access to

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[5] *E.g.*, with respect to the 3.1-3.45 GHz, Secretary of the Navy Del Toro testified that relocating the Navy's systems alone is "enormous…upwards of $250 billion probably". Testimony of Secretary of the Navy Carlos Del Toro before the United States Senate Committee on Armed Services (Apr. 18, 2024).

[6] *See NSS* at note 1.

[7] Lockheed Martin strongly supports expansion of the *NSS* such that commercial bands are also studied for repurposing, however recognizes such policy issues are outside the scope of this *NOI*.

bands utilized by national security systems to protect U.S. citizens and U.S. interests. Commercial devices are increasingly comprised of software defined radios with poor cyber-secure implementations that enable assembly of large quantities of interfering agents. DSS R&D must develop mechanisms to address the nefarious co-optation of such systems in order to degrade or otherwise harm DoD's incumbent capabilities within the band.

We further wish to clarify that a national security-first approach does not mean that all aspects of Federal systems' use of spectrum should remain unchanged. Rather, as discussed above, it means that the operational considerations for such systems should retain primacy over those of aspirant commercial new entrants in bands that are already committed to national security and other critical uses. For instance, in bands where new entrants seek exclusive high-power use, but where such use is incompatible with incumbent Federal systems, R&D should focus on achieving co-existence with Federal systems, as opposed to compressing Federal operations.

2.2 Leveraging existing work

As the NSF well knows, there is much disparate spectrum R&D underway across government, industry, and academia. We recommend the establishment of a mechanism through which entities can report to the NSF the nature and progress of their work such that R&D may be catalogued in order to identify both possible synergies between different groups and unnecessary duplication of efforts.

2.3 Testing and evaluation as a continuum

For spectrum R&D to remain agile, testing and evaluation must (i) evolve to provide focused and relevant information supporting decision-making continually throughout capability development and (ii) be predicated upon a sturdy foundation of in-place data and analytics. Such enhancements would allow testing and evaluation to move from a serial set of activities conducted largely and independently of systems engineering and mission engineering to a new framework focused on a continuum of activities. Test and evaluation as a continuum is being adopted by the DoD,[8] and we recommend that the NSF similarly consider its applicability for the R&D Plan.

3. Priority Areas for Spectrum R&D

3.1 In general

Excepting spectrum utilization efficiency, as discussed in the next section, Lockheed Martin is generally supportive of R&D in those areas outlined within the *RFI* by the NSF, as well as the topics associated with the enumerated priority areas.

3.2 Spectrum utilization efficiency

Lockheed Martin has elsewhere[9] and here too emphasizes that establishing a maximally shared spectral environment is a preferable objective over utilization efficiency, as efficiency is too relative a term. However, should the NSF choose to continue researching utilization efficiency, a

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[8] *See* Christopher Collins and Kenneth Senechal, "Test and Evaluation as a Continuum", ITEA Journal of Test and Evaluation Vol. 44 Iss. 1 (Mar. 2023), https://itea.org/journals/volume-44-1/test-and-evaluation-as-a-continuum/.

[9] *See* Comments of Lockheed Martin (FCC WT Docket No. 23-232) (Oct. 3, 2023), https://www.fcc.gov/ecfs/document/100493560734/1.

crucial initial step is defining "efficiency" and for whom. For example, what Lockheed Martin considers to be efficient for military radars is likely not the same as what mobile network operators consider as efficient for their networks (and vice-versa). Further, we recommend developing a methodology allowing for the incorporation of qualitative spectrum use information, as opposed to purely quantitative data, *e.g.*, the FCC has noted that "several bands may exhibit infrequent usage that are nonetheless mission critical for their intended uses…".[10] The mission criticality of systems cannot be appropriately captured through quantitative data.

3.3 Dynamic spectrum sharing, generally

We agree with the *NSS*' characterization of spectrum as "congested",[11] and believe that DSS will play a critical role in expanding spectrum access for *both* Federal and non-Federal users, and also help stakeholders move past a zero-sum, winner-take-all spectrum mindset.

Regarding specific existing work, the Citizen's Broadband Radio Service ("CBRS") represents an initial starting point for further R&D into low-power sharing regimes capable of effectively enabling co-existence between Federal incumbents and commercial new entrants. Not only does the NTIA consider CBRS a success,[12] it is making significant progress in closing the digital divide: 70% of all active (CBRS) devices are deployed in rural census blocks.[13] Further, 45% of all (CBRS) devices are deployed in counties where spectrum is shared with DoD, highlighting low-power 5G's ability to co-exist with national security incumbents.[14] Appropriately directed R&D funding can facilitate the development of the next generation of a CBRS-like operating environment.

3.4 Dynamic spectrum sharing for assured access for critical mission applications

An ideal DSS system for DoD co-existence offers an opportunity to both provide an economic benefit, and improve electromagnetic battle management approaches for coalition and joint communications and electronic warfare. We recommend that DSS R&D focus on developing a solution which can:

1. Provide sharing mechanisms that can cope with malicious contention, both in terms of adversarial actions (*e.g.*, spoofing and jamming), as well as additional non-collaborative interferers that native systems were not designed to address (*e.g.*, military heterogeneous networks);

2. Provision for mechanisms to handle failure modes of commercial equipment during operation, as well as improper and malicious deployments. Such mechanisms should include real-time direction finding and geolocation;

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[10] FCC, *Advancing Understanding of Non-Federal Spectrum Usage* at ¶ 22, Notice of Inquiry, WT Docket No. 23-232, FCC 23-63 (rel. Aug. 4, 2023).

[11] At 11.

[12] NTIA, The Innovative Spectrum Sharing Framework Connecting Americans Across the County (accessed Dec. 6, 2023), https://www.ntia.gov/blog/2023/innovative-spectrum-sharing-framework-connecting-americans-across-country.

[13] *Id.*

[14] *Id.*

3. Mitigate Electronic Attack ("EA") techniques which are easier and more successful against targets operating in narrow slices of spectrum;

4. Provide mechanisms to address the co-optation of what will become a ubiquitous deployment of commercial devices designed to occupy and share bands with DoD systems. These commercial devices are increasingly comprised of software defined radios with poor cyber-secure implementations that enable assembly of large quantities of interfering agents (a scenario that would have otherwise required an adversary to overcome the challenge of covertly deploying a large number of EA assets);

5. Support graceful degradation of spectrum sharing in a way that supports mission critical users without compounding problems through "fail open" (suppress all transmission) designs;

6. Avoid revealing any aspects of military tactics, techniques, and procedures through the long-term analysis of military system reactions to system inputs. This is essential to prevent adversary adaptive systems from determining the behavior of defensive systems through machine learning techniques; and

7. Enable defense systems to use more spectrum than previously allocated during mission critical events (*e.g.*, by enabling increasingly agile DoD systems to leverage additional commercial and unlicensed spectrum during emergencies (an expansion of the first responder models for national defense scenarios)).

Co-existence between critical national security and commercial systems inherently introduces national security vulnerabilities. It is imperative that a spectrum access management system prevent commercial or secondary users from disrupting Federal spectrum usage while ensuring commercial users have ample opportunity to use their allocated spectrum (or more importantly, bandwidth). Potential vulnerabilities of such a DSS infrastructure must be fully understood and carefully mitigated to minimize impacts on national security.

When considering threats, a DSS system with the following components should be utilized:

1. United States Government ("USG") Incumbent Users ("UIU"): USG users provided priority access to spectrum, such as Federal radiolocation systems, satellite access systems, and components of a DoD private 5G network.

2. Real-Time Spectrum Sensors ("RTSS"): Sensors installed in the field to detect USG asset spectrum usage, authorized commercial user devices, and unauthorized or failed devices. The RTSS could be an explicit device, as in CBRS, or an intrinsic capability of UIU systems.

3. Real-Time Spectrum Management ("RTSM") system: a system that allocates spectrum to authorized users and coordinates their access in frequency, time, and geographic area. A critical aspect of real-time assessment of spectrum resource assignments, which also serves as the basis for USG situational awareness.

4. Authorized Commercial Users: commercial users such as 5G gNodeB base stations that use the spectrum under the control of RTSM.

4. Conclusion

We applaud the NSF's efforts to develop an organizing national document for spectrum R&D, which will go a long way to helping ensure that our Nation's scarce spectrum resource best serves all spectrum users across all spectrum access models. Given the criticality of national security systems, it is imperative that the R&D Plan adopt a national security-first approach, and prioritize the development of DSS technologies which would allow national security incumbents to remain in the spectrum needed to successfully perform their statutorily mandated missions. Lockheed Martin thanks the NSF for the opportunity to provide feedback to the *RFI* and looks forward to working with the NSF on this most important effort.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Shared Spectrum Company (SSC)

Shared Spectrum Company's Comments on
Request for Information on the National Spectrum Research and Development Plan
March 21, 2024

Background:

The National Spectrum Strategy (Strategy), November 13, 2023, Strategic Objective 3.2 directs the U.S. Government, through the White House Office of Science and Technology Policy and in coordination with the Federal agencies, to develop a National Spectrum Research and Development Plan (R&D Plan). The R&D Plan will act as an organizing national document, providing guidance for government investments in spectrum-related research and offering valuable insights. The plan will identify key innovation areas for spectrum research and development and will include a process to refine and enhance these areas on an ongoing basis. OSTP has tasked the NITRD Wireless Spectrum Research and Development Interagency Working Group (WSRD IWG) to draft and coordinate development of the National Spectrum R&D Plan. The R&D Plan is expected to be released in late 2024. Revisions will occur periodically. The NITRD WSRD IWG requests input from the public, including academia and industry, to assist in development of the National Spectrum R&D Plan.

Introduction:

There have been a large number of spectrum related research projects in the past twenty-five years that have created significant insights on spectrum sharing challenges, approaches, and technical capability. Most of this capability has not transitioned into use for two main reasons:

- Viable spectrum sharing solutions vary across spectrum bands due to requirement differences related to technical, business, operational, and policy factors. Adding technology solutions modifies these requirements. It takes significant research and effort to obtain the requirement knowledge, and this information is not widely available to the broader research community. Spectrum problems are usually quite complex with multiple subtle interactions between systems. As a result, most proposed solutions are incomplete and will not solve the problem.

- There has been minimal funding/projects to develop or field test spectrum sharing technologies. Thus, spectrum-related technologies are typically dismissed because they are perceived as unproven (i.e., too much risk) or don't meet all of the requirements (i.e., too expensive). To avoid this, the tests need to include operational legacy systems and consider all requirements. The field test needs to be of interest to the stakeholder, and not a generic test.

Despite these challenges, technology and system concept advances over the past 25 years have produced the essential building blocks to produce band-specific needs.

Shared Spectrum Company (SSC) Recommendations:

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering.

The National Spectrum R&D Plan should focus spectrum-related R&D on specific spectrum bands. System requirement studies that assume alternate solution approaches should be performed by contractors to establish what is needed in all dimensions (technical, business, existing spectrum eco-system compatibility, and policy factors).

The National Spectrum R&D Plan should fund development and test of solutions in specific spectrum bands. These projects should mature the spectrum-related technologies so that they meet most of the requirements. The projects should include an advisory board that contains representatives of all involved parties to validate the test plans and the test results. Multiple solution approaches should be funded in parallel so that critical technology-based decisions are based on experimental evidence and not solely untested proposed solutions.

The plan should also seek to understand what capabilities from the prior 25 years of research can be leveraged. This should include an assessment of what sharing problems they address, how they fit within effective operational architectures, how mature they are, and what investments are required to achieve an operational readiness.

The National Spectrum R&D Plan should address high priority ‘hard’ spectrum bands and ‘easy’ spectrum bands. Hard spectrum band examples include DoD sharing with commercial cellular providers, which has huge relocation costs and national security issues. Easy spectrum band examples include the 2025-2110 MHz ENG band and sharing within federal only bands. The Easy band solutions will be achieved at lower cost and more rapidly than the Hard spectrum bands. The Easy band solutions will provide lessons learned and experience.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas.

As mentioned above, the National Spectrum R&D Plan needs to focus the majority of resources on development and test. In particular, the plan should establish a persistent test and evaluation capability in which solution providers can test, evaluate, and demonstrate their capabilities for assessment. This capability should allow for iterative testing and provide the Government with the ability to form collaborations among solution providers to achieve desired integrated capabilities.

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts.

Grand challenges need to focus on specific band, comprehensive system solutions. It is unclear that a dramatic improvement in any one technology would make a significant improvement.

4. Recommendations on spectrum R&D accelerators.

The National Spectrum R&D Plan should assemble all stakeholders in specific spectrum bands into working groups. The groups should postulate alternate technical solutions and create requirements. Some system solutions might include combinations of technical approaches. Reallocation could be one potential approach. The goal is to understand and to document all concerns so that the research community and the stakeholders have a common understanding.

5. Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Small Cell Forum Ltd (SCF)

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A response to the Request for Information on the National Spectrum Research and Development Plan - 03/21/2024

About the SCF[1]

SCF is a global organization whose mission is to enable and accelerate the sustainable digital transformation of industry, enterprises and communities. We do this by supporting a range of agile, cost-effective, scalable, cellular infrastructure and solutions for established and emerging service providers and deployers.

Our Membership & Board is drawn from across the global Telecoms supply chain. Countries and Regions that are represented include (but are not limited to) UK, EU, US, India and Middle East. Members come from the Service provider and neutral hosting as well as network product and chipset segments.

We gather requirements from service providers' businesses and, directed by our Board, these inputs shape our work program. Our specifications, technical papers and enterprise-focused outputs are made freely available to benefit the wider industry.

Today our members are working on projects spanning disaggregated network architectures, private networks, neutral host requirements and business model evolution, 5G small cell products, and policy and regulation.

Response to R&D Plan

Having reviewed the National Spectrum Strategy from the National Telecommunications and Information Administration (NTIA), we have the following recommendations regarding the creation of the R&D plan.

The SCF has noted the development of initiatives regarding the concept of a **Spectrum Sandbox**. We bring to your attention recent notable activities in the UK[2] and in India[3]. Members of the SCF take an interest in these activities and in some cases are participating. We see relevance of the Spectrum Sandbox in informing multiple of the pillars of the strategy, in particular pillar one and pillar three:

- For Pillar One establishing a spectrum pipeline to ensure U.S. leadership in advanced and emerging technologies. The spectrum sandbox can enable an evidence-based approach to the technology and spectrum bands mix in which efficient use of spectrum can be improved through the optimisation of technologies across the 7-layer ISO stack.
- For Pillar Three establishing Unprecedented Spectrum Access and Management through Technology Development. The spectrum sandbox concept enables an evidence-based approach to the refinement of data driven and Telecoms management system approaches. This may lead to aligned Spectrum user and spectrum regulator automated mechanisms. The CBRS protocol has been seen to enable usage of spectrum in a

[1] https://www.smallcellforum.org/about-us/
[2] https://uktin.net/whats-happening/news/everything-you-need-know-about-spectrum-sandboxes
[3] https://www.deccanherald.com/business/dot-unveils-spectrum-regulatory-sandbox-to-promote-r-d-in-telecom-2931836

particular band, this may be expandable to other bands, or new mechanisms and automations can be discovered through R&D.

A typical Spectrum Sandbox may be constituted as a one-off collaborative project between industry and academia or could be a capability built into existing facilities in the US or collaboratively with similar initiatives overseas. Typically, the Spectrum Sandbox would have the following activities:

1. Deployment of (pre-)commercial systems to run trials and gather data to capture real world performance of radio systems. Typically to investigate the efficient use of spectrum for co-existence of pairs of technologies and how the protocols and algorithms can be adjusted within existing standards or to investigate evolution of standards. Pairs could for example include Wi-Fi and mobile, Satellite and private networks spectrum, x-haul like configurations with fronthauling and backhauling co-existence.
2. Simulation and modelling to utilise the data from the trials systems and perhaps also to extend the insights through further simulations that investigate extrapolations from the trials.
3. Economic analysis that investigates the cost and benefit implications of the technology innovations and the more efficient use of spectrum. In the case of co-existing systems, the degree to which different efficient use of spectrum approaches can have wider economic benefits can be tested as part of the sandbox conclusion development.

From an area network (City, Campus, in-building, near in-building) perspective, where multiple stakeholders are involved, warranting infrastructure capacity to enable infrastructure sharing and enabling of neutral hosting multi-operator approaches. We see the following opportunities for R&D investigations framed within a spectrum sandbox:

- Coexistence / Interference (Adjacent / co-channel, multi-path, and other wireless characteristics)
- Adjacent Band considerations
- Spectrum aggregation and Carrier Aggregation)
- Power level studies
- Scenario based sharing studies (WLAN/WWAN) (Indoor/Outdoor/Mixed)
- "unexplored' bands such as 7-24 GHz, including Channel Models
- Spectrum quality studies (stability, availability)
- Drone-based / Swarm Small Cell deployments
- Sensing and Fast Mitigation Spectrum Studies
- Novel spectrum sharing techniques for Dynamic Users
- Dynamic Spectrum Slicing
- Disjoint Spectrum Banding
- Use of data-driven, AI-based realtime technologies for dynamic spectrum management
- Cross layer approaches to spectrum utilization and management

We welcome this opportunity to provide an input to the development of the National Spectrum Research R&D Plan. The Policy and Regulation Group of the SCF remains at your disposal for any clarifications and to further assist with the refinement of requirements of our recommended Spectrum Sandbox approach.

SCF Chair and Chair of the Regulatory and Policy Group (RPG) - [redacted]
SCF Chief Strategy Officer – [redacted]

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Spectrum Effect

SPECTRUM EFFECT

Spectrum Effect Response: NSF RFI on the National Spectrum R&D Plan

Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO), National Science Foundation

March 21, 2024

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www.spectrumeffect.com

Spectrum Effect welcomes the opportunity to respond to the National Science Foundation's (NSF) Request for Information (RFI) on the National Spectrum R&D Plan.

COMPANY PROFILE

Spectrum Effect develops software for the global mobile operator community with state-of-the-art solutions for radiofrequency (RF) interference analysis and mitigation. Spectrum Effect's leading product, Spectrum-NET, utilizes patent-protected machine learning (ML) algorithms in private and public cloud environments to analyze cellular network performance data and provide operators with improved situational awareness and the ability to mitigate harmful interference in near-real time. More than 7,000,000 hours of labeled RF interference data from 50+ mobile operator networks are used to train Spectrum-NET's Convolutional Neural Network (CNN) models, resulting in the industry's highest accuracy solution for automatically classifying RF interference signatures.

We are a U.S. company headquartered in Kirkland, WA. The Spectrum Effect team is passionate about creating disruptive technologies, engineering excellence, and enhancing the experience of mobile operators. Our perspectives reflect our role as a developer of software used by Tier-1 U.S. mobile carriers and as a party interested in assisting federal stakeholders better craft solutions for efficient spectrum management.

SPECTRUM EFFECT'S OVERALL COMMENTS ON THE RFI

Spectrum Effect appreciates that NSF, through the NITRD NCO, is collecting industry feedback as it implements the National Spectrum Strategy (NSS) and works towards promoting an R&D ecosystem that can aid the future spectrum economy.

From our perspective, it is essential that federal R&D efforts select the correct targets for promoting key areas of innovation. The creation of an R&D plan that supports the strategic goals of the NSS will undoubtedly lead to closer public-private collaboration on technical standards and policy related to spectrum management technologies. This is particularly true for Spectrum Effect, which has historically operated in the commercial market, but would be further enabled by the opportunity to partner with federal agencies and research organizations on their efforts to promote the adoption of advanced spectrum management capabilities.

Our data scientists and engineers have developed innovative solutions in-house which are covered by over 30 patents. However, we have not yet had the opportunity to collaborate more broadly with academic institutions or civil society organizations. We understand how costly the R&D value chain can be for private sector entities. We support NSF's efforts to coordinate R&D investment amongst government agencies, academia, and civil society groups. This would help ensure spectrum management technologies are designed and built to better meet the public interest and the needs of federal stakeholders alike.

Due to our company's limited engagement with federal R&D stakeholders, we feel most credentialed to assist with several specific items on this RFI. We believe we can share our experience utilizing Artificial Intelligence (AI)/ML technologies for automatic and rapid mitigation of interference problems, spectrum situational awareness at scale, and spectrum resilience and assured access for critical mission applications **[Question #2].** We also appreciate the opportunity to share our perspective on defining "dynamic spectrum sharing" in the context of federal R&D lines of effort **[Question #7].**

PROMOTE STANDARDS FOR COLLECTING AND REPORTING INTERFERENCE DATA

Our flagship product, Spectrum-NET, has been deployed in real-world, nationwide mobile networking scenarios. This has given our company insight on the feasibility of collecting and analyzing reported network performance data in near real-time using AI/ML applications in the software layer of mobile networks.

We believe that the largest barrier to broader spectrum efficiency – either maximizing the utility of a given spectrum asset for a licensee or proving out the feasibility of a sharing environment for federal bandwidths – lies in opening up access and standardizing select key network data for researchers and engineers.

To understand better where certain frequencies could feasibly be shared, we believe the federal government should:

1. Facilitate the establishment of standards for software developers to enable the reporting, ingestion and analysis of mobile network performance data and build upon the foundations being set by the O-RAN community.
2. Promote the creation of regulatory framework(s) which encourage collaboration without onerous technology mandates or reporting requirements.

Given that the technical and legal implications for network data collection vary greatly depending on the networking environment (i.e., public vs private networks), there are myriad software and hardware standards which would have to be further developed to make network data collection a useful venture for performing bulk data analytics.

In Spectrum Effect's April 2023 submission to NTIA's Inquiry on the Development of a National Spectrum Strategy (Docket Number 230308-0068), we presented a view on how best to promote and implement a non-regulatory regime to collect and manage reported network performance data from incumbent users and advocated for the adoption of a common spectrum management framework.[1]

In that document, we asserted several positions that we believe should be a key consideration in the establishment of an R&D plan – particularly on how federally-sponsored testbeds may

[1] https://www.ntia.gov/sites/default/files/publications/spectrum_effect.pdf

provide opportunities for closer public-private collaboration.

For NSF, these items could be enabled by broader investment and engagement with federal and non-federal R&D stakeholders. In our filing, we recommended that the federal government take a few specific actions. Those recommendations included the following:

1. NTIA and FCC should jointly establish and operate a Spectrum Analysis, Strategy, and Planning Organization tasked with managing the collection of spectrum usage data.
2. Leverage the vast deployment of RAN equipment by mobile operators to measure and report on interference in adjacent government bands.
3. Drive real-time monitoring and control within mobile networks and private networks for optimal spectrum sharing.
4. Serve as a world leader in setting global standards for spectrum management and equip allies with a common standardized framework.

These recommendations are policy suggestions, not technical ambitions, and should not directly drive R&D efforts. However, to achieve more efficient spectrum use and enable closer collaboration on dynamic spectrum sharing between federal and non-federal users, the federal government needs to encourage federal and commercial incumbents to adopt technologies within the network software layer. Those technologies should be guided by standards that are informed by federal R&D efforts and exercised through the testbeds proposed in the NSS.

As a template for technical standards that federal research organizations could help develop, we want to highlight some of the capabilities that we provide to our customers. We believe these should be minimum standards in the future mobile networking environment.

Spectrum-NET's capabilities include:

1. Automated (AI/ML) analysis and mitigation of RF interference on a continuous basis.
2. Seamless operation on all RF bands (shared spectrum and non-shared spectrum) across multi-vendor radio equipment and multiple technologies (NR, LTE).
3. Ingestion of performance data reported regularly by the operator's Radio Access Network (RAN) equipment for analysis.
4. Ingestion of network topology data and tailored analysis for each type of site (outdoor, indoor, power level, etc.).
5. Machine learning to accurately classify RF signals and trigger mitigation actions.
6. Enhanced visibility into spectrum resources including spectral efficiency, RF interference, and Quality of Service data collection.
7. Closed-loop actions to maneuver spectrum resources and avoid RF interference.

When compared to traditional network management methods that rely on manual network monitoring and lengthy, complex troubleshooting of RF interference issues, developments in

AI/ML provide capabilities that can make dynamic spectrum sharing possible. However, this relies on the creation of underlying standards and requirements that enable the reporting and sharing of structured data for use in AI/ML-powered network analysis and management tools.

DEFINITION OF "DYNAMIC SPECTRUM SHARING (DSS)"

As a provider of software that helps mobile operators use spectrum assets more efficiently, Spectrum Effect is fully invested in the future of the mobile networking software layer and policy efforts to standardize related terminology.

As the federal government uses its R&D investments to pursue developments in technologies which could enable federal and non-federal users to share spectrum assets, we believe that NTIA and FCC should accompany any R&D advancements with a well-defined regulatory framework which can set forth responsibilities for both agencies to jointly collect network data. We believe these entities should also set minimum standards for the software layer of mobile networks which could be applied across LTE, 5G, and O-RAN deployments. However, for the purpose of R&D, we would encourage NSF to adopt a technology-agnostic definition of DSS.

Spectrum Effect supports major carriers globally, including several major mobile carriers in the U.S. Spectrum Effect would benefit by suggesting policies which using our existing capabilities to push a narrow definition for DSS. However, we believe that at this stage, an overly narrow definition of DSS would discourage civil society engagement, limit the ability for innovative proposals, and prematurely restrict the ability for researchers and engineers to work through U.S. universities and Federally Funded Research and Development Centers to propose new standards or mobile networking capabilities.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Spectrum for the Future

March 21, 2024

Mallory Hinks, Technical Coordinator
Networking and Information Technology Research and Development (NITRD)
National Coordination Office (NCO)
National Science Foundation,
2415 Eisenhower Avenue Alexandria, VA 22314

Re: Response to Request for Information on the National Spectrum Research and Development Plan

Dear Ms. Hinks:

Spectrum for the Future greatly appreciates the opportunity to contribute to structuring the National Spectrum Research and Development Plan through a response to the request for information issued by the NITRD Wireless Spectrum Research and Development Interagency Working Group (WSRD IWG). As the WSRD IWG and the White House Office of Science and Technology Policy conduct their work, Spectrum for the Future stands ready to collaborate to help develop an R&D Plan that will best meet the goals set out in the National Spectrum Strategy.

As a coalition representing a wide array of innovators, anchor institutions, and technology companies, Spectrum for the Future is organized around leveraging shared and locally licensed spectrum to fortify America's technological leadership, industrial strength, and global competitiveness. Our collective experience underscores the vital role that structured research and development can play in pushing the boundaries of the technical sciences. To this end, we propose several considerations for developing the National Spectrum R&D Plan:

> **Clarification on Dynamic Spectrum Sharing (RFI Item 7)**: As a threshold matter, it is crucial that the National Spectrum R&D Plan accurately defines Dynamic Spectrum Sharing (DSS) as it is commonly understood. Specifically, DSS must refer to the sharing of identical frequency ranges within a given geography, without merely dividing a frequency range between federal and non-

federal users. While dividing a band between users may appear to be 'sharing,' it is better understood as a spectrum allocation policy choice.

Building on Existing Successes and a Focus on Sharing Between Non-Federal and Federal Stakeholders to Prevent Duplication (RFI Item 1 & 2): We urge the WSRD IWG to build beyond the frameworks and successes of Spectrum Access Systems in the Citizens Broadband Radio Service, the Automated Frequency Coordinator in the 6 GHz band, and the PATHSS process outcomes. The focus of these efforts should not be to make specific refinements as they relate to these existing processes, because these techniques are viable today and are either being refined by commercial stakeholders or a combination of commercial and federal stakeholders. The WSRD IWG will be able to use the different technologies developed for these frameworks as building blocks for use in future spectrum bands with different and evolving interference scenarios.

Additionally, the R&D plan should focus on developing sophisticated coexistence techniques that are focused on sharing between federal and non-federal users. The federal government is ideally situated to understand how it can coexist with other federal systems. Non-federal users, similarly, have found many ways to coexist with one another, including contention-based protocols, dynamic database management, and emissions masks. The National Spectrum R&D Plan presents an opportunity to research how to bridge this gap. Perhaps innovative techniques for sharing amongst non-federal users like those named above can be adapted to the federal and non-federal sharing context. Even more, the plan could focus on developing wholly new frameworks for federal and non-federal sharing that enable multiple different non-federal or commercial uses.

Conduct A Robust Stakeholder Consultation Process Open to All (RFI Item 6): A successful R&D Plan will facilitate the emergence of innovative, resilient technologies that improve the lives of individual Americans. The emphasis on DSS in the R&D Plan is not only pivotal for economic growth but also for fostering competition among new entrants and smaller telecom providers. Shared license models that could be promoted by DSS have already proven their value across various sectors by enabling innovative applications and ensuring access to spectrum resources for Tribal groups, educational institutions, and local governments.

To refine and enhance the R&D Plan on an ongoing basis, the WSRD IWG should include robust participation by non-federal stakeholders. These non-federal stakeholders will have a central role in adapting and deploying any new technologies developed through this process. There must then be clear communication between the federal and non-federal stakeholders so that any research is informed by what is commercially viable, especially insofar as the techniques being researched are ultimately envisioned for use by the private sector. Public in-person and virtual working group meetings, as well as open electronic dockets for stakeholder submissions, all focused on the drafting and refining of the WSRD IWG's R&D Plan are the best ways to facilitate the type of collaboration required. The announcement of the May 2024 public meeting already proposed in the WSRD IWG's Request for Information is very encouraging with respect to this point.

A National Spectrum Research and Development Plan that reflects these principles can help cement the United States' position as a global leader in technology and innovation. We look forward to engaging with the WSRD IWG in further discussions.

Thank you for considering our input.

Sincerely,

Spectrum for the Future

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The Alliance for Telecommunications Industry Solutions (ATIS)
Next G Alliance

NITRD NCO Request for Public Input on development of National Spectrum Research and Development Plan

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NITRD NCO Request for Public Input	)
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Comments of ATIS' Next G Alliance
On the
National Spectrum R&D Plan

The Alliance for Telecommunications Industry Solutions' (ATIS') Next G Alliance, an initiative to promote North American leadership in 6G, takes this opportunity to provide input in response to the Request for Information (RFI) released February 20, 2024, by the Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO). This RFI seeks input on the drafting and development of the White House Office of Science and Technology's (OSTP) National Spectrum Research and Development Plan (R&D Plan). Spectrum is the essential ingredient for the next generation network and it is critical that the R&D Plan helps to advance and accelerate spectrum availability without adding unnecessary delays.

I. Background

ATIS is a leading technology and solutions development organization that brings together the top global ICT companies to advance the industry's business priorities. ATIS' Next G Alliance brings together the private sector, academia, and government interests to drive North American leadership in 6G. Over the past three years, the Next G Alliance has brought together hundreds of subject matter experts to define 6G research drivers, technologies, use cases, and societal needs.[1] This includes extensive, ongoing efforts focused on 6G spectrum needs and radio

[1] To date, the Next G Alliance has produced more than 20 white papers aimed at driving North American 6G leadership. Available at https://www.nextgalliance.org/6g-library.

technologies to promote more efficient spectrum utilization. Additionally, the Next G Alliance Research Council brings together some of North America's top academics and industry members to identify research and development priorities needed for North American 6G leadership.

II. Discussion

Topic 1of the RFI – "Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering" -- specifically asks about "methods/approaches to increase coordinated investment in R&D amongst government agencies, academia, civil society, and the private sector" and "structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D."

ATIS' Next G Alliance recommends that investments in R&D should be coordinated not only amongst government agencies, academia, civil society, and the private sector, but also coordinated with other like-minded organizations around the world when possible. For example, the Next G Alliance worked with 6G-IA, at the behest of the U.S.-E.U. Technology and Trade Council, to provide the U.S. and E.U. governments with a joint roadmap for future collaboration opportunities to promote 6G development.[2] The paper contains a set of key strategic observations and recommendations for 6G networks and services and offers a candidate roadmap for future opportunities through E.U. and U.S. funding.[3] In terms of structural and process improvements, the NSF Directorate for Technology, Innovation and Partnerships (TIP) is a promising way to provide support for use-inspired research and the translation of research results to the market and society, however, it will require funding to deliver those benefits. To this end, we are concerned that the appropriated 2024 funding for NSF's Research and Related Activities is significantly less than both the amount requested by NSF as well as the amount that had been promised under the CHIPS and Science Act of 2022 (CHIPS Act) which created TIP.[4] Restoring full funding

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[2] ATIS Next G Alliance and 6G-IA Press Release. *ATIS and EU Smart Networks and Services Joint Undertaking Publish "Beyond 5G & 6G Roadmap" for EU-US Collaboration* https://www.atis.org/press-releases/atis-and-eu-smart-networks-and-services-joint-undertaking-publish-beyond-5g-6g-roadmap-for-eu-us-collaboration/

[3] ATIS Next G Alliance and 6G-IA. *EU-US Beyond 5G/6G Roadmap.* https://nextgalliance.org/wp-content/uploads/2024/01/EU-US-Aligned-6G-Roadmap-Joint-Paper.pdf

[4] Science. *Analysis: How NSF's budget got hammered.* March 14, 2024. https://www.science.org/content/article/analysis-how-nsf-s-budget-got-hammered

should be a top priority to ensure that NSF and TIP can achieve the important objectives of the CHIPS Act and, importantly, advance research and results to the marketplace.

With regard to RFI Topic 2 – "Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas" -- the Next G Alliance notes that it has developed a set of Research Priorities, that include Advanced multiple-input multiple-output (MIMO) and THz/SubTHz, 6G Air Interfaces, Joint Communications and Sensing (JCAS), Spectrum Sharing and Enhanced Spectrum Access and Radio Access Technologies, the last two of which focus on various aspects of spectrum utilization and optimization for 6G Physical Layer (PHY) and Medium Access Control (MAC) designs to optimize coverage and capacity tradeoffs.[5]

The Next G Alliance Technology Working Group has developed a *6G Radio Technology Part I: Basic Radio Technologies*[6] white paper, which addresses research challenges associated with key technologies such as Waveform, Coding and Multiple Access Schemes, JCAS, Spectrum Sharing, MIMO, and Advanced Duplexing Technology, which should be priority areas for the R&D Pan.

The mobile communications industry has an established record in adopting state-of-the-art technologies, including academic research, on waveform techniques, channel coding, and multiple access techniques to improve spectrum utilization and spectrum efficiency across the past five generations of mobile technologies. This trend will continue with 6G as the industry improves the ability for the next generation to innovate by improving our ability to use spectrum that may be shared between disparate radio services.

Figure 1 illustrates the relationship between spectrum use and various forms of sharing by charting the paths of the two major regulatory regimes -- licensed and unlicensed spectrum. The Next G Alliance treats medium access control techniques, including scheduled transmissions or contention-based access such as Listen-Before-Talk (LBT) protocols as multiple-access techniques, acknowledging their role as effective sharing methodologies.

[5] Next G Alliance. *Research Priorities – Technology.* https://www.nextgalliance.org/research-priorities/technology/
[6] Next G Alliance. *6G Radio Technology Part I: Basic Radio Technologies.* https://www.nextgalliance.org/white_papers/6g-radio-technology-part-i-basic-radio-technologies/

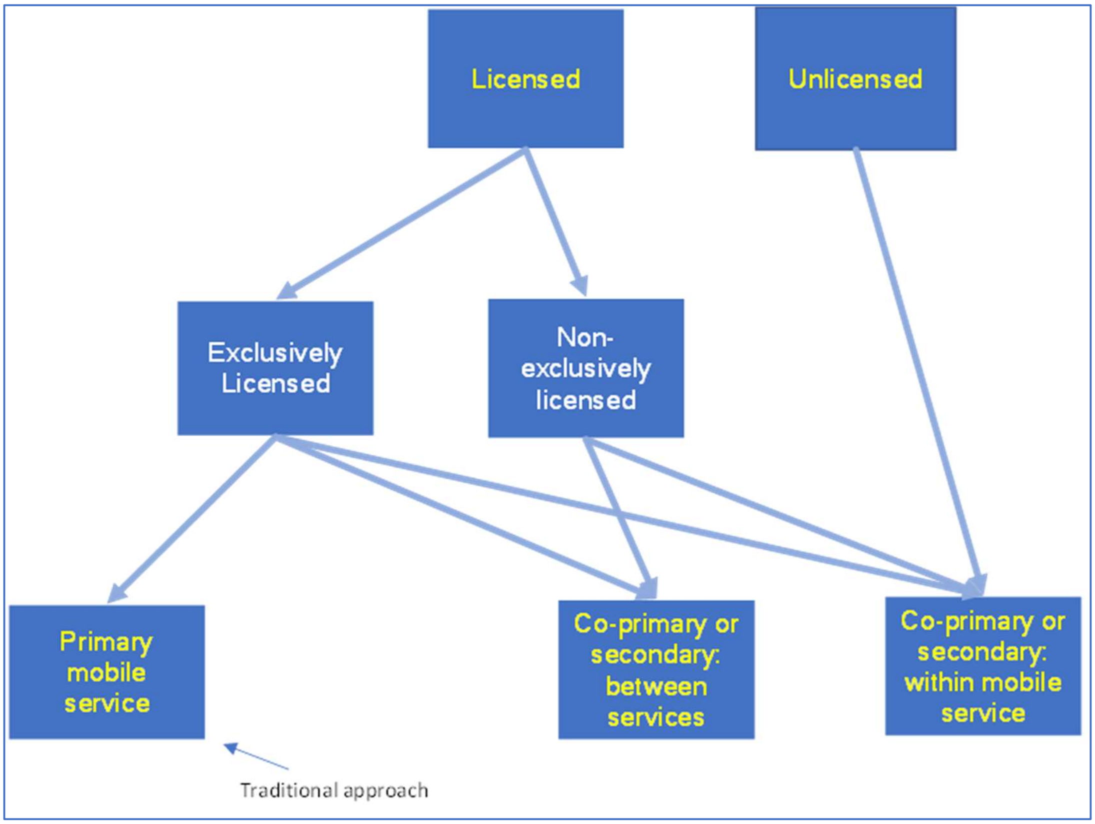

Figure 1: A tree diagram illustrating the relationship between spectrum use and various forms of sharing; the boxes with yellow text depict typical regulatory mechanisms and implementation methodologies

As the National Spectrum Strategy Implementation Plan notes, "dynamic spectrum sharing (DSS) involves the operation of independent systems close enough together (in frequency, space, or time) that dynamic access methods are required to prevent harmful interference."[7] And, as the radio coexistence environment becomes increasingly complicated from both a device and network perspective, 6G spectrum sharing native design is anticipated to accommodate wide variety of use cases.

In the context of uncoordinated spectrum sharing, 6G systems are expected to exploit high-precision spectrum shaping and advanced band-pass filter designs (similar to or better than those in 5G) to be robust toward adjacent channel interference. At the same time, there are challenges in the way legacy technologies address filter selectivity or interference resilience relative to the

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[7] National Telecommunications and Information Administration, *National Spectrum Strategy Implementation Plan*, March 12, 2024, pg. 19.

current state of the art. Some incumbents are passive Radio Frequency (RF) systems, such as radio astronomy and remote sensing, which require a quiet RF environment to maintain satisfactory spectrum or system sensing and measurement performance. Passive systems are thus often sensitive even to interference from adjacent channels. Coexistence between active 6G and passive RF systems needs to be thoroughly researched.

Achieving coexistence of incumbent and new entrant services presents several challenges. To constructively share the spectrum with incumbent systems, studies must first establish the characteristics of all services that may access a frequency range that would be pertinent to the ability of the mobile network to share spectrum. Further, there must be an understanding of the improvements that can be made to any service that enhances and simplifies the ability to implement spectrum sharing between the relevant radio services. Additionally, the new entrant services may have to implement active spectrum sensing themselves or utilize a spectrum sensing capability provided by an external spectrum access system (analogous to the e.g., 6 GHz Automated Frequency Coordination (AFC) server or, Citizens Broadband Radio Service (CBRS) Spectrum Access System (SAS), or future, possibly with enhancements) to avoid harmful interference with incumbent systems. R&D priorities should include how to suppress or mitigate interference to increase Signal-to-Interference-plus-Noise Ratio (SINR); allocation of time, energy, and bandwidth resources among the sensing and communications functions; how to ensure viability of new entrant services while providing reasonable and mission-appropriate protection to primary incumbent users.

The impact on 6G networks and devices could result in the need for some operational parameters – such as frequency, bandwidth, power, beamforming, and others –to be modified on a short-term basis to adapt to new radio environments. Spatial processing techniques can be employed to minimize interference, but more research is needed to determine whether receivers can be adequately protected. New interference assessment and avoidance methods must be researched. Although individual user equipment (UE) processing capability is limited, the aggregated processing capability of a group of UEs can be substantial. Therefore, collaborative spectrum sensing and corresponding sharing mechanisms should be a priority research area, as well.

Spectrum sharing among co-licensees for commercial services could provide an opportunity to improve spectrum utilization. Research topics include improving shared access by means of network intelligence, including the moderation of medium use between shared-license holders. Machine learning could be utilized to optimize RF medium and spectrum access in a shared license network while addressing any privacy or operational security concerns that may exist. Examples include sharing among 6G co-licensees and bi-directional sharing between 6G and federal services, which would allow access to additional spectrum bands.

Unlicensed spectrum utilizes medium access protocols to prevent collisions among users and to manage interference. More research is needed to improve spectrum sensing, channel selection, and medium access procedures targeted for dense network deployments in unlicensed spectrum bands.

In addition to the aforementioned foundational technology aspects like waveform, modulation, multiple access, and channel coding, 6G systems are also expected to advance features in the areas of MIMO, millimeter wave (mmWave) spectrum, JCAS, and full duplex operation. MIMO enhancements for very large antenna arrays are, for example, expected to play a crucial role in the centimeter spectrum regime, sometimes called the upper mid-band or frequency range FR3, where they can potentially be leveraged for spectrum sharing with incumbents. In low-band spectrum, such large antenna arrays may additionally be realized as massively distributed MIMO systems and to maintain a strong position in the 6G era, North America should keep investing in cutting-edge research in these areas. This may particularly be relevant for mmWave spectrum, where North America has been at the forefront of adopting 5G NR mmWave technologies with considerable investments in mmWave spectrum. 6G research should focus on advancing and streamlining mmWave technology by making it simpler to implement, easier to deploy, easier to integrate, able to better co-exist with current and future technologies, and helping networks and UEs and other nodes have better performance. Other technologies, that may either benefit from newly available spectrum in 6G systems, such as FR3 or (sub)THz, or that may significantly increase spectrum utilization efficiency regardless of any specific band considerations, include reflective intelligent surfaces (RIS), JCAS, and full-duplex operation. From a North American technology leadership perspective, these, and many others, are key research areas whose continued advancement must be ensured. A more detailed summary is provided in NGA's 6G Technologies report[8] with a more rigorous treatment of basic 6G radio technologies in *6G Radio Technology Part I: Basic Radio Technologies.*[9] [10]

III. Conclusion

The National Spectrum R&D Plan is an important step toward ensuring continued U.S. leadership in critical and emerging technologies such as 6G. ATIS' Next G Alliance looks forward to working with NITRD NCO, OSTP, NSF, and other stakeholders on the development of the R&D Plan and would be happy to answer any questions or to discuss our comments in more detail. We urge the development of a bold R&D Plan that expeditiously drives increased availability and efficient usage of spectrum to meet the timelines envisioned for deployment of 6G.

Respectfully Submitted,

David Young
VP, Technology & Solutions and Managing
Director of the Next G Alliance

Alliance for Telecommunications Industry
Solutions
1200 G Street, NW Suite 500
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[8] Next G Alliance. *6G Technologies*. https://nextgalliance.org/white_papers/6g-technologies/
[9] Next G Alliance. *6G Radio Technology Part I: Basic Radio Technologies.* https://www.nextgalliance.org/white_papers/6g-radio-technology-part-i-basic-radio-technologies/
[10] Part 2 of the *6G Radio Technology Part I: Basic Radio Technologies* paper is in preparation with an anticipated publication date in 2024.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The Association of Public-Safety Communication Officials International, Inc. (APCO)

Networking and Information Technology Research and Development National Coordination Office Request for Information on the National Spectrum Research and Development Plan

Comments of APCO International

The Association of Public-Safety Communications Officials International, Inc. (APCO)[1] submits these comments in response to the Networking and Information Technology Research and Development National Coordination Office's request for information regarding the creation of a National Spectrum Research and Development Plan (R&D Plan).[2] APCO appreciates the opportunity to provide a public safety perspective on the priority areas for spectrum research and development.

The R&D Plan should take public safety's unique spectrum needs into account. As APCO noted in comments to the National Telecommunications and Information Administration regarding development of the National Spectrum Strategy, public safety agencies depend on a broad range of spectrum bands to support their mission critical communications needs and require heightened reliability, priority, and interference-free access to spectrum.[3] Public safety agencies use spectrum to dispatch first responders, provide incident-related data such as suspect descriptions and scene-safety information essential to law enforcement, fire, and EMS officials, establish backup links for 9-1-1 networks, support life-safety communications for first

[1] Founded in 1935, APCO is the nation's oldest and largest organization of public safety communications professionals. APCO is a non-profit association with over 40,000 members, primarily consisting of state and local government employees who manage and operate public safety communications systems – including 9-1-1 Emergency Communications Centers (ECCs), emergency operations centers, radio networks, and information technology – for law enforcement, fire, emergency medical, and other public safety agencies.
[2] Request for Information on the National Spectrum Research and Development Plan, 89 Fed. Reg. 12871 (Feb. 20, 2024) *available at* https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan.
[3] Comments of APCO International, National Telecommunications and Information Administration, National Spectrum Strategy (Apr. 17, 2023) *available at* https://www.apcointl.org/~documents/filing/apco-comments-ntia-nss-041723.

responders, and coordinate the incident response through its resolution.

The most important area for spectrum research and development from a public safety perspective is the development of mechanisms that enable the automatic and rapid mitigation of interference problems. Public safety agencies use spectrum in many different types of systems. These systems are not designed to detect interference and are incapable of attributing it to a particular source. Attempting to identify the source(s) of interference is a long, resource-intensive process, and even after the source has been identified agencies often struggle to promptly and permanently eliminate interference. This is a problem in traditional spectrum environments, such as land mobile radio systems encountering interference from improperly installed/programmed distributed antenna systems and "near/far" interference arising from commercial cellular systems. And new spectrum environments with increasing numbers of unlicensed devices – currently an issue for public safety 6 GHz microwave systems – pose an especially difficult interference threat given that unlicensed devices have no readily-identifiable responsible party, can be highly-concentrated, often transmit from inside private homes and businesses, operate intermittently, and employ frequency hopping technology.

APCO also supports prioritizing research and development for dynamic spectrum access and management. Some bands relied upon by public safety are already subject to dynamic spectrum sharing, and public safety licensees might benefit from expanding spectrum sharing mechanisms to other bands if, for example, that leads to lower prices or more equipment options. However, spectrum sharing mechanisms must be thoroughly evaluated with real-world testing in advance of their deployment to ensure they are effective at protecting public safety communications. Simulations and lab-based testing alone are inadequate when public safety is involved. Furthermore, spectrum sharing mechanisms must respect public safety's unique needs and mission critical design elements. For example, public safety microwave systems are designed with large fade margins to ensure they remain operational during events such as extreme weather that can significantly degrade signal quality. The fade margin in public safety systems should not be mistaken for an opportunity to leverage underutilized spectrum.

Finally, insofar as the R&D Plan addresses economic concerns, APCO encourages research into how to lower costs for public safety spectrum users. Public safety agencies often lack the resources needed to acquire new spectrum technologies or augment existing systems to make them more resilient to interference. They also typically face long equipment lifecycles and procurement processes. These constraints, along with the life-safety nature of public safety spectrum use, underscore the need for an R&D Plan that takes the public safety community's unique needs into account.

Respectfully submitted,

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Request for Information on the National Spectrum Research and Development Plan

The Institute for the Wireless Internet of Things (WIoT) at Northeastern University

Before the

Networking and Information Technology Research and Development (NITRD)

National Coordination Office (NCO), National Science Foundation

Alexandria, VA 22314

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Spectrum Research and Development Plan	)	

COMMENTS OF THE INSTITUTE FOR THE WIRELESS INTERNET OF THINGS AT NORTHEASTERN UNIVERSITY

The Institute for the Wireless Internet of Things (WIoT) at Northeastern University respectfully files these comments on the NITRD Wireless Spectrum Research and Development Interagency Working Group (WSRD IWG) Request for Information (RFI) on the National Spectrum Research and Development Plan. WIoT commends the WSRD IWG for seeking comments on this topic. This document aims to provide comments on a specific subset of matters raised by the WSRD IWG, as outlined below.

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering. This includes, but is not limited to, the following:

- Methods/approaches to increase coordinated investment in R&D amongst government agencies, academia, civil society, and the private sector
- Structural and process improvements in the organization and promotion of Federal and non-Federal spectrum R&D

The strong push toward coexistence among diverse and heterogeneous spectrum users and services calls for research which has an interdisciplinary and collaborative nature, bringing together existing and prospective stakeholders. Interdisciplinary research makes it possible to combine complementary skills and expertise to offer a complete and more accurate overview of the problem and available tools, and develop solutions that go beyond traditional sharing approaches and consider all the stakeholders' needs. At the same time, it opens new funding opportunities for research projects which may cater to the interests of multiple stakeholders.

An example of successful collaboration between researchers working on different spectrum services is in the coexistence research for the spectrum above 100 GHz published in [1], which brought together experts in cellular networks and next-generation wireless systems, policy experts, and radio astronomers. The paper has explored the needs of different stakeholders above 100 GHz, interference modeling, and coexistence mechanisms at different layers of the protocol stack. This line of research, informed by stakeholders in the passive sensing and Earth Exploration-Satellite Service (EESS) communities, has resulted in additional publications that explore interference modeling at an unprecedented scale [2] and the first experimental demonstration of sharing above 100 GHz [3].

Eventually, such collaborations can lead to unlocking new funding opportunities centered around the interdisciplinary expertise and research and innovation that considers the need of heterogeneous stakeholders. An example is the recent collaboration established between the WIoT and Colorado State University (CSU)[1] to study the coexistence between a terrestrial sub-THz system and an in-orbit satellite. Thanks to the collaboration with the Remote Sensing team at CSU, lead by Prof. Steven Reising, researchers at WIoT will transmit a signal at 165 GHz to the TEMPEST-H8 sensor on board the International Space Stations (ISS). This offers exciting opportunities not only to analyze the Radio Frequency Interference (RFI) and its impact on the meteorological data collected by the sensor but also to explore the ground-to-space signal propagation at these frequencies in a real scenario.

Most of the studies on RFI, particularly on ground-to-satellite, are theoretical and, while worthy and meaningful, lack practical and experimental validation. This is due to several reasons, among which are the prohibitive costs to produce receivers (transmitters) that have characteristics representative of the incumbent (interferer) and deploy them in realistic locations and settings. Indeed, we remark that this kind of study is only possible when the stakeholders collaborate, which optimizes resources and offers accurate and realistic results on the actual systems that are under study.

An additional opportunity where an initial seed investment can generate further research is that of testbed development, which we discuss in details later in this document.

[1]Through the National Science Fundation (NSF) Award No. 2332721 Collaborative Research: "SWIFT-SAT: DASS: Dynamically Adjustable Spectrum Sharing between Ground Communication Networks and Earth Exploration Satellite Systems Above 100 GHz". Abstract Available at: https://www.nsf.gov/awardsearch/showAward?AWD_ID=2332721&HistoricalAwards=false

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas. Areas of interest include, but are not limited to, the following:

- Dynamic spectrum access and management
- Spectrum situational awareness at scale
- Automatic and rapid mitigation of interference problems
- Modeling for coexistence analysis

We believe that to advance coexistence and sharing it is necessary to adopt and develop holistic solutions that combine all the points mentioned in the request for information, so that sharing can advance from research and early prototypes to the de-facto way of accessing spectrum in next-generation wireless systems. Further, this is a critical moment for developing sharing approaches that can be factored in next-generation sensing, radio astronomy, and wireless networking systems, allowing coexistence embedded in the technology rather than layered on top as an afterthought. In the following paragraphs, we discuss research results and directions related to spectrum sharing solutions for next-generation wireless networks.

Automatic spectrum sensing is becoming a necessity for the coexistence of different wireless technologies in shared bands. The timely identification, classification, and localization of interference or unauthorized transmission are fundamental elements of the future spectrum sharing and management infrastructure. In [4] we proposed an automatic "spectrum segmentation" framework to simultaneously classify and localize signals in time and frequency at the I/Q level. Contrary to most of the state-of-the-art approaches, our solution has a lower latency (2.6 ms) and achieves a mean Intersection over Union (IoU) of 96.70% across different devices and protocols. Similarly, research on RFI detection and classification algorithms should focus on solutions that can be deployed on real systems, taking into account not only their accuracy but also their speed and reliability and the capability to generalize to unseen sources or waveforms.

Furthermore, spectrum use and occupation are under scrutiny as the first step to reform its allocation. Spectrum usage varies greatly in position and time, in a way that is hard to predict based solely on service allocation. Also in this case, adopting an experimental approach, i.e., surveying the spectrum through field measurements, can lead to a more accurate assessment, discriminating among different locations, times, and stakeholders. Approaches like the one presented in [4] can significantly speed up the analysis of the collected data and thus of the spectrum usage.

Another approach that we deem of interest to this request for information is service sharing. As outlined in our paper [5], deploying programmable and open platforms for the Radio Access Network (RAN) of cellular systems, either mobile or fixed, has the potential to boost spectrum sharing by leveraging the same infrastructure to offer different services (e.g., remote sensing) on a time, space, waveform, or frequency sharing basis. In this context, the Open Radio Access Network (O-RAN) paradigm, based on principles of virtualization, programmability, and plug-and-play disaggregation, can enable dynamic solutions supporting spectrum and services sharing across different frequencies. The shift towards network softwarization facilitates the deployment of bespoke functionalities in the cellular base stations, and thus the introduction of new services the leverage the existing infrastructure, spectrum, and, potentially, waveforms. These services can be dynamically managed and adjusted over time to align with user demands, enhancing spectrum utilization, with input and/or feedback from existing incumbents.

To design sharing systems, it is important to properly understand and characterize the RFI patterns. In the last decades, several contributions have offered interesting results using theoretical and simulation tools but were not validated by on-field experiments. Moreover, the need for tractability leads to strong assumptions or simplifications in the models. Decision makers as well as spectrum management tools require pushing this research to the next, required step, by focusing on the following aspects:

- Theoretical and simulation models should continue paving the way to real deployment and experiments. Theoretical models can be used to gain valuable insights on the RFI and coexistence without the physical and economic constraints of real-world scenarios. Similarly, simulation models, thanks to the full control that a digital representation can offer to the researcher, can be leveraged as fundamental tools in the exploration of groundbreaking solutions in a risk-free environment. As we explored in [2] using ITU-compliant models, there are aspects of RFI that are hard to capture experimentally, but that can be fully characterized via analytical and simulation tools. Scale, for instance, is an aspect of modeling that can only be tackled using these tools, and that has not yet been fully explored.
- Supporting the experimental validation of the models. Designing, deploying, and making experimental testbeds and facilities available to the research community through an open approach (following the current trend, which led to successful solutions such as, e.g., O-RAN, OpenAirIn-

terface (OAI)) should be a priority for the National Spectrum Research and Development Plan. In particular, a shared validation pipeline to test theoretical/simulation models would push forward robust and high-quality results. Our NSF SWIFT-SAT project represents a step in this direction, as it evaluates, experimentally, some results and assumptions of [2].

These two approaches to RFI modeling are complementary and should be joined together in a closed-loop manner, where analytical and simulation results orient the research in a risk and cost-free environment, and experiments validate them while offering also data for their refinement or for the development of new models.

4. Recommendations on spectrum R&D accelerators such as the following:

- Shared public datasets
- Open-source software/projects
- Cost-effective flexible radio platforms
- Testbeds, research infrastructure, and collaboration support

Infrastructure (i.e., testbeds and open software) will play a key role in the development and validation of solutions for the National Spectrum Strategy (NSS), by serving as a common playground for researchers across academia, government, and industry. Therefore, it is important to support access to a programmable, flexible, and virtualized platform, based on open - preferably open source - components. The sharing platform will need to include the different components of end-to-end next-generation wireless systems as well as sensing, radio astronomy, and other incumbents. This presents the community with a common and shared canvas where it is possible to develop improved and intelligent sharing solutions. Finally, once the solutions have been developed and tested in controlled environments, e.g., large-scale wireless emulators or radio dynamic zones, there should be ways to transition to commercial networks - considering both technological and policy implications.

A tool that can be useful in assessing sharing solutions without RFI is that of the Digital Twin (DT). A DT is an accurate digital replica of a real product, object, or environment, that can be interacted with in the digital world to obtain data applicable to the real one. DTs are considered a major enabler by the wireless communication community for a number of applications, e.g., industry 4.0, product development and prototyping, and, more recently, spectrum research. Having an accurate digital representation of the Electromagnetic (EM) propagation environment allows to experiment and test solutions in a risk-free environment. For instance, a "Digital Spectrum Twin" is presented in [6], combining geographic features and radio maps. Furthermore, decisions and previsions can be made in the DT to be then relayed to the real system.

In [7, 8], we envisioned an emulation-based DT based on the Colosseum, the world's largest wireless network emulator with hardware-in-the-loop. Colosseum has been developed by a consortium led by DARPA to run the spectrum collaboration challenge, and since 2020 is operational at Northeastern University and open to the research community. Colosseum has been used to develop intelligent wireless networking solutions and spectrum sharing mechanisms. In [9], a dataset of Wi-Fi and cellular traces in overlapping bands was collected using Colosseum. A recurrent neural network was then trained on the data, to identify spectrum usage patterns and detect the presence of Wi-Fi and cellular transmission in the same Wi-Fi channel. Based on the output of the detector, the sharing mechanism can then move the cellular operations to a different band.

Similarly, in [7], the coexistence between a radar and a 5G system is tested in the 3.55-3.7 GHz Citizens Broadband Radio Service (CBRS) band [10]. In this band, different spectrum users coexist in the U.S., with priority allocated to existing radar and satellite uplinks and access granted to wireless networking solutions through a tiered system. The detection of radar incumbents is performed by an Environmental Sensing Capability (ESC) network, which relays information to a Spectrum Access System (SAS), prompting cellular users to vacate the spectrum upon detection. In [7], 5G base stations function as environmental sensors, leveraging deep learning algorithms on uplink I/Q samples to swiftly clear the 5G spectrum within seconds, instead of minutes. The radar waveforms are replicated in the DT using Colosseum Software Defined Radios (SDRs).

These results showcased the potential of the digital twins for spectrum research in the increasingly complex network environment, and how leveraging Artificial Intelligence (AI)-based, model-free approaches makes it possible to remove assumptions on the spectrum incumbents, a further step forward to the full automation of the spectrum management.

On the other hand, DTs can be used to push forward coexistence research in frequency bands that have the potential to be shared among different stakeholders, but for which devices do not exist yet. A recent example is the upper midband, or Frequency Range (FR)-3, which offers interesting characteristics for 6G cellular networks. Mobile radios for FR are currently in their prototype stage. However, assessing the impact of the RFI in those bands would significantly contribute to the ongoing discussion on spectrum allocation. Thus, we released [11], a DT for the City of Boston, consisting of a detailed 3D model of the buildings and of the location of the wireless antennas in the area. In [5], we used it to characterize the coverage and RFI in the novel FR-3 band, to understand the advantages and drawbacks when compared to the existing deployment.

Finally, shared datasets are essential to the spectrum research to provide ubiquitous and open access to high-cost data, that, if shared openly, can become a benchmark where to test and compare novel solutions and approaches. For this reason, in [4] we proposed a novel data generation method. We generated a small dataset of easy-to-collect, real-world wireless signals using different testbeds, e.g., Arena, over three days, with multiple antennas, multiple sampling frequencies, and multiple radios. We then "stitched them together" to generate large-scale, wideband, and diverse datasets. We released the corresponding 17 GB dataset and code. Other spectrum-related datasets can be consulted on the website of the RFDataFactory project, funded by the NSF, at `https://www.rfdatafactory.com`.

To conclude, we commend the WSRD IWG for seeking feedback on future directions for spectrum sharing research and development. We believe that sharing is an integral part of the vision toward next-generation wireless systems, and look forward to further research and development activities in this area.

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Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The Internet & Television Association (NCTA)

March 21, 2024

Networking and Information
Technology Research and Development (NITRD)
National Coordination Office (NCO),
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Re: Request for Information on the National Spectrum Research and Development Plan

NCTA – The Internet & Television Association ("NCTA") appreciates the opportunity to comment[1] in response to the Networking and Information Research and Development ("NITRD") National Coordination Office ("NCO") Request for Information on the National Spectrum Research and Development Plan ("R&D RFI").[2] The Nation stands to benefit greatly from next-generation spectrum coexistence tools. New technologies are advancing coexistence among diverse groups and types of users, making it possible to open previously inaccessible bands for new commercial services. Dedicated and collaborative spectrum research and development efforts can yield a new generation of technologies and tools that will allow coexistence to produce even greater utility gains for the country. In these comments, we offer suggestions for how the National Spectrum R&D Plan can best achieve that objective while also promoting the use of existing spectrum sharing technologies—and the spectrum sharing frameworks they enable—to meet near-term needs.

Spectrum sharing and coexistence-based frameworks, of course, are not new. Shared-licensing frameworks and rules enabling unlicensed operations, for example, rely on well-established spectrum coexistence tools, such as those used in the Citizens Broadband Radio Service ("CBRS") and 6 GHz bands. Such coexistence mechanisms have facilitated commercial access to important spectrum bands, protected incumbents, and are currently available to expand utility in the bands that are being considered in the National Spectrum Strategy ("NSS"), especially the 3.1 GHz band and 7/8 GHz range.

Spectrum sharing offers significant benefits, and it is increasingly the most realistic solution to create more commercial bandwidth to meet consumer needs given scarce or nonexistent greenfield spectrum resources. It also significantly reduces the cost and impact of those efforts on U.S. government operations by minimizing or eliminating the need for incumbents to clear or relocate from particular frequencies. A shared-licensed framework—using reasonable geographic license sizes, with lower-site, lower-power transmitters compared to exclusive-licensed bands—promotes innovation and competition by making spectrum accessible

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2 Request for Information on the National Spectrum Research and Development Plan, 89 Fed. Reg. 12871 (Feb. 20, 2024) ("R&D RFI").

to a diverse set of users and new entrants. Clearing incumbents and using large license areas designed for nationwide carriers' high-power transmitters limits diversity and innovation, as only a handful of companies operate the wide-area coverage networks that make high power levels and large license areas technically and economically feasible. In contrast, spectrum sharing approaches using lower power levels and smaller license areas enable *both* the deployment of mobile wireless networks *and* new, innovative uses such as private wireless networks—while also promoting coexistence among federal incumbent users and new entrants.

The R&D Plan is an opportunity to explore additional spectrum sharing capabilities and build new coexistence tools, to advance the state of the art, and to expand already-successful frameworks, such as in the national dynamic spectrum sharing ("DSS") testbed. In parallel with those efforts, it is critical that, as a country, we also continue to press ahead with using existing sharing tools for near-term objectives.

Topic #1—Recommended Strategies to Minimize Spectrum R&D Duplication

The R&D RFI seeks comment on "[r]ecommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering."[3] NCTA agrees that progress on spectrum R&D requires forward movement rather than delaying progress. But productive R&D also requires long lead times and involves risk. It is, therefore, critical to pursue the study of next-generation spectrum sharing in a way that allows the country to move ahead, in parallel, with expanding the use of the bands identified in the NSS more rapidly than permitted by R&D schedules.[4]

The R&D Plan should focus on developing the next generation of spectrum sharing technologies for future bands. With increasing consumer demands for unlicensed Wi-Fi and technologies supported by shared-licensed approaches, continued access to new frequencies will be required. Bands already identified for consideration generally require action on a more aggressive schedule than those for long-term R&D. We should adapt existing sharing tools for near-term objectives and invest in finding new sharing tools for longer-term objectives.

The NSS identifies the 3.1 GHz band and 7/8 GHz range for near-term action.[5] These bands are primed for commercial deployment by adapting today's proven coexistence approaches—specifically those already in use in the CBRS and 6 GHz bands.

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3 *Id.* at 12872.

4 Comments of NCTA – The Internet & Television Association on Implementation Plan for National Spectrum Strategy at 22, NTIA-2023-0003 (filed Jan. 2, 2024), *available at* https://www.ntia.gov/sites/default/files/ncta-written-input.pdf ("NCTA NSS Implementation Comments").

5 *National Spectrum Strategy*, THE WHITE HOUSE 6 (Nov. 13, 2023), *available at* https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf ("National Spectrum Strategy" or "NSS").

The NSS and NSS Implementation Plan rightly call for study of these bands as soon as possible,[6] and it is important that those studies will consider coexistence approaches alongside other possibilities for these bands. Stalling action on these bands pending their study as part of the R&D Plan would be significantly duplicative of previous work and would delay action longer than the country can afford. In the 3.1 GHz band, for example, the Partnering to Advance Trusted and Holistic Spectrum Solutions ("PATHSS") Task Group conducted a two-year, multi-stakeholder study—known as the Emerging Mid-band Radar Spectrum Study ("EMBRSS")—that merged the expertise of the Department of Defense, interagency partners, industry, and academia to evaluate the future use of the band, including to "explore dynamic spectrum sharing."[7] As the NSS stated, the EMBRSS Study found that "sharing is feasible" with advanced mitigation and a coordination framework.[8]

While the NSS has determined that additional study is needed for the 3.1 GHz band, opening this band for sharing does not require R&D on next-generation coexistence technologies. Basing a spectrum sharing framework in the 3.1 GHz band on the CBRS band's coexistence approach will open it up for use by nationwide carriers, cable providers developing their own competitive networks, wireless internet service providers, universities, manufacturing centers, utilities, and many more potential users. Using adapted versions of current sharing approaches, this diverse ecosystem of spectrum users would be able to access the 3.1 GHz band without disrupting critical military operations.

The NSS Implementation Plan calls for an initiative to "substantially improve the efficiency of spectrum use" by "leveraging new technologies and capabilities."[9] The National Telecommunications and Information Administration's ("NTIA") projected timeline appropriately reflects that technical work on sharing approaches in the 3.1 GHz band should run simultaneously to that effort, with input from the initiative "augment[ing]" the already-underway sharing studies.[10] The R&D Plan should similarly reflect that the best use of R&D in this area is to fine-tune existing technologies, rather than multi-year study that would further delay consideration of spectrum sharing in this band and undermine the goals of the NSS.

The 7/8 GHz range is similarly poised for near-term action based on current coexistence approaches. Because of its proximity to the 6 GHz band, which is currently the biggest growth band for unlicensed innovation, the 7/8 GHz range has the promise to unlock enormous consumer benefits and economic value. Importantly, opening this band to commercial operations also does not require R&D to explore next-generation technologies. Rather, NCTA has explained to NTIA that the lowest frequencies in the range can be made available using the same rules the Federal Communications Commission ("FCC") has used to protect commercial Fixed Service

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6 *National Spectrum Strategy Implementation Plan*, NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION A-6, A-7, A-9 (Mar. 12, 2024), *available at* https://www.ntia.gov/sites/default/files/publications/national-spectrum-strategy-implementation-plan.pdf ("NSS Implementation Plan").

7 NSS at 6.

8 *Id.*

9 NSS Implementation Plan at 19.

10 *Id.* at A-6, A-7.

(“FS”) incumbents in the 6 GHz band. Federal incumbents with different coexistence needs higher in the range may require additional study coordinated by NTIA, but that study can focus on the right application of existing tools, rather than a longer-term R&D strategy.

We also recommend minimizing duplication and achieving measurable advancements by bringing together federal stakeholders and commercial users early in the R&D planning process. Critically, to foster such collaboration, those efforts should include representatives of all industry perspectives who are interested in advancing spectrum sharing technologies, and not only particular segments of industry.

Topic #2—Recommended Priority Areas for Spectrum R&D

The R&D RFI asks for “[r]ecommended priority areas for spectrum research and development.” We will focus on three of the RFI’s recommended priority areas: (1) spectrum utilization efficiency; (2) dynamic spectrum access and management; and (3) modeling for coexistence analysis.[11] The R&D Plan should prioritize advancements in these areas.

Spectrum Utilization Efficiency. First, to promote spectrum efficiency, it is important that R&D measure the total utility created by a set of frequencies rather than treating received power or channel occupancy as a proxy for utility or efficiency. Measuring only channel occupancy or received power does not accurately capture spectrum utilization. For example, merely assessing the presence of signals—without also measuring how much total data signals of that type carry in a particular frequency range in a particular geographic area—does not provide reliable data into how much utility the service produces. Moreover, a measurement system that relies on received energy at outdoor listening points as a proxy for overall band utilization risks undervaluing low-power, low-activity-factor, and predominantly indoor operations, such as Wi-Fi, compared to higher-power, high-activity-factor, outdoor operations, even if those operations create less overall utility for consumers than Wi-Fi. Instead, the assessment of utility should measure how much total data is carried by all users of a particular service in a particular spectrum range, recognizing differences between technologies rather than designing a measurement system with one technology or service in mind.

Second, over-conservative spectrum sharing approaches undermine efficiency. To this end, the R&D plan should consider how to reduce false positives in sensing of incumbent uses of spectrum and how to more accurately implement database-protection zones so that commercial operations are not inefficiently blocked. Such inefficient blocking of use can occur as a result of (1) overly conservative propagation models; (2) assumptions regarding incumbent operations based on the use of substandard receivers; or (3) models that undervalue building entry loss or far-field losses from proximity to the body or objects.

Third, the use of lower power levels promotes overall efficiency by supporting a variety of diverse uses in nearby geographic areas, even if it may require the use of more transmission facilities than high-power coverage networks. As described above, lower-power levels make spectrum more widely accessible to new and diverse entrants, promoting competition and new, innovative uses. It also facilitates greater spectrum reuse and coexistence among operators. The

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[11] R&D RFI at 12872.

R&D Plan should consider how network densification and these lower-power approaches maximize flexibility and efficient spectrum use.

Dynamic Spectrum Access and Management. The R&D Plan should support the development of technologies that permit new uses to coexist with incumbent federal and non-federal uses. For example, the Incumbent Informing Capability ("IIC") is a promising development that could improve on the Environmental Sensing Capability in the CBRS band by allowing Spectrum Access System operators and users to rely on government notifications in near real-time. If implemented effectively, it could help reduce both false positives of government use and overbroad preemption of spectrum availability. Similarly, the Telecommunications Advanced Research and Dynamic Spectrum Sharing System ("TARDyS3") provides spectrum scheduling, interference protection, detection, and resolution capacity. Additional R&D can move these technologies forward and make other dynamic approaches effective for both incumbents and new users.

R&D efforts should also focus on advancing the state of databases modeling buildings and other structures for use in interference-protection mechanisms and propagation models. Such databases could allow for a more accurate determination of how to maximize use of a spectrum band without causing harmful interference. Other areas of focus to improve dynamic spectrum access and management include studying methods to (1) reduce the complexity of the process of aggregate interference protections to lower the computational load on DSS systems; (2) address potential over-reservation of spectrum by Federal users in DSS bands; and (3) improve advanced notification of scheduled Federal events to commercial users. Some R&D efforts may target large jumps in technology, but these more incremental advances would have an outsized benefit.

Modeling for Coexistence. The R&D Plan should also focus on developing updates to existing propagation models. As discussed below, existing propagation models are outdated and should be improved to better account for advances in our understanding of signal propagation. Importantly, in updating propagation models, the R&D Plan should recognize that modern wireless systems are not characterized by the use of only high-site/high-power transmitters. Clutter measurements should emphasize the use of lower sites, indoor operations, and other network designs that operate in higher clutter environments than those used in past propagation modeling. In addition, the R&D Plan should invest in developing better use of probabilistic analysis for interference analyses rather than static analyses based on worst-case assumptions. As the FCC has explained in the context of unlicensed operations, for example, static analyses "neglect the effects of the sporadic nature of most unlicensed transmissions . . . and the probability of co-channel operation of the unlicensed device and licensed service."[12] Instead, coexistence analyses "should take into consideration the specific behavior of services involved and the complexity of the propagation environment where the services operate."[13] Static analyses and worst-case assumptions will not support the coexistence needed between Federal systems and commercial use in new bands.

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[12] *See Unlicensed Use of the 6 GHz Band; Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd. 3852, 3893 ¶ 116 (2020) ("*6 GHz First Report and Order*").

[13] *Id.*

Topic #3—Recommendations on "Grand Challenge" Problems

The R&D RFI seeks comment on "[r]ecommendations on grand challenge problems for spectrum R&D" and describes such grand challenge problems as "problems that if attacked will help motivate and coalesce R&D efforts."[14] NCTA identifies two such challenges that are fundamental to moving the needle forward in spectrum research: (1) accurately measuring spectrum utility and (2) accurately measuring spectrum propagation characteristics.

Measuring Spectrum Utility. Accurate and reliable data on spectrum use and utility is critical to understanding and developing a successful spectrum sharing ecosystem. The FCC recently published a Notice of Inquiry to gain greater insight into measuring non-Federal spectrum use.[15] The NSS R&D Plan presents an opportunity to harmonize the Administration's measurement efforts with the FCC's measurement efforts. Specifically, as described above, any measurement approach should be neutral to avoid over- or under-valuing a particular service or technology. For instance, a measurement approach that mistakes received power as a proxy for utility will likely produce unreliable results.[16]

Propagation Modeling. Propagation modeling often has a significant impact on technical and policy decisions regarding commercial spectrum use. However, existing propagation models have become outdated. For example, current propagation models used in spectrum sharing, such as Free Space and the Irregular Terrain Model used in the 6 GHz band for shorter and longer distances respectively, are now many years old and in need of an update. There are now tools and technologies available that could help evolve the existing models so that they better account for signal propagation and attenuation due to clutter such as buildings and foliage. It is also important that assumptions in propagation models' clutter measurements account for modern wireless systems. Modeling should include not only high-site/high-power transmitters, but also the lower-site and indoor transmitters that operate in a different clutter environment. This work is important so propagation loss is not underestimated and predicted interference levels are not overestimated. Further study should prioritize improving propagation models to inform both existing and future spectrum sharing models.

Topic #4—Recommendations on Spectrum R&D Accelerators: Shared Public Datasets, Testbeds, and Collaboration Support

The R&D RFI requests "[r]ecommendations on spectrum R&D accelerators" such as shared public datasets as well as "testbeds, research infrastructure, and collaboration support."[17] Such efforts to simulate real-world shared-spectrum ecosystems as well as efforts to increase transparency will significantly boost spectrum R&D efforts.

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[14] R&D RFI at 12872.

[15] *Advancing Understanding of Non-Federal Spectrum Usage*, Notice of Inquiry, FCC No. 23-63, WT Docket No. 23-232 (rel. Aug. 4, 2023).

[16] *See* Comments of NCTA – The Internet & Television Association at 5-7, WT Docket No. 23-232 (filed Oct. 3, 2023).

[17] R&D RFI at 12872.

Testbeds. NCTA supports efforts to research a national testbed for dynamic spectrum sharing.[18] We agree with SpectrumX's recommendation that testbeds "should consider commercial use cases beyond high-power, outdoor, mobile cellular which are the most difficult for sharing."[19] Such commercial use cases include local-area networks and private cellular networks. Because they use lower-power, localized transmissions, they would be able to share spectrum with incumbents.[20] As SpectrumX explains, "[i]f future Federal systems that are being designed today continue to assume access to exclusive spectrum for perpetuity, then real progress will be limited since the onus of dynamic sharing will continue to fall fully on new entrants."[21]

In addition, it is critical that research testbeds do not interfere with the application of existing coexistence tools to bands that are primed for near-term use. The testbeds should be focused on next-generation technologies and approaches for future bands. For example, the NSS Implementation Plan calls for near-term sharing studies in the 3.1 GHz band, augmented by work from the DSS initiative rather than delayed pending that work's completion. Opening this band does not require next-generation coexistence technologies, even as additional work may build upon and improve existing approaches, such as those already in use in the CBRS band. The R&D Plan should ensure that the DSS initiative focuses on fine-tuning and is designed to supplement the existing and upcoming spectrum sharing studies.

Public Datasets and Collaboration. NCTA agrees with SpectrumX that increased transparency in the spectrum R&D process requires including as many stakeholders as possible. As Spectrum X explains, "[w]e recommend that NTIA along with other Federal agencies convene the relevant stakeholders, including academia as a neutral participant, in studies that evaluate fairly how spectrum may be repurposed, reallocated, and/or shared."[22] It is important that the country develop better mechanisms for including the full range of spectrum users in the discussions about new bands—restricting access to Federal agencies for the critical early stages of consideration of a band is counterproductive. Moreover, involving industry in these processes earlier on will help focus the research to include analysis of which commercial use cases are feasible, rather than addressing those questions after significant work already has been done.

NCTA also recommends that the R&D Plan consider improvements to the mechanism for obtaining security clearances to participate in R&D fora.[23] While the current PATHSS process fosters important technical discussions, it is also difficult to participate if an organization does not have large numbers of engineers with security clearances.[24] Security clearances, needed for PATHSS process participation, currently require a government agency sponsor and are tied to a

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18 NSS at 16; NCTA NSS Implementation Comments at 22.

19 Comments from SpectrumX, the NSF Spectrum Innovation Center at 6, *available at* https://www.ntia.gov/sites/default/files/comments-from-spectrumx.pdf.

20 *Id.*

21 *Id.*

22 *Id.* at 3.

23 NCTA NSS Implementation Plan Comments at 20.

24 *Id.*

contract with that agency. This can be limiting for smaller organizations that do not have active government contracts. Further, NCTA suggests that technical and operational information related to spectrum R&D should be unclassified whenever possible to further increase collaboration.[25]

Topic #5—Recommendations on Near-Term Federal Activities to Make Progress on Activities Discussed in Topics ##1-4

In the short term, NCTA recommends that the Federal government should work to apply existing co-existence tools and approaches to the 3.1 GHz band and 7/8 GHz range. As described above, facilitating coexistence between Federal operations and new commercial use of the 3.1 GHz band does not require the development of new coexistence technologies. Applying the coexistence approaches used in the CBRS band, adapted for the incumbent users present in the 3.1 GHz band, will protect Federal operations while opening the band for commercial operations. Additional work on DSS can expand those sharing possibilities and make even more efficient use of the band, but it is not a precondition to sharing. Similarly, the 7/8 GHz range does not require the development of new co-existence technologies. Co-existence techniques used in the 6 GHz band, such as rules for low-power indoor use and the Automated Frequency Coordination ("AFC") systems recently approved for standard-power operations, will protect incumbent Federal operations and bring next-generation Wi-Fi to American consumers.

Topic #7—Terminology and Definitions for Spectrum R&D

The RFI specifically seeks comment on the definition of "Dynamic Spectrum Sharing," as it "is a focus of the [NSS] but was not defined."[26] DSS by its nature will need to be flexible and capable of implementation in a variety of circumstances and incumbent use environments. Any definition of DSS should recognize several important aspects of the concept:

First, spectrum sharing is "dynamic" when a sharing mechanism enables frequent or even constant change to promote coexistence and intensity of use. Sharing is not dynamic if sharing is made possible through episodic change or stable relationships between different spectrum users.

Second, a spectrum sharing approach can be dynamic with regard to how one set of entities shares spectrum with another set of entities with superior use rights. For example, the CBRS band's DSS approach is dynamic in how Priority Access Licenses ("PAL") and General Authorized Access ("GAA") licensees share spectrum with incumbent Federal systems. Here, the Spectrum Access System protects Federal spectrum users by using sensing to require channel vacation. Similarly, the U-NII-2 band's use of Dynamic Frequency Selection is dynamic because it permits unlicensed operations to share the band as Federal radar systems by using sensing to require channel vacation.

Third, a spectrum sharing approach can also be "dynamic" among entities with the same access rights. Wi-Fi's contention-based protocol, for example, permits DSS among a wide range of diverse spectrum users with the same access rights to unlicensed bands. Specifically, these

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[25] *See id.* at 21.

[26] R&D RFI at 12872.

users can operate in the same channel without pre-coordination because of politeness protocols that facilitate such use.

Fourth, a spectrum sharing approach can allow a band to be shared with entities with superior use rights in a manner that is not "dynamic" but is still appropriate and effective, especially when use of the band by the entities with superior rights is not itself dynamic. For example, the FCC's 6 GHz rules require standard-power Wi-Fi access points to share the 6 GHz band with incumbent Fixed Service operations, managed by AFC systems.[27] These systems use an FCC database to protect Fixed Service operations that (because they are fixed) do not require dynamic protection—change is needed only episodically when a new Fixed Service facility comes online. Importantly, imposing extra regulation by forcing Wi-Fi devices to employ a dynamic protection method in this band would have been unnecessary and inefficient. While AFC systems must be updated in a timely manner, these updates do not make AFC "dynamic" because they are not characterized by frequent or constant change.

Fifth, a sharing approach can be effective if it is not "dynamic." For example, Low-Power Indoor ("LPI") access points in the 6 GHz band effectively share the band with incumbent Fixed Service operations and other incumbent users because they are limited in power and may only be used indoors.[28] LPI devices do not need to consult a database or be governed by a spectrum sensing mechanism to protect those operations. Instead, the lower power levels and building entry loss are effective in allowing coexistence, and they permit the design of LPI devices that are more cost effective and energy efficient than would be the case for a more dynamic approach.

For the purposes of the R&D plan, it is essential to recognize that certain aspects of dynamic sharing—such as incumbent alerting systems or new sensing approaches, as described above—may benefit from R&D efforts. However, that does not mean that these kinds of dynamic spectrum sharing approaches are not already primed for commercial use. Or that DSS is always the right approach to promoting coexistence when non-dynamic sharing accomplishes the goal with more simplicity and lower cost than either DSS or a clear-and-auction approach. Rather, as the above examples demonstrate, spectrum sharing is a success today precisely because of its dynamic *and* non-dynamic characteristics. To this end, as a country, we must work to advance DSS to address tomorrow's challenges while, at the same time, recognizing its existing substantial contributions to resolving today's challenges.

* * *

NCTA stands ready to work with the NITRD working group, NSF, and other federal partners to prepare an R&D Plan that facilitates the development of new tools and technologies that promote spectrum sharing. Next-generation technologies will advance coexistence among a wide range of users and open previously inaccessible bands for new commercial services, yielding significant benefits for the Nation. At the same time, it is important that the R&D Plan pursue the study of next-generation spectrum sharing in a way that allows the country to move

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27 *6 GHz First Report and Order* ¶ 17.

28 *Id.* ¶¶ 98-99.

forward with the bands already primed for commercial use—and to provide the significant benefits offered by spectrum sharing.

Respectfully submitted,

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March 21, 2024

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The MITRE Corporation

MITRE's Response to the OSTP RFI on Spectrum R&D

March 21, 2024

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MITRE's spectrum-focused activities are organized into three categories:

- In our role supporting federal agencies through FFRDCs, we offer critical assistance to both military and civilian agencies in managing and utilizing the electromagnetic spectrum.
- Through our public-private collaboration efforts, we work towards overcoming USG-Industry spectrum negotiation/coexistence challenges. This includes addressing issues such as potential impacts to GPS signals from in-band cellular emissions and possible interference to Radio Altimeters from 5G cellular in the 3.7-3.98 GHz band.
- Our independent research focuses on emerging technology and innovation, economic analysis, impact and risk analysis, policy and regulation, and acquisition support.

MITRE's spectrum goal is to help create whole-of-nation spectrum solutions that balance the critical spectrum needs of competing stakeholders while meeting national goals of next generation wireless technology deployment across the United States.

Introduction and Overarching Comments

Spectrum, a critical and scarce resource, plays a pivotal role in various aspects of national security, economic prosperity, and individual connectivity. It is utilized to protect the nation, perform fundamental scientific research, and enable safety in aviation and other means of transportation. Moreover, it stimulates commerce by providing ready access to the internet and serves as a fundamental resource for communication used by millions of Americans. The importance of spectrum necessitates a comprehensive and effective National Spectrum Research and Development Plan (R&D Plan) to manage its use and development efficiently. The following sections provide detailed insights and recommendations on the approach, objectives, and priorities for this R&D Plan.

Take a Strategic Approach to the R&D Plan

A National Spectrum R&D Plan should have two ends in mind: supporting the National Spectrum Strategy and ensuring advancement of spectrum capabilities necessary to ensure future national security and economic prosperity. To ensure both are accomplished, MITRE recommends taking a comprehensive approach to crafting this R&D Plan by using a strategic planning framework that is consistent with the Government Performance and Results Act.[1] This R&D Plan must also reach beyond the National Science and Technology Council's (NSTC) normal focus of federal R&D coordination to maximize needed collaboration with nongovernmental organizations.

If we assume that the vision for this R&D Plan is meeting the two ends proscribed above, a draft set of high-level goals that collectively meet this vision would be:

- Goal 1: Develop new technology for improved spectrum awareness.
- Goal 2: Create actionable tools/technologies that identify/enable opportunities for spectrum coexistence, data analysis, and dynamic sharing, through collaborative R&D (both nationally and internationally), researcher user facilities, and leveraging advanced sensing technologies and artificial intelligence and machine learning (AI/ML) techniques.
- Goal 3: Enhance spectrum management infrastructure and policy development.

The R&D Plan should identify priority objectives to meet each goal, and then assign agency actions to meet each objective. Doing so helps ensure the strategic comprehensiveness of the R&D Plan so that it meets the government's vision and provides the Executive Office of the President (EOP) an ability to measure and track progress.

Systemic Overview and Assumptions for Spectrum R&D Prioritization

Setting priorities for spectrum R&D requires a top-down systems perspective of the desired functionality. An operational view, like Figure 1, showcases a large-scale cellular network coexisting with various USG assets across regions. Consistent with the National Spectrum Strategy's aim to maximize technology use for spectrum sharing, we assume that spectrum sharing gives priority to systems that depend on or are enabled by the spectrum in a specific region to perform their tasks over a certain time. The sharing arrangement, which could be exclusive or cooperative, may vary based on time, location, or frequency.[2]

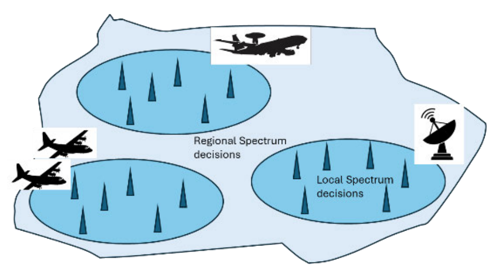

Figure 1 - Operational View (OV-1) of Spectrum Sharing

Figure 2 provides a more detailed view of the activities within the regions depicted in Figure 1, offering a deeper understanding of the complexity of an advanced sharing system. This figure presents a functional block diagram, indicating the presence of various entities within the region, without specifying their exact physical locations.

[1] D. Blackburn. Effective EOP Leadership – Learned Guidance for an Incoming Appointee. 2024. MITRE, https://www.mitre.org/sites/default/files/2024-02/Effective%20EOP%20Leadership-2_AM508.pdf. P5.

[2] Alternatively, employing techniques such as orthogonal polarization, modulation, and coding schemes can enable truly simultaneous use of the spectrum where time, space, and frequency boundaries are not necessarily needed; such schemes are likely of little near-term value given the lack of flexibility in existing USG programs of record that are expensive and difficult to modify.

The intent of Figure 2 is to illustrate a notional computational cycle of a spectrum sharing system. In this cycle, radio frequency (RF) information is sensed, digitally processed, and combined with other relevant information to facilitate spectrum decisions. This information is passed to a decision engine, which may also receive additional data and which predictively schedules spectrum decisions that are disseminated to entities within the region. RF emissions from these entities are subsequently sensed as the spectrum situation continues to evolve.

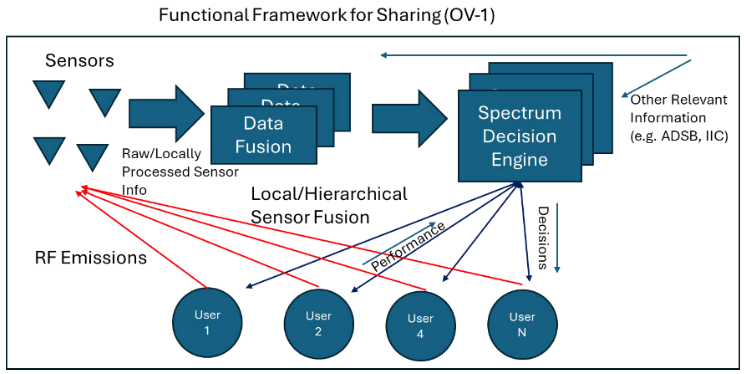

Figure 2 - Functional Block Diagram of Regional Spectrum Sharing

The elements of Figure 2, along with consideration for their physical placement, highlight some of the research priorities that should be addressed and prioritized. These specific priorities, in relation to this figure, are discussed in more detail in subsequent sections of this document.

Evaluation Mechanisms and Technology Maturation

In the diverse field of spectrum research, prioritizing activities based on the stages of technology maturation is crucial. To facilitate this, MITRE recommends incorporating specific evaluation and maturation mechanisms, as illustrated in Figure 3.

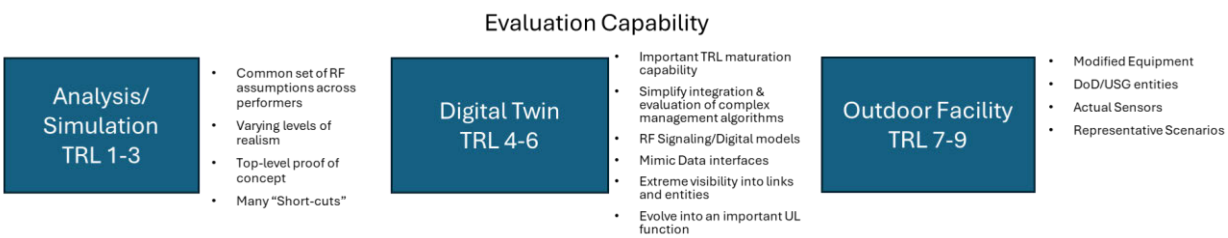

Figure 3 - Readiness Tiers of Evaluation

Modeling & Simulation (M&S) for Coexistence Analysis (Technology Readiness Level [TRL] 1-3)

R&D initiatives should focus on establishing a set of acceptable methodologies, M&S tools, propagation models, and geographic information system datasets to maximize potential alignment at the conclusion of studies. Additionally, the strategy should consider the possibility of centralizing an evaluation capability for M&S, where feasible.

Digital Twins for Spectrum Sensing/Sharing (TRL 4-6)

Digital twins accurately emulate real site topology data for federal and commercial users, providing precise digital representations of propagation environments.

As concepts mature, costs increase, but efficiencies can be realized by creating testbeds for comparing various techniques. The most significant return is likely at the mid-TRL range, where decisions transition a concept into a detailed design phase. Digital twins offer unique insights into new concepts' performance at scale, without the need for detailed design or physical prototyping.

Testbeds and digital twins are crucial tools in spectrum research and development, forming key components of a cooperative R&D infrastructure. They provide a controlled, adaptable environment for simulating and emulating interactions between different systems in a spectrum sharing scenario. This supports the evaluation of various spectrum sharing strategies and algorithms, enabling a comprehensive understanding of the algorithms' impact across all stakeholders.

These tools foster national collaboration across government, industry, non-profit organizations, and academia, aligning with Pillar Two of the National Spectrum Strategy (Strategy).[3] They facilitate agreement on metrics, methods, models, and solutions, providing a common platform for diverse stakeholders to work toward shared objectives. This is in line with the Strategy's call for a persistent strategic spectrum planning process guided by the best available science and data (Strategic Objective 2.1).

By accurately replicating real-world conditions, digital twins enable the use and analysis of extensive and shared data, promoting data-driven decision making. This is a key aspect of the Strategy's approach to improving spectrum efficiency and bolstering coexistence by facilitating investments in new and emerging technologies (Strategic Objective 3.1).

Outdoor Test Facility (TRL 7-9)

While the main spectrum sharing testbed may be hosted by the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS), a federated virtualized approach is necessary to connect other testbeds to it. For example, the National Science Foundation (NSF) funded SpectrumX testbed and the Department of Defense (DoD)-funded Playas testbed should have the capability to interface directly with the NTIA testbed. These testbeds play a crucial role in facilitating the testing and validation of new sensing technologies, data analytics, sharing, and coordination protocols over large geographic scales. They should provide a realistic environment for spectrum sensing, encompassing both urban and rural settings, and be accessible to researchers from government, industry, and academia.

International Collaboration

Although not a test facility per se, the importance of international collaboration in this context is paramount. An advanced sharing system in the US may yield economic benefits domestically. However, the approach to collaboration with international partners, particularly as it pertains to the DoD, is critical. If not handled appropriately, it could potentially jeopardize unimpaired DoD access to certain spectrum.

Beyond R&D

The task of designing a new sharing system that optimizes spectrum utility for all stakeholders is daunting, and it is important to consider future implications. In a free market, numerous capable commercial entities may propose products that purport to comply with the interfaces, standards, and principles established by this R&D effort. Given the complexity of this solution, and the crucial role of spectrum for stakeholders, it will be essential to establish a function akin to an Underwriters Laboratory. This would subject all proposed solutions to rigorous testing. Given the complex interactions involved, such exhaustive testing is warranted.

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[3] National Spectrum Strategy. 2023. The White House, https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf.

Answers to Questions Posed in the RFI

1. Recommendations on strategies for conducting spectrum research in a manner that minimizes unnecessary duplication, ensures that all essential spectrum research areas are sufficiently explored, and achieves measurable advancements in state-of-the-art spectrum science and engineering.

There is recognition that advancing critical and emerging technologies within the context of modern international science and technology (S&T) competition will require greater collaboration.[4,5] A recent MITRE analysis[6] also shows that providing additional resources and enabling specific public-private collaboration *at the right time and with the right focus* within the technology lifecycle can rapidly accelerate S&T development and its application across a variety of use cases. This analysis uncovered that there are four points (or "levers") within a technology development process where coordinated attention across the public and private sectors will yield greater return on investment and accelerate S&T innovation and adoption compared to generally targeted collaborations pursued historically, as illustrated in Figure 4.

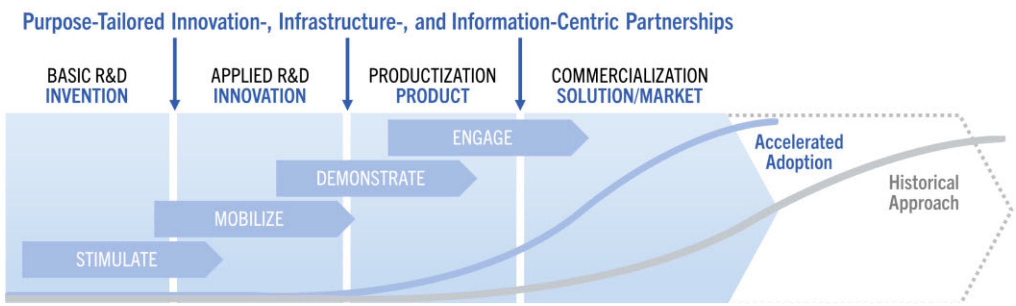

Figure 4 - Strategic Collaboration at Four Levers in a Technology's Evolution Can Accelerate Its Adoption

Applying this lever concept to spectrum R&D produces the following suggestions for activities and incentive structures:

- Lever 1: Stimulating Research and Creating Interest
  - Establishing Public-Private Partnerships: Encourage partnerships between government agencies, academia, and the private sector to jointly fund and conduct early-stage spectrum research. This can leverage the strengths of each sector and increase overall investment in spectrum R&D.
  - Developing Innovation Clusters: Establish a nationwide facility for spectrum research to serve as a centralized hub for collaboration among various stakeholders. This facility could become a geographic concentration of interconnected businesses, suppliers, and associated institutions in the field of spectrum research.

[4] C. Ford et al. A "Horizon Strategy" Framework for Science and Technology Policy. 2021. MITRE, https://www.mitre.org/sites/default/files/2021-11/prs-21-1440-horizon-strategy-framework-science-technology-policy.pdf.

[5] Platforms Interim Panel Report. 2022. Special Competitive Studies Project, https://www.scsp.ai/wp-content/uploads/2023/01/Platforms-Panel-IPR.pdf.

[6] D. Blackburn et al. Partnerships to Accelerate Advancement of Priority S&T. 2023. MITRE, https://www.mitre.org/news-insights/publication/partnerships-accelerate-advancement-priority-st.

- Lever 2: Mobilizing a Network (Active Ecosystem)
  - Creating an R&D Consortia: Establish a network that brings together spectrum researchers, investors, and end users to exchange information. Foster collaboration to create a sense of shared ownership and commitment, thereby leading to increased investment.
  - Lowering the "Cost of Entry": Explore capabilities that provide researchers with access to facilities and data necessary for their work. Making existing resources available for use would lower the "cost of entry" for participating entities, allowing them to focus on their specific research interests without the burden of creating their own infrastructure. This approach could stimulate more investment in spectrum R&D by making it more accessible and cost-effective for a wider range of researchers.
- Lever 3: Demonstrating Impactful Solutions
  - Implementing Co-funding Mechanisms: Encourage partnerships between government agencies, academia, and the private sector to jointly fund and conduct research. This can leverage the strengths of each sector and increase overall investment in spectrum R&D.
  - Enhancing Awareness of Research Activities: Regularly disseminate information about ongoing research findings and technological advancements to enhance awareness among public and private sectors. This broad awareness supports follow-on research and technology commercialization, fostering a vibrant ecosystem of innovation. In addition, this continuous flow of information can inform updates to the R&D Plan, ensuring that future investments are targeted to the most-needed areas, thereby maintaining the plan's relevance and continuing to attract investment from all stakeholders.
- Lever 4: Increasing Business/Industry Engagement
  - Establishing Clear Goals and Metrics: Set clear and measurable objectives for this latter-stage R&D, and track progress toward these goals to ensure that investment in R&D is targeted and effective.
  - Equipping Potential Users with Knowledge on the Commercial Market: The Spectrum R&D Plan should direct investments to agencies' spectrum R&D offices to either internally or externally contract research in state-of-the-art spectrum sensing and sharing capabilities to support future mission spectrum requirements. With increased awareness, agencies will come into these studies more willing to consider dynamic coexistence solutions.

2. Recommended priority areas for spectrum research and development, as well as productive directions for advancing the state-of-the-art in those areas.

The following sections highlight specific research areas that ought to be undertaken to meet the objectives of the National Spectrum Strategy.

Spectrum Awareness: Supporting and enabling spectrum awareness[7] and spectrum coexistence[8] should be a fundamental aspect within the R&D Plan. As a critical enabler for dynamic spectrum

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[7] Spectrum awareness implies the availability of specific information necessary to make optimal decisions related to spectrum management. Information includes but is not limited to understanding the current spectrum utilization, efficiency, availability, and potential interference within a current region and across diverse geographical locations and time. The full suite of information to meet the definition of this term will be fleshed out through the research proposed.

[8] Spectrum coexistence refers to the ability to have more than one system and/or stakeholder utilize the same band.

access, efficient spectrum utilization, and interference mitigation, spectrum awareness forms the backbone of modern spectrum management strategies. This effort should aim to quantify, in mathematical terms, the intuitive concepts prevalent in this domain wherever feasible. However, achieving comprehensive spectrum awareness, both on a national scale and within the "Decision Engines" of Figure 2, presents significant technical and operational challenges. These challenges range from the development of advanced sensing technologies and analytics for real-time spectrum monitoring to the establishment of protocols for data sharing and coordination among a diverse range of spectrum stakeholders, including federal agencies, commercial entities, and academia.

<u>A Comprehensive System-Engineered Framework for Sharing/Dynamic Spectrum Access</u>: Research should aim to develop a comprehensive framework that includes acceptable mechanisms for data sharing, data analytics, data collection from advanced sensing technologies, and management of spectrum coexistence in various potential approaches. Extensive R&D is needed to evaluate, refine, and mature the approaches under consideration for implementation. These solutions either will drive or must align with a more refined version of Figure 2. A top-down system engineering approach is necessary to ensure that all components are clearly defined and understood, eliminating any "black box" scenarios.

<u>Improving Economic and Policy Drivers and Their Influence on Technical Requirements</u>: R&D efforts should investigate the influence of economic incentives and policy on stakeholder decisions regarding spectrum efficiency, access, and innovation. This includes understanding how these factors shape the development and deployment of spectrum technologies and their adaptation for new uses. Research insights can guide the creation of new economic models and policy frameworks to achieve national spectrum goals.

Unique spectrum considerations for the USG include the need to test electronic warfare without impacting non-military spectrum allocations and understanding the effects of evolving cellular technology (5G/6G) on USG incumbents. Future missions related to homeland security, aviation, and ground transportation also require specific attention. Solutions should balance the spectrum needs of the USG and other stakeholders.

Spectrum management operates under evolving rules and policies. The system should be designed to interpret these policies and translate them into algorithmically actionable information. For instance, spectrum resilience and assured access are critical for certain mission applications and passive scientific observation.

A balanced set of quantifiable target metrics is crucial for a common discourse on spectrum issues. While spectrum utilization efficiency is important, it shouldn't overshadow other metrics like national security, transportation safety, or economic efficiency. These metrics can guide spectrum decisions and inform the modernization of practices/algorithms to enhance spectrum use for all stakeholders.

<u>Implementing Technology and an Algorithmic Framework for Overall Spectrum Sharing</u>: The ultimate technological goal is to align the sharing mechanism's operation with the operational timescales of individual systems to optimize access. Given the small timescales of cellular operation (e.g., 0.5 ms in Mid-Band), practical issues like latency in information transmission and processing are crucial to the sharing system's timing budget. These constraints direct research toward decentralized systems for local decision making, predictive systems, and systems with control aspects operating at different timescales as latency allows.

It's also important to consider decision making with only partial information, as achieving "Full Spectrum Awareness" even within a region may be unattainable in the short term. Therefore, a robust R&D plan should acknowledge the practical and fundamental limitations of the achievable information level. Specific functions from Figure 2 are detailed below:

- Advanced Spectrum Sensing Technologies: R&D should focus on advanced sensing technologies, including quantum sensing, that can provide real-time, accurate, and high-resolution data on spectrum usage across diverse frequency bands and geographical locations. This includes the development of cost-effective, scalable, and robust spectrum sensors that can be distributed nationwide.
- Data Analytics and Artificial Intelligence: The vast amount of data generated by spectrum sensors requires processing and analysis to extract meaningful insights about spectrum usage and availability. R&D should concentrate on advanced data analytics, machine learning, and artificial intelligence techniques that can process and analyze spectrum data in real time, detect patterns of spectrum usage, predict future spectrum availability, and identify potential interference.
- Spectrum Data Sharing and Coordination: Achieving national spectrum awareness requires effective coordination and data sharing among diverse spectrum stakeholders. R&D should aim to develop secure, scalable, and efficient protocols for spectrum data sharing and coordination, including privacy-preserving data sharing protocols. This includes creating common data formats and interfaces for spectrum data exchange, as well as protocols for collaborative decision making in dynamic spectrum access.
- Dynamic Spectrum Access and Management: Research should focus on improving the management of dynamic spectrum access and use. This includes exploring how information about managing prospective interference might be reported and what the operations security concerns are. Key characteristics include:
    - Automatic and Rapid Mitigation of Interference Problems: This needs to be a priority, with research being a collaborative effort between government, for interference requirements, and commercial entities, led by the latter as they will need to implement interference mitigation techniques at scale and prove they are meeting interference thresholds.
    - Decision Making with Partial or Imperfect Information: While total spectrum awareness should be the ultimate goal, it is unachievable in the near term. Therefore, R&D is also needed to support decision making based on partial or imperfect information. This includes the development of robust decision-making algorithms and models that can handle uncertainty and incomplete data.
    - Decentralized Spectrum Management: Given the vast scale and complexity of the spectrum environment, a decentralized approach to spectrum management is necessary. This means that decisions need to be made somewhat locally, based on the spectrum data available in a specific geographical area or "footprint." R&D is needed to develop effective methods and protocols for decentralized spectrum management, such as game-theoretic, blockchain, or market-based approaches.
    - Federated Solutions: Given the predictive nature of spectrum solutions, there exists a class of solutions where localized decision making can be informed or augmented centrally with known information such as a platform's mission plan, or via AI/ML updates to processing engines that learn from previous decisions and consequences.

- Cybersecurity in Spectrum Technologies: As spectrum-dependent technologies continue to evolve and become more integrated into our daily lives and critical infrastructure, the need for robust cybersecurity measures becomes increasingly paramount. R&D efforts should focus on developing secure spectrum access technologies and encryption methods for spectrum data. This includes researching potential cybersecurity threats specific to wireless technologies and developing proactive measures to mitigate these threats. It is also important to consider the security implications of spectrum sharing and dynamic spectrum access, ensuring these technologies are designed with security in mind from the ground up.
- User Experience Research: While the technical and engineering aspects of spectrum use are crucial, understanding the end-user experience is equally important for the successful implementation and acceptance of new technologies. R&D efforts should focus on studying user behavior, needs, and acceptance of new spectrum technologies and services. This includes researching how different spectrum-dependent technologies are used in various contexts (e.g., home, work, public spaces), how users interact with these technologies, and what barriers or challenges they face. The insights gained from this research can inform the design and development of user-friendly, accessible, and inclusive spectrum technologies.
- Assessment and Certification of Advanced Systems: Research should also focus on the assessment and certification of advanced systems. This would involve developing standards and procedures for evaluating the performance and reliability of new spectrum technologies and systems.

3. Recommendations on grand challenge problems for spectrum R&D. Grand challenges are selected research problems that if attacked will help motivate and coalesce R&D efforts.

A decentralized approach to spectrum management is essential, allowing decisions to be made locally based on the spectrum data available in a specific geographical area or "footprint." A valuable grand challenge that could inform solutions in this area would be the outdoor proof-of-concept implementation of a dynamic sharing scenario. This scenario would involve a two-tier decentralized decision-making solution, where local decisions are made for nodes grouped in clusters by proximity, with coordination across clusters for regional-level decisions.

MITRE further recommends a risk-informed spectrum analytic approach be adopted to provide more granular information, including quantification of the likelihood and impact of adverse effects, such as harmful interference, to support decision makers in minimizing interference risk and maximizing spectrum utilization.[9]

4. Recommendations on spectrum R&D accelerators

The use of digital twins, as previously discussed, is a relevant and viable accelerator for the spectrum R&D process. Another strategy to expedite the process is to employ parallel workstreams. For example, as a testbed is being developed, stakeholders and industry should engage in forums to define use cases of interest, outline specifications for proof-of-concept activities, and plan early pilot implementations. This approach ensures that when technologies

[9] "Commerce Spectrum Management Advisory Committee (CSMAC) Report of Subcommittee on Electromagnetic Compatibility Improvements," CSMAC, December 19, 2023. Robert Henry and Harris Zebrowitz, "Risk-Informed Spectrum Sharing and Management Capability," The MITRE Corporation, ISART 2022.

and solutions become available, workstreams can converge for a faster outcome, thus reducing the time from research to implementation.

6. Recommendations on a process to refine and enhance the R&D plan on an ongoing basis

The R&D Plan must be continuously refined and enhanced to keep pace with the rapidly evolving field of spectrum science and engineering. A structured and systematic process for updating the plan ensures its relevance, effectiveness, and alignment with the latest advancements and research activities. This process should involve regular reporting from agencies, consistent analysis of new studies, routine review and update of the plan, and feedback from stakeholders. The following recommendations outline a process for refining and enhancing the R&D plan on an ongoing basis.

Coordinated Reporting Process: Establish a coordinated process for agencies to report updates on their respective spectrum research. This process should involve regular reporting intervals and a standardized format for reporting to ensure consistency and ease of comparison across different agencies' reports. The collected information should be used to update the R&D plan, ensuring it reflects the most recent advancements and ongoing research activities.

Regular Analysis of New Studies: The R&D Plan should consistently analyze and incorporate new International Telecommunications Union coexistence and other spectrum studies. This involves setting up a dedicated team or mechanism to regularly review these studies, extract relevant findings, and update the R&D Plan accordingly. This ensures that the plan remains up to date with the latest global advancements in spectrum science and engineering.

Regular Review and Update of the R&D Plan: The R&D Plan should be reviewed and updated on a regular basis, such as annually or biannually. This review should consider the progress made toward the plan's objectives, the effectiveness of the strategies employed, and any changes in the spectrum research landscape. The review findings should be used to refine the plan, adjusting objectives, strategies, and priorities as necessary.

Stakeholder Feedback: Seek feedback from stakeholders, including non-federal entities such as industry and academia, on the R&D Plan. This feedback can provide valuable insights into the plan's effectiveness and areas for improvement. The feedback should be considered in the regular review and update of the R&D Plan.

7. Terminology and definitions relevant for spectrum R&D.

Dynamic Spectrum Sharing (DSS), a focus but undefined phrase in the Strategy, is a set of technologies that allow wireless systems to adaptively share spectrum resources. DSS makes real-time adjustments to spectrum use based on changing conditions like user demand or interference levels. The goal of DSS is to enhance spectrum efficiency and flexibility, supporting various applications and services. By dynamically sharing spectrum, DSS aims to maximize spectrum utilization, accommodate more users, and improve wireless service performance and reliability.

Spectrum awareness, while intuitively important both nationally and at each decision-making point (e.g., the decision engines of Figure 2), needs to be defined in a quantifiable manner.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The mmWave Coalition

Response of the mmWave Coalition

To

National Science Foundation's
Request for Information on the National Spectrum Research and Development Plan
(89 FR 12871)

The mmWave Coalition, "mmWC" is pleased to present to NSF these suggestions for future funding areas to support the development of new communications technology above 100 GHz and to support US leadership in this technology. mmWC is a group of innovative companies and universities[1] united in the objective of removing unnecessary regulatory barriers to technologies and using frequencies ranging from 95 GHz to 450 GHz. The Coalition does not limit itself to supporting any particular use or technology but rather it is working to create a regulatory structure for these frequencies that would encompass all technologies and all possible uses, limited only by the constraints of physics, innovation, and the imagination.

The term "subTerahertz" or sub-THz is often used now to describe frequencies between 100 and 300 GHz, an area where there is little present active spectrum use, where

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[1] Members of the mmWC are : 2π-LABS GmbH, American Certification Body, Inc., Azbil North America Research and Development, Inc., Brown University, Keysight Technologies, Nokia Corporation, Northeastern University, Nuvotronics, Inc., NXP Semiconductors, NYU WIRELESS, Oklahoma State University, Qualcomm, RaySecur, TCB Council, The University of Arizona, VEGA Americas, Virginia Diodes, Inc., and VUBIQ Networks

the FCC has authorized experimental use since 2019 resulting in products being spawned in such frequencies[2], and where national and international spectrum policies complicate such use due to a high density of passive frequency allocations. ITU Radio Regulation 5.340, which protects many of these bands, begins with a phrase first used for lower frequency allocations in passive bands; "All emissions are prohibited in the following bands:". There are additional passive allocations that are protected by regulatory terms that are somewhat more flexible. National and international spectrum regulations, together, prevent the use of transmitters with bandwidth greater than about 30 GHz, essentially negating the main benefit of operating in such high bands.

Most of the allocations above 100 GHz were made at the ITU's 2000 World Radio Conference, "WRC-2000", as a result of parallel proposals from both the US and European countries represented by CEPT. Both the US and CEPT proposals for multiple passive bands above 100 GHz expressed doubt as to whether the classic, "all emissions are prohibited" terms of 5.340 were necessary at these higher bands, due to the different physics at these high bands with respect to both radio propagation and short wavelengths that enable antenna design options that are impractical at lower bands. WRC-2000 adopted both the new allocations along with Resolution 731, "Res. 731", requesting ITU-R study of the feasibility of sharing passive bands in 71-275 GHz with communications

[2] T. S. Rappaport et al., Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond, IEEE Access, pp 78729 - 78757, May 2019. DOI: 10.1109/ACCESS.2019.2921522 (.https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8732419)

subject to specific quantitative limits of the resulting interference to passive users.[3] This adopted resolution also specifically stated,

> "that, to the extent practicable, the burden of sharing among active and passive services should be equitably distributed among the services to which allocations are made".

Res. 731 has been revised at both WRC-19[4] and WRC-23[5], but the basic provisions considering sharing at 71-275 GHz and for "burden sharing" have never been changed.

Most of the 5G and 6G spectrum policy discussions to date have focused on lower frequencies. A key reason for this is that it is hard to justify a business case for sub-THZ mobile spectrum use at present as there are now basic technical questions, technological hurdles, and cost issues, yet these are fertile and active areas of research which may eventually lead to compelling opportunities for mobile use in this spectrum. [6] However, 5G and 6G in US policy deliberations addresses **both** fixed and mobile users, and the 5G and 6G mobile uses are dependent on fronthaul and backhaul which are essentially fixed services. While these fixed links are often implemented in non-spectrum fiber optic links, there is a vast, growing need for wireless backhaul, especially in rural, underserved areas often where fixed wireless access is vital for rural households, and often backhaul requirements cannot always be implemented in fiber technology, due to installation

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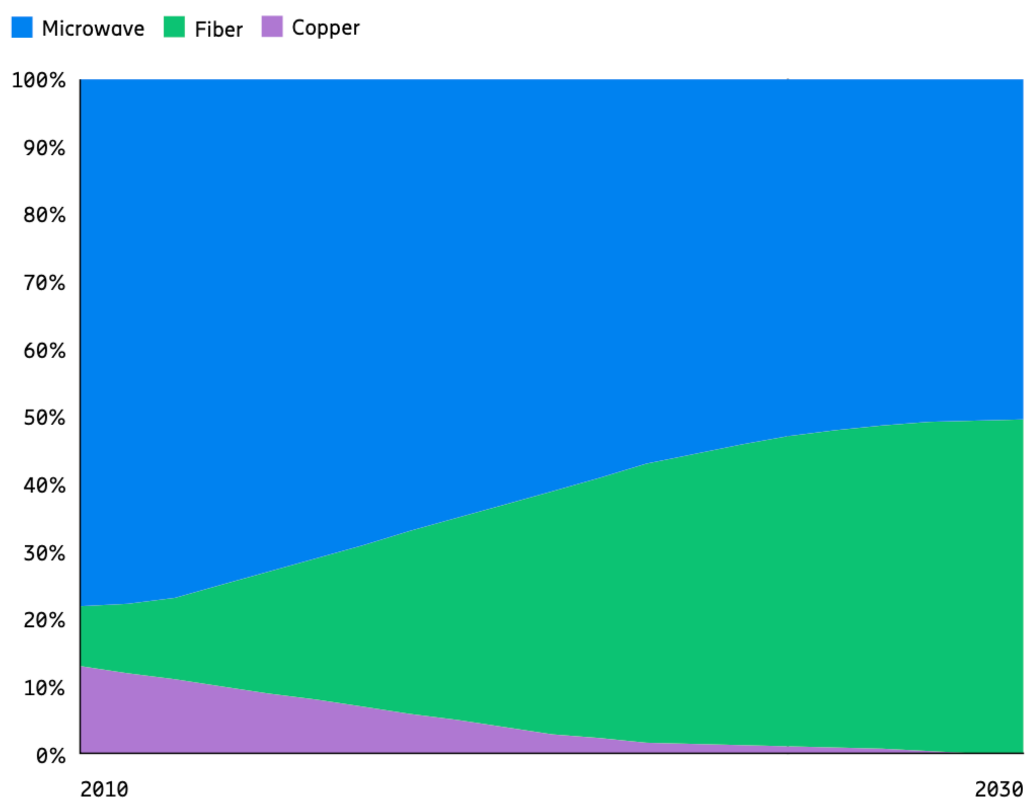
[3] https://www.itu.int/net/ITU-R/conferences/docs/ties/res-731-en.pdf
[4] https://www.itu.int/dms_pub/itu-r/oth/0C/0A/R0C0A00000F00149PDFE.pdf
[5] Res. 731 (Rev. WRC-23) WRC-23 Prov.Fin.Acts p. 412 (https://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.15-2023-PDF-E.pdf)
[6] T. Rappaport *et al.*, Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond, *IEEE Access*, June 2019 (https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8732419)

urgency requirements, local terrain features that delay or block installation, cost, or short term requirements that make fiber optic installation uneconomical.

A recent publication[7] by a major equipment manufacturer predicts that backhaul will continue to be implemented in a mix of both spectrum and non-spectrum technology as shown below:

Figure 1: Predicted global backhaul media distribution up until 2030



The growing interest in Fixed Wireless Access[8] as well as growing reliance upon 5G millimeter wave spectrum to support massive data rates in stadiums, concert venues, and

[7] Ericsson Microwave Outlook, 10th Edition, October 2023 (https://www.ericsson.com/en/reports-and-papers/microwave-outlook)

[8] https://newsroom.uscellular.com/uscellular-qualcomm-inseego-launches-5g-mmwave-high-speed-internet-service-in-10-cities/

urban cores by two of the three major US cellular carriers[9] will also increase demand for future mobile users as well as increase the demand for even greater high speed fixed wireless links that cannot be implemented in present allocations below 100 GHz. It is important to note that "killer applications" for 5G have not yet been realized but are being developed and created, and will come to consumers just as has always happened in past generations of cellular technology and expansion of the Internet. Thus, the Fixed Service and Mobile Service needs for wide bandwidths in sub-THz can justify considering mobile and fixed terrestrial technology that will allow sharing with space-based passive satellites under the conditions specified in Res. 731 based solely on the present fixed communication requirements, without waiting for resolution on whether mobile links would be needed. Research and development of technology for terrestrial based mobile and fixed links and devices must be fostered, in light of the viability for sharing with passive bands that meet the limits of Res. 731. All the Fixed and Mobile Service allocations above 100 GHz are now actually coprimary Fixed and Mobile allocations, so both services are entitled to access to the spectrum. NSF should help foster fundamental and eventual commercialization of mobile and fixed terrestrial communications, sensing, antenna technologies, and innovative spectrum management in light of Res. 731.

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https://newsroom.uscellular.com/uscellular-qualcomm-inseego-launches-5g-mmwave-high-speed-internet-service-in-10-cities/

[9] https://www.sdxcentral.com/articles/analysis/verizon-taylor-swifts-swifties-are-the-ultimate-mmwave-use-case/2023/12/
https://www.fiercewireless.com/tech/5g-drives-network-capacity-super-bowl-srg

While sharing passive bands below 71 GHz is very challenging and may be nearly impossible due to many reasons, not limited to congestion of the spectrum, difficulty in controlling mobile and fixed device radiation patterns from existing antenna technology, Res. 731 recognizes there is uncertainty whether such limitations on practical sharing between space-based passive receivers and terrestrial transceivers that is also applicable to 71-275 GHz, where atmospheric absorption has a large impact on radio propagation[10] and where the small wavelengths enable alternative antenna designs that are more focused/directional and are not practical in lower bands. Several possible sharing approaches for this band have been described in the literature[11] and it is likely that further research will contribute fundamental knowledge useful for achieving tremendous capacity and capability advances in terrestrial based networks used by humans and machines on Earth.

Research on sharing the sub-Terahertz spectrum is not only very technically challenging but it also has a high burden of "regulatory risk" for corporations contemplating investment, because such technology cannot be implemented without both national and international regulatory changes that could require 5 to 10 plus years to be approved. As a result, private sector funding in this area has been complicated and substantially limited,

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[10] M. Marcus, X. C. Roman and J. Jornet, "Millimeter-Wave Propagation: Spectrum Management Implications-An Update for >100 GHz [Speaker's Corner]," in *IEEE Microwave Magazine,* vol. *24,* no. 1, pp. 91-94, Jan. 2023, doi: 10.1109/MMM.2022.3211599.
Y. Xing, et. al., Terahertz Wireless Communications: Co-Sharing for Terrestrial and Satellite Systems Above 100 GHz*, IEEE Wireless Communications Letters*, Vol. *25*, No. 10, pp. 3156-3160, Oct. 2021, doi: 10.1109/LCOMM.2021.3088270.
[11] M. Polese *et al.*, "Coexistence and Spectrum Sharing Above 100 GHz," in *Proceedings of the IEEE*, vol. *111*, no. 8, pp. 928-954, Aug. 2023, doi: 10.1109/JPROC.2023.3286172

requiring NSF and other government agencies to realize the importance of funding in this area for the long term national competitiveness of the US wireless and integrated circuit industries, as well as the potential benefit of massively broadband wireless networks for US consumers. mmWC urges NSF to make funds available for new initiatives for communications systems that are designed to occupy large contiguous blocks of spectrum in 71-275 GHz while also protecting the allocated passive users in those bands to the levels of interference permitted by Res. 731.

mmWC also suggests that NSF fund collaborations between the communications technology community and the passive scientific communities involved in 71-275 GHz usage in the Radio Astronomy Service and the Earth Exploration-Satellite (passive) Service to explore possible approaches to "burden sharing" involving design tradeoffs in the active and passive systems using overlapping spectrum. For example, one possible sharing approach could be using multiple element antennas for terrestrial communication transmitters that used antenna nulling technology to minimize the effective radiated power towards any passive satellite that is in line of sight as it passes within the radio horizon of the transmitted signals of terrestrial devices.[12] This type of protection would only work if the number of satellites in a specific frequency band visible above the horizon at the transmitter as well as the number of terrestrial transmitters with a given sidelobe attenuation level, are subject to known maximums. Thus, the active and passive technology participants in the study of these options should consider the impact of

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[12] Y. Xing*, et. al.,op. cit.*
M. Polese *et al.*, *op. cit.*

requiring operators of passive satellites to coordinate their orbit parameters in ways that have never been done before.

Another important topic for NSF to consider relates to its long-term funding of NASEM's Committee on Radio Frequencies "CORF".[13] The role of CORF is to

> "consider the needs for radio frequency requirements and interference protection for scientific and engineering research, coordinates the views of the U.S. scientists, and acts as a channel for representing the interests of U.S. scientists in the work of the inter-union commission on frequency allocations for radio astronomy and space science (IUCAF) of the International Council of Scientific Unions."

CORF in its analyses, publication, and advocacy before FCC historically has opposed *any* spectrum policy change that might result in *any* increases of interference to passive systems. Thus NSF-funded CORF has never been willing to review spectrum sharing options involving passive spectrum because of its interpretation of the funding it receives from NSF and NASA. While CORF's Statement of Work from the agencies that fund it, including NSF, are not readily available, NASEM representatives have stated that CORF is not funded to consider many spectrum sharing issues and focuses solely on protecting passive users. However, in the case of spectrum in 71-275 GHz this refusal to consider appears inconsistent with the Res. 731 framework that the US originally proposed at WRC-2000 and which has remained intact, despite explicit review and updating of the resolution at two different WRCs.

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[13] https://www.nationalacademies.org/our-work/committee-on-radio-frequencies#sectionProjectScope

mmWC urges NSF to include in CORF's future Statement of Work *some* level of consideration of how the sharing goals in Res. 731 can be implemented, subject to the explicit protection levels in that long standing document, as the benefit to US competitiveness, and potential gains by US industry and consumers are at stake.

/s/

Mark Cudak
Chair of Steering Group
mmWave Coalition

March 21, 2024

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

The OnGo Alliance

March 21, 2024

Ms. Mallory Hinks
NITRD NCO
2415 Eisenhower Avenue
Alexandria, VA 22314

Re: Request for Information on the National Spectrum Research and Development Plan

Dear Ms. Hinks:

The OnGo Alliance[1] ("the Alliance") appreciates the opportunity to provide comments[2] in response to the Request for Information ("RFI") issued by the Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO) on the National Spectrum Research and Development Plan ("R&D Plan").[3]

The Alliance shares the assessment articulated in the National Spectrum Strategy that "the United States is uniquely positioned to embrace a whole-of-Nation approach to advance the state of technology for dynamic forms of sharing,"[4] and we are pleased to offer our perspectives on key innovation areas for spectrum research and development that will achieve "measurable advancements in state-of-the-art spectrum science and engineering."[5]

The CBRS experience is a shining example of state-of-the-art spectrum science and engineering in the context of dynamic spectrum sharing. Since the authorization of full commercial service in early 2020, approximately 370,000 CBRS devices (CBSDs) are in operation, facilitated by over 250 FCC-certified models of CBSDs, more than 700 FCC-certified models of CBRS end-user devices and components, and a

[1] The OnGo Alliance is a coalition of over 120 member companies, including mobile operators, cable operators, managed service providers, mobile virtual network operators, fixed wireless operators, enterprises, and more. Our members have deployed 3GPP technology-based solutions (both 4G LTE and 5G NR) in the Citizens Broadband Radio Service (CBRS) band to enable in-building and outdoor broadband coverage and capacity expansion at massive scale. Since 2016, the OnGo Alliance and its members have focused time, energy, and innovation to develop reliable, secure, and cost-effective wireless services for the 3.5 GHz CBRS band. The Alliance also established an effective product certification program for OnGo ensuring multi-vendor interoperability, with over 90 models of CBRS base stations (CBSDs) having achieved OnGo certification to date.
[2] This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.
[3] NITRD NCO, Request for Information on the National Spectrum Research and Development Plan; *available a*t https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan ("RFI").
[4] Available at https://www.ntia.gov/issues/national-spectrum-strategy.
[5] RFI.

vast network of over 1,000 operators satisfying a wide range of use cases, including mobile broadband, fixed wireless access, and enterprise private networks – all on a shared basis under the management of commercial Spectrum Access System (SAS) technology and solutions.

With zero reports of interference from incumbent federal and commercial users, the CBRS experience demonstrates that dynamic spectrum sharing works and should be a model for sharing in other frequency bands. That being said, there are opportunities to enhance and improve upon dynamic spectrum sharing technology and process. We encourage the National Science Foundation (NSF) and other federal agencies to work closely with the Alliance and other organizations with significant technical and commercial expertise as well as institutional knowledge regarding dynamic spectrum sharing and the ways in which it can be advanced. NSF and other agencies should encourage researchers to work closely with the wireless industry to help develop mid- and long-term research areas that are informed by the needs of the wireless community and the realities of commercial spectrum access, and to leverage some of the spectrum sharing technology that the wireless industry has already developed or is in the process of developing.

With regard to a specific element in the R&D Plan:

> **7. Terminology and definitions relevant for spectrum R&D. One term of interest is ‘‘Dynamic Spectrum Sharing’’ which is a focus of the National Spectrum Strategy but was not defined.**
>
> The Alliance defines DSS as the use of automation technology together with information sourced from databases, sensors and/or informing portals to manage access on a near real-time basis to spectrum by more than one user in the same or nearby geographic areas while minimizing harmful interference and maximizing efficient use.

The Alliance and our members stand ready to work with NTIA, the Federal Communications Commission, the other federal agencies, and our fellow industry partners to ensure the vision articulated in the NSS becomes a reality.

Respectfully submitted,

<u>*/s/ Preston Marshall*</u>
Preston Marshall
Chair

<u>*/s/ Stephen Rayment*</u>
Stephen Rayment
President

March 21, 2024

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Ultra Wide Band (UWB) Alliance

Comments of the

Ultra Wide Band (UWB) Alliance

on

Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO) of the National Science Foundation

Request for Information: National Spectrum Research and Development Plan (R&D Plan)

About the UWB Alliance

The Ultra Wide Band (UWB) Alliance is a global not-for-profit organization that works to collectively establish ultra-wideband (UWB) technology as an open-standards industry. A coalition made up of vendors that either design, manufacture, or sell products that use ultra-wideband technology, the UWB Alliance aims to promote and protect the current allocation of bandwidth as well as promote the continuing globalization of the technology. As part of our mission, we advocate UWB technology and use cases to promote verticals showing the value of UWB for IoT and Industry 4.0 and to build a global ecosystem across the complete UWB value chain, from the silicon to the service. In addition, the Alliance is promoting and assuring interoperability through its work with Standards Development Organizations such as the IEEE and ETSI and then working with members to define upper layers and testing to assure compliance. For more information, please visit us at www.UWBAlliance.org.

1 Introduction

The Utlra Wide Band (UWB) Alliance thanks NITRD for the opportunity to provide input to the development of the National Spectrum Research and Development Plan[1].

UWB is a rapidly growing industry that is providing spectrum-efficient solutions in applications with high economic and social value. UWB is inherently a sharing technology, with low-to-no impact on other services. UWB is expanding use of available spectrum without repackaging or repurposing of spectrum. UWB is compatible with many other uses and users of spectrum. UWB is a complement to other technologies, increasing capability and capacity without increasing need for new spectrum allocations. The UWB industry has much to contribute to the future use of spectrum and so we feel is an important perspective to include in research and development of sustainable spectrum strategies, methods, and policy.

The UWB market is in the early stages of significant growth. The global UWB market is generally considered to be in the range of $1-2 billion USD as of 2024, with a CAGR (Compound Annual Growth Rate) of 17%, reaching up to $4 billion USD by 2029. Key market drivers for UWB include:

- **Consumer Electronics.** Increasing adoption of UWB in smartphones is facilitating features like secure sharing, precision location tracking for AR/VR experiences, and improved connectivity between devices**.**
- **Automotive:** UWB is used by vehicle access control systems to provide keyless entry and enhanced security. Additionally, UWB is being used to detect when a child is left unattended in a vehicle to prevent accidental heat strokes.
- **Healthcare:** UWB is used for tracking life-saving equipment in hospitals such as infusion pumps, mobile X-ray machines, and defibrillators. UWB is also being used to monitor patient vitals, track the location of staff and patients, and monitor environmental factors in sensitive areas that require precise temperature, humidity, and air quality.
- **Manufacturing:** UWB is used for real-time location tracking of materials, tools, and finished products on factory floors. It is also used for streamlining operations and improving worker safety.
- **Retail:** UWB improves inventory management and customer experience through targeted advertisements and product information based on customer location relative to products.

UWB adoption is expected to accelerate as UWB technology awareness among consumers increases, as the cost of UWB chipsets decreases, and as universally standardized protocols for UWB are developed.

It should be noted that UWB has been operating in the frequency range of 3.1 GHz to 10.6 GHz on an unlicensed basis for over 20 years. Beginning with the adoption of FCC Part 15 subpart F in 2002. In 2005, the FCC adopted rules for Wideband devices operating in the 6 GHz band via Part 15.250 with transmit power limits equivalent to subpart F. It is often misstated that the 2020 revision of subpart E

[1] https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan

“opened the 6 GHz band for unlicensed operation” when in fact the band had been in use on an unlicensed basis for nearly two decades at that time. The revision to subpart E allowed substantially higher power unlicensed operation in the band. In two decades of operation under Subpart F, UWB and 15.250 Wideband rules there has been no case reported of interference with other services. The characteristics of UWB such as ultra-low transmit power are proven effective in sharing spectrum without negative impacts.

2 NSF Topics:

2.1 Recommendations on strategies for conducting spectrum research

Among essential strategies, we encourage research to enable greater diversity of use in the available spectrum. Research that expands traditional models of spectrum usage and for evaluating efficiency is needed. Traditional models of spectrum usage such as exclusive use or sharing via coordinated or non-coordinated avoidance have resulted in an unsustainable need for ever greater spectrum allocations.

More effective use of spectrum must include true sharing techniques, not just focused on traditional models of sharing that depend on coordinated or non-coordinated avoidance of simultaneous occupancy. Studies should include consideration of methods and technologies that can enable simultaneous use through positive coexistence. UWB is an example of technology that presents a different sharing model than higher power radios and supports simultaneous use by a large number of devices and compatibility with a diversity of other technologies. Any study of future sharing should include UWB and ultra-low power techniques.

Consideration of diversity of use and deeper sharing techniques requires new methods for evaluating coexistence performance. Collaborative measurement-based studies can be an effective method identifying potential areas of incompatibility. The approach should aggregate a mix of technologies and stakeholders with different spectrum usage needs.

Sharing information and creating collaborative opportunities such as shared test beds can reduce duplication of effort while also ensuring diversity of views. As part of an R&D investment strategy, making resources for simulation and measurement-based testing available to a wide range of stakeholders will enable greater collaboration. Making resources available to smaller yet innovative entities and individuals enables contribution on a larger scale.

2.2 Recommended Priority areas for spectrum R&D

Methods to expand sharing of spectrum through positive coexistence should be a priority area for spectrum research and development. Research beyond traditional usage models is needed to achieve sustainable growth. Real coexistence of different services, technologies and users will enable more users and new capabilities without new dedicated spectrum allocations.

NITRD identifies dynamic spectrum sharing as an important area of research and development. There are various degrees of dynamic in the context of spectrum usage. Database driven models for coordinated spectrum access such as Automated Frequency Coordination (AFC) and Spectrum Access Systems used by Citizens Broadband Radio Service (CBRS) are examples of slowly changing conditions:

the information that is the basis for access decisions changes slowly. These models assume access to a central or distributed database, usually via the public internet. For a great number of applications this is not available. This limits the usefulness of this kind of access for many applications: examples include power-constrained sensor networks in industrial settings, or even metro-area IoT which do not need or cannot have gateways to external networks.

These methods follow the temporal and spatial separation model of mutual avoidance. “Sharing” in this context means exclusive use for some time period and area. Traditional methods such as listening before talk are more dynamic, making decisions based on a snapshot of channel conditions, but typically with small amounts of information with which to inform the condition e.g. instantaneous energy level. These methods are still focused on exclusive use for some time period.

We suggest alternative dynamic sharing methods that utilize active situational awareness of spectrum usage coupled with coexistence methods that enable simultaneous use. Research areas should include passive techniques to reduce impact area (e.g. extremely low transmit power). Research should also include active techniques that intelligently assess real-time and predictive trends to greatly augment coexistence and thus sharing. Combined with other positive coexistence techniques we can challenge the assumptions that limit overall capacity.

Refining methods for measuring spectrum efficiency is a priority. Diversity of use is an important metric in evaluating spectrum utilization efficiency. Evaluation of efficiency should include methods for evaluating coexistence impacts and compatibility metrics. The capacity to support many users and different uses simultaneously is an important metric of efficiency.

Coexistence studies should include methods to control and reduce impact footprint. Some examples to explore include improving algorithms for transmit power control, link adaptation, spatial containment via smart(er) antennas (e.g. beam steering) and other antenna techniques that reduce impact area.

Current practice for many services is to configure transmitters based on achieving a certain link margin under the worst-case conditions expected. The result is that much of the time they are transmitting at much higher power than needed for a given link. This practice greatly decreases the capacity of a frequency band. This in turn drives demand for larger spectrum allocations. Developing more appropriate “use only what you need” methods will increase overall capacity. The vast number of variables that affect radio performance in real-world situations makes dynamic optimization a complex problem. This also makes it a rich area of research, with the potential for major gains.

Another important area of research is in reducing the energy consumed by wireless systems. Even small improvements become significant when multiplied by the many billions of consumer devices in use. Areas of research include efficiencies at the semiconductor process level as well as at the protocol levels. Advances in device efficiency will provide future gains, while protocol improvements yield benefits more immediately and in ways that can be applied to already deployed physical devices.

An important priority is to make more information available via measurement-based studies. Measurement based studies (testing) using a variety of technologies and services, including UWB, should have as primary goals:

- Include a mix of multiple technologies and systems
- Include methods for evaluating coexistence performance

- Identifying areas of potential incompatibility
- Evaluate methods for achieving compatible uses
- Include study of real-world conditions

Research should include more complete characterization of real-world conditions, so that the assumptions used in both lab-based testing and simulations can be improved. The complexities of real-world RF conditions create significant challenges for which new, innovative methods are needed.

We strongly support the concept of aggregation research that mix multiple technologies, both measurement-based and via simulations. Studies that aggregate multiple technologies such as UWB, Wi-Fi, mobile and Bluetooth must include participation of experts from each of these areas. This is an important step in identifying potential compatible and incompatible use and informing development of effective techniques to increase compatibility. Additionally, such studies can be used to evaluate other performance characteristics, for example effects of (and on) ambient noise floor, receiver performance, channel access algorithms and link adaptation techniques.

We encourage research into effective means to improve receiver performance. Such research can benefit both commercial and government users. There are widely varying ideas as to what performance metrics are meaningful. This suggests a priority area of research is to evaluate metrics and find those that correlate well to specific goals. The record suggests "easy" metrics such as receiver sensitivity are insufficient. Development of more useful metrics for performance are needed to enable research into methods to improve performance. Studies should promote technology transfer so that established techniques in one area can feed innovation in another. For example, receiver design methods used in UWB systems enable link margin at extremely low transmit power; such techniques may benefit developers of other systems in achieving performance targets at lower transmit power.

The UWB Alliance strongly endorses the concept of a national test bed that is made available openly. There are many technical challenges to implementing such a test bed, including enabling remote participation, which is essential to include the widest range of researchers and stakeholders. A priority is reducing the financial thresholds for participation. This will enable participation by small entities and individuals without the extensive resources of large companies. Technological innovation often comes from small entities such as start-ups and incubators that typically have very limited financial resources.

The national test bed must include a wide range of technologies, including UWB. UWB is playing a critical role in expanding capabilities for consumer devices and increasing non-interfering use of existing spectrum allocations. Compared to other commodity wireless technologies, UWB is at an earlier stage of evolution and on a steep innovation curve.

In addition to a physical testbed, the national testbed should include simulation models and access that is not geographically dependent. Simulation based testbeds should provide access to all researchers irrespective of entity size. A virtual testbed or set of testbeds creates a level playing field in which all can contribute and learn. Openness is essential so that the models and methods used by any group are available to, and understood by, others. This provides the greatest opportunity validation and repeatability of study results by multiple peers and peer groups. Openness also increases credibility, confidence and applicability of results.

2.3 Recommendations on grand challenge problems for spectrum R&D.

One of the greatest challenges is changing traditional thinking. The current mindset in wireless systems is to think of different technologies and systems as competing for the same uses, users and resources. This leads to an "I can do it all with one radio" mindset limiting the ability to optimize spectrum usage. This mindset is obsolete and results in huge inefficiencies that waste spectrum resources and drive the unsustainable need for ever more spectrum allocations.

To achieve optimal solutions, the wide array of available technologies must be considered. Better matching of the radio to the application needs will result in greater efficiencies. Enabling synergies will increase performance, capabilities, and capacity. Better understanding through research demonstrating the advantages of "using the right tool for each part of the job" can expand awareness of the many possibilities for improvement. The "right tool" solution drives innovation in multiple technologies.

The UWB industry is an example of how a more inclusive mindset is leading to more efficient solutions: UWB can work efficiently in situations where other technologies do not, or do not work as efficiently or effectively. When paired with traditional wireless such as Bluetooth and Wi-Fi, the combined solution offers capabilities not achievable alone, and improves efficient use of the spectrum. A specific example is use of UWB in nearby sharing applications, where the precise range and angle of arrival information provided by the UWB radio identifies the correct peer quickly with minimal communication. This in turn reduces the overhead for discovering and connecting, reducing use of the band. While the value of synergies has been shown, developers have only scratched the surface of what is possible. The "one size fits all" mindset continues to be a challenge and limitation.

The simple goal is to expand diversity of use for a given band without repackaging, repurposing, or new spectrum allocations. A clear metric is: are we preserving the usability of existing allocations while expanding uses, or are we driving a need for ever more spectrum allocations?

2.4 Recommendations on spectrum R&D accelerators

As noted, sharing of information and resources is an effective way to accelerate research. We endorse NSF efforts to create means to share data, test resources, and ideas in ways that include small entities and individual developers. The idea of shared testbeds, both physical and virtual (simulations), is a powerful means to accelerate R&D by providing deeper understanding of the characteristics of technologies, environments, and the resulting trade-off decisions that will lead to better development.

We strongly support sharing of testbeds and research infrastructure, with related support for collaboration. Collaboration among a wide range of researchers and practitioners is extremely valuable.

Benchmarks and competitions have limited value in promoting innovation. Challenges include selecting meaningful criteria for benchmarks and selecting "winners". Collaboration is a much more effective path to discovery.

2.5 Recommendations on near-term Federal activities to make progress towards anything identified in responses 1–4.

We recommend prioritizing true co-existence over more limited sharing. Sharing is most often defined in a way that results in temporary exclusive use of a given frequency range and/or area. This can greatly improve utilization over static allocations; however, it limits the number of uses available in that temporary period. A priority goal should be to stimulate innovations in coexistence that allow true simultaneous use by many devices operating in the same space and time. Investing in coexistence research and development leads to sustainable approaches to spectrum usage growth.

Near term actions can include policy measures that place priority on coexistence, that preserve useability of allocated spectrum based on positive coexistence capabilities. Requests for exclusive access to spectrum already being shared should be discouraged until and unless it can be shown:

a) Compatibility with current users sharing effectively is preserved
b) Technologies employed are up to the best operating performance standards
c) Operational strategies and coexistence techniques are used to minimize the need for more spectrum or more power.

Increasing transmit power and thus impact area is potentially disruptive and limits overall spectrum capacity. The "ever more" approach is unsustainable and alternatives should be given priority.

2.6 Recommendations on a process to refine and enhance the R&D plan on an ongoing basis.

To refine and enhance the R&D plan, include many stakeholders in regular review and revision of the plan. To effectively improve, metrics for evaluating performance of the plan are needed. Meaningful metrics that relate goals to progress are challenging but form the foundation of improvement. Given the vast diversity of spectrum users and uses, inclusion of the widest possible set of perspectives is essential. Lowering the barriers for participation, in terms of time or financial resources, is critical.

Organized reviews using virtual meeting tools can be useful, but finding suitable meeting times can be difficult. Non-real time review methods can be more easily used by more participants. Leveraging both on-line and off-line review is necessary.

Sharing of research and development resources will not only facilitate progress in more research areas by more researchers, but it can also provide feedback on which resources are most valuable. Likewise sharing research methods can provide feedback on what works.

2.7 Terminology and definitions relevant for spectrum R&D.

Several terms are used frequently but with varying meanings. Clarification with respect to R&D planning would facilitate clear communication.

Low power: This term is used in the context of both radio transmit power and energy consumption of the devices. We recommend "power" be in the plan context to mean *energy emitted* (transmitted) by the device or system.

Low energy: We recommend this term "energy" be used in the context of energy consumed. What constitutes "low" is challenging to quantify.

Very low power: Confusion exists over what "very low" means. In the UWB industry this means at or below regulatory limits defined in FCC part 15 subpart F and 15.250, while recently amended FCC regulations in subpart E define "very low" to be much higher than this. For consideration moving forward we recommend VLP as used in FCC U-NII regulations and introduce "Extremely low power".

Extremely low power: we recommend this term for power substantially below "very low" as used in FCC subpart E, corresponding to typical UWB limits.

Dynamic: This term is problematic in that there are many levels of dynamic in discussing wireless systems. This can mean both active and passive adaptation. It is often used to mean "not static" (anything other than exclusive, licensed access). We suggest that resolving to a set of context-specific meanings is not trivial and that additional terms may need to be defined to clarify each type of "dynamic" meant in a specific context.

Coexistence: Coexistence is the ability of multiple systems to share spectrum in the same time and space. There can be levels of coexistence. Broadly, positive coexistence is the ability to operate without disruption of either system; negative coexistence is when one or more systems are disrupted.

Sharing: The most common use is broadly inclusive of any allocation that is not fixed and exclusive.

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Verizon

Before the
NATIONAL SCIENCE FOUNDATION
Alexandria, VA 22314

In the Matter of	)	
	)	
Request for Information: National Spectrum Research and Development Plan	)	Fed. Reg. Document No. 2024-03400
	)	

COMMENTS OF VERIZON[1]

The National Spectrum Research and Development Plan ("R&D Plan") will serve as a key element to advance the National Spectrum Strategy ("Strategy"), and Verizon welcomes the opportunity to provide comment in response to the National Science Foundation's ("NSF") Request for Information.[2] We support a coordinated, strategic view of research and development ("R&D") spectrum initiatives, as expressed in the Strategy's just-released Implementation Plan:

> The spectrum research community must enhance the coordination of its [R&D] endeavors and identify and address critical areas of spectrum R&D. By doing so, we can amplify the impact of collective efforts and foster important advancements. Our spectrum policies also must be designed to optimize flexible use and support emerging technologies.[3]

The RFI calls for spectrum research that "ensures that all essential spectrum research areas are sufficiently explored,"[4] and the R&D Plan, therefore, should embrace a broad view of

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[1] This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

[2] *See* National Spectrum Strategy, The White House (Nov. 13, 2023), https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf ("Strategy"); Request for Information on the National Spectrum Research and Development Plan 89 Fed. Reg. 12871 (Feb. 20, 2024) ("RFI").

[3] National Spectrum Strategy Implementation Plan, National Telecommunications and Information Administration, at 15 (Mar. 12, 2024) ("Implementation Plan").

[4] RFI, 89 Fed. Reg. at 12872.

sharing[5] – one that encompasses mechanisms such as "repacking, relocation, and compression."[6] To that end, the R&D Plan should promote opportunities to advance full-power commercial spectrum with assured access. Such access supports wide-area mobile networks that are critical to enable the technologies that fuel the U.S. economy, encourage competition, further connectivity, and protect national security. In particular, the R&D plan should account for the incentives and disincentives for commercial investment and emphasize that any spectrum research must result in commercially viable solutions. Projects to study dynamic spectrum sharing ("DSS") should take into account lessons learned from previous efforts – including the importance of accurate coexistence models. Spectrum R&D should also support increased transparency and information sharing between federal and commercial stakeholders.

Finally, the Administration should move swiftly to advance the near-term study of key mid-band spectrum with a key goal of repurposing for commercial, full-power, licensed use.[7] The Implementation Plan reinforces the Strategy's intent to study these bands independent of, and in advance of, the R&D initiative presented here.

I. SPECTRUM R&D SHOULD EXPLORE WAYS TO ADVANCE FULL-POWER COMMERCIAL SPECTRUM LICENSES WITH ASSURED ACCESS. (Q1, Q2)

A. The R&D Plan Must Prioritize Efforts That Can Support Full-Power, Licensed Spectrum with Assured Access That Enables the Wide-Area Deployments Critical to U.S. Interests. (Q1; Q2, Bullets 3, 8)

The RFI recognizes that "priority areas" for spectrum R&D should account for "[e]conomic-, market-, social-, and human-centric concerns" and "[b]usiness and economic

[5] *Id.* (Q1; Q2, Bullet 3). The NSS references a "moonshot" effort to research spectrum access, "with an emphasis on dynamic forms of spectrum sharing for all users," Strategy at 13, Strategic Objective 2.3, but the R&D Plan led by NSF is distinct from this moonshot effort and must take a broader view of spectrum R&D.

[6] Implementation Plan at A-3.

[7] *See* Comments of Verizon, Docket No. NTIA-2023-0003, at 14 (filed Apr. 17, 2023) ("Verizon Strategy Comments"); Comments of Verizon, Docket No. NTIA-2023-26810, at 1 (filed Jan. 2, 2024).

models," among other factors.[8] The R&D Plan should therefore recognize the value of wide-area, full-power commercial wireless networks, which are critical to enable innovation, expand connectivity and coverage, promote broadband competition, and advance U.S. economic and national security interests.

The wireless industry contributes heavily to our nation's economy, thanks in large part to wide-area networks deployed at scale that are the foundation for mobile connectivity, innovation, and ever-growing reliance on all things wireless. The numbers back this up:

- During the 4G decade, from 2010 to 2020, the wireless industry supported one out of every six American jobs,[9] and gross output from the U.S. wireless industry topped $9.5 trillion; [10] and
- 5G is projected to create an additional 4.6 million jobs and contribute up to $1.7 trillion to U.S. GDP over the next decade, spurring activity across the consumer, industrial, and public sectors.[11]

This economic success is grounded in wireless providers' access to full-power, licensed, reliable spectrum, which provides the certainty and reliability to enable investment in networks at scale.[12] Of course, these networks are also driving competition that directly benefits consumers today and advances consumer welfare. As but one example, fixed wireless access continues to grow in scale and bring new competition in the home broadband market, which is especially important for underserved and marginalized communities. In fact:

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[8] RFI, 89 Fed. Reg. at 12872, Q2, Bullet 8.

[9] *The 4G Decade: Quantifying the Benefits*, Recon Analytics, at 3, 6 (July 29, 2020), https://api.ctia.org/wp-content/uploads/2020/07/The-4G-Decade.pdf.

[10] Aren Megerdichian, *The Importance of Licensed Spectrum and Wireless Telecommunications to the American Economy*, Compass Lexecon, at 3 (Dec. 7, 2022), https://api.ctia.org/wp-content/uploads/2022/12/Compass-Lexecon-Licensed-Spectrum-Report.pdf.

[11] Enrique Duarte Melo et al., *5G Promises Massive Job and GDP Growth in the US*, Boston Consulting Group, at 3 (Feb. 2021).

[12] *See* Verizon Strategy Comments at 4-5. Note that Verizon uses the term "reliable spectrum" in these comments to capture the idea that the licensees would have assured access and protection from harmful interference.

- In 2022, fixed wireless access accounted for 90% of net broadband additions, over traditional options like cable, fiber, or DSL;[13] and
- Verizon expects to cover 50 million homes with its fixed wireless access service by the end of 2025.[14]

Wide-area networks do not just power the economy and promote competition; they also profoundly shape the American experience today. Wireless networks at scale support critical spectrum-based services including smart manufacturing, smart cities, telehealth, and remote learning. These networks allow Americans to work remotely, stream videos or calls, attend telehealth appointments, access connected education in the classroom and at home, and much, much more. It has never been more important to promote spectrum access models that will enable all Americans to access next-generation technologies from wherever they are.

Continued support for commercial, wide-area, full-power, reliable networks is also critical for protecting our national security interests.[15] The United States is competing with China and other rival nations for technological superiority.[16] If the U.S. is not strategic about investing in opportunities to make wide-area, full-power, reliable, harmonized spectrum opportunities available for commercial providers, it may find itself on the outside looking in on future bands and policies that will be used for 5G and serve as a foundation for 6G. Similarly, pursuing novel or unique spectrum policies isolates the U.S. wireless marketplace and puts the country on a

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[13] *Annual Survey Highlights*, CTIA, at 6 (2023), https://api.ctia.org/wp-content/uploads/2023/11/2023-Annual-Survey-Highlights.pdf.

[14] *See Investor Day 2022*, Verizon, at 53 (Mar. 3, 2022), https://www.verizon.com/about/sites/default/files/2022-05/Investor-Day-2022-Presentation_rv1.pdf.

[15] RFI, 89 Fed. Reg. at 12872, Q1.

[16] Verizon Strategy Comments at 2, 6. Today, China and other nations are identifying additional bands for 5G, for wide-area, full-power licensed networks. By 2027, China is expected to have more than double, and perhaps more than three times, the amount of licensed spectrum than the United States. Janette Stewart, Chris Nickerson, & Juliette Welham, *Comparison of total mobile spectrum in different markets*, Analysys Mason, at 11 (Sept. 2022), https://api.ctia.org/wp-content/uploads/2022/09/Comparison-of-total-mobile-spectrum-28-09-22.pdf.

spectrum island, increasing costs for unique network equipment and devices while positioning other nations to advance their technology leadership in countries with aligned spectrum allocations and frameworks. Additionally, there is little evidence that international partners and allies are moving away from traditional licensed models for spectrum, necessitating continued domestic focus on similar spectrum access models. Spectrum R&D should focus on projects that will ultimately foster a strong U.S. presence in global bands for 5G and for 6G in the future.

B. The R&D Plan Should Consider Incentives and Disincentives for Innovation and Investment When Evaluating Spectrum R&D Opportunities. (Q1; Q2, Bullet 3)

The Implementation Plan appropriately calls for an R&D working group to "survey key Federal and non-Federal spectrum users to identify motivating factors for investing in spectrum innovation, as well as those that disincentivize investment or that pose challenges to research efforts."[17] For commercial wireless operators, full-power, wide-area spectrum that offers assured access and protection from harmful interference is essential to incentivizing investment and innovation. A comparison of two bands in the 3 GHz frequency range demonstrates the incentives and disincentives associated with spectrum access rights. The 3.7 GHz band, with full-power, wide-area, reliable spectrum has been extensively deployed on an aggressive timeframe. Meanwhile, the low-power, experimental Citizens Band Radio Service ("CBRS") has seen less deployment even though it has been available to operators longer due in part to its unreliability, and power limitations that result in small cell sizes and poor coverage.[18] The commercial value of these different spectrum access models is also reflected in the per-MHz PoP

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[17] Implementation Plan at 15, Outcome 3.1(b) (citing Outcome 2.1(a)).

[18] *See, e.g.*, Doug Brake, *CBRS Spectrum Is Lightly Used, Whereas C-Band Is Deployed Extensively*, CTIA Blog (Sept. 25, 2023), https://www.ctia.org/news/cbrs-spectrum-is-lightly-used-whereas-c-band-deployed-extensively.

prices at auction, as the 3.7 GHz band raised five times more on a per MHz-PoP basis than CBRS.[19]

Research related to spectrum efficiency, resilience, mitigation tools, coexistence modeling, and more can all contribute to more opportunities for spectrum repurposing that will drive massive investment in commercial networks at scale. Thus, NSF should ensure that R&D projects not only include dynamic frameworks, but also advance targeted and predictable sharing regimes that ensure licensees and spectrum users have certainty as to their access rights and obligations. Specifically, the R&D Plan should prioritize efforts that will advance static sharing models that have proven effective and workable in past federal/commercial sharing frameworks, and which create more certainty for all affected stakeholders. Such efforts would be more likely to result in viable near-term economic and business solutions.

C. The R&D Plan Should Promote Several Key Areas of R&D to Advance the Goals Set Forth in the Presidential Memorandum – Including Licensed Spectrum. (Q2)

The Presidential Memorandum on spectrum accompanying the Strategy identifies several important goals including increased efficiency of spectrum use and increased transparency into current and future spectrum use.[20] These goals hold the promise of expanding opportunities for

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[19] The 3.7 GHz auction had net winning bids of more than $81 billion for 180 megahertz of spectrum while the CBRS auction had net winning bids of $4.5 billion for 70 megahertz of spectrum. *See Auction of Flexible-Use Service Licenses in the 3.7-3.98 GHz Band Closes, Winning Bidders Announced for Auction 107*, Public Notice, 36 FCC Rcd 4318 (2021), https://www.fcc.gov/document/fcc-announces-winning-bidders-37-ghz-service-auction, for 3.7 GHz auction results; *compare* to *Auction of Priority Access Licenses in the 3550-3650 MHz Band Closes, Winning Bidders Announced for Action 105*, Public Notice, 35 FCC Rcd 9287 (2020), https://www.fcc.gov/document/fcc-announces-winning-bidders-35-ghz-band-auction, for CBRS auction.

[20] *Memorandum on Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy*, The White House, at Sec. 3(c) (Nov. 13, 2023), https://www.whitehouse.gov/briefing-room/presidential-actions/2023/11/13/memorandum-on-modernizing-united-states-spectrum-policy-and-establishing-a-national-spectrum-strategy/ ("Presidential Memorandum").

wide-area, full-power spectrum use, and the R&D Plan can have a real impact by enabling spectrum research investments that support the President's goals.[21]

Spectrum Efficiency. Efforts across government are necessary to ensure that finite spectrum resources are efficiently used and that all spectrum users are good stewards of the airwaves. R&D that could lead to more efficient federal spectrum use is critical to unlocking spectrum necessary to support the growing demands being placed on our scarce spectrum resources, including by encouraging agencies to enhance spectrum sharing amongst themselves and to explore opportunities to compress or channelize their operations.[22] Where possible, spectrum research should focus on ways to incentivize and enable federal spectrum efficiency, as is the case with full-power, wide-area commercial spectrum use.[23] Given the economics of acquiring spectrum, wireless providers are geared to leverage more bits out of every megahertz of spectrum available and "refarm" legacy spectrum to the extent possible to replace older technologies with advanced, more efficient services. And network slicing will enable already efficient 5G networks to be used to deliver specialized offerings.

Transparency and Shared Knowledge. To achieve meaningful advances in spectrum R&D, the R&D Plan should promote processes that build on and improve information sharing between commercial and federal stakeholders.[24] To achieve meaningful research around spectrum efficiency, assured access for critical mission applications, DSS, modeling, coexistence analysis, etc., the R&D Plan should reflect the following:

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[21] RFI, 89 Fed. Reg. at 12872, Q1, Q2.

[22] *Id*. at Q2, Bullet 1.

[23] For example, commercial wireless licensed spectrum use became 42 times more efficient during the 4G decade, and 5G networks will further increase spectral efficiencies by as much as 52 percent by some estimates in the mid-band range. *See Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum*, CTIA, at 3, 7 (July 9, 2019), https://www.ctia.org/news/smarter-and-more-efficient-how-americas-wireless-industry-maximizes-its-spectrum.

[24] RFI, 89 Fed. Reg. at 12872, Q1; Q2, Bullets 6, 4; Q 4.

Commercial operators need to better understand incumbent federal operations, including visibility into the federal operating environment, the capabilities of federal systems (not just operating parameters), as well as information about the inputs and assumptions made in interference analyses and technical parameters of the federal operations, and information about how, when, and where federal users operate. With greater transparency around federal spectrum needs, industry could be a strong partner on R&D that would promote greater spectrum efficiency by federal operators.

Federal stakeholders would benefit from a better understanding of commercial operating parameters.[25] The R&D Plan should promote this knowledge exchange – which will lead to better R&D – by leveraging NTIA's Institute for Telecommunication Sciences ("ITS"). ITS is well-positioned to serve as the U.S. government's resident expert on commercial technologies and network operations. For example, ITS could work with other government entities in bands of interest to understand commercial systems, as a necessary part of evaluating how government and commercial systems may impact one another, or finding solutions to enable coexistence.

Additionally, processes for collaboration and sharing of classified, unclassified, controlled unclassified information, and commercial proprietary information should be improved.[26] Collaborative dialogue across industry and government should build and improve on the processes undertaken in prior spectrum analyses – in particular, the Partnering on Advancing Trusted and Holistic Spectrum Solutions ("PATHSS") task group evaluation of the lower 3 GHz band. Finally, to promote information sharing, the R&D Plan could seek to expand use of Cooperative Research and Development Agreements (CRADAs).

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[25] *Id*. at Q1; Q2 Bullets 4, 7.

[26] *Id*. at Q1, Bullet 2.

II. R&D FOR DYNAMIC SPECTRUM SHARING SHOULD BUILD OFF LESSONS LEARNED ALREADY. (Q2, BULLET 3; Q7)

While the R&D Plan should explore DSS, it is not a panacea for the current spectrum crunch facing the wireless industry. To date, DSS remains unproven – or more precisely, DSS frameworks have proven not to serve wide-area deployments – and an overreliance on such approaches risks undermining the U.S. wireless ecosystem and isolating the United States as other, rival nations advance a harmonized, fully licensed framework across the globe. Any R&D for DSS should consider models that would allow for full-power commercial use with assured access or near-assured access rather than focusing on frameworks that do not result in commercially viable solutions.[27] Dynamic sharing models such as CBRS are better viewed as opportunities to augment capacity and coverage in limited geographical areas rather than as a playbook for successful nationwide deployments at scale given the limitations associated with channel availability, reliability, and decreased power levels.[28] Thus, it is important that the R&D Plan not premise research into DSS on a CBRS-like model, but explore foundational questions about other possible forms of DSS.

When designing the R&D Plan and any DSS research projects, there are lessons to be learned from CBRS. First, transparency and modeling are key. But so too is a process to update the modeling inputs over time. In the CBRS band, through collaboration and better modeling, the U.S. government was able to shift to "dynamic protection areas" from "exclusion zones." But huge swaths of CBRS spectrum remain affected by these dynamic protection zones. Improving and refining the coexistence modeling could narrow these zones without jeopardizing

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[27] The Implementation Plan acknowledges that the CBRS framework could benefit from leveraging new technologies and capabilities. Implementation Plan at 19, Outcome 3.2(f).

[28] The CBRS technical rules only allow low-power use, which restricts deployments at scale, and in any event the service is preemptible. Further, service may be disrupted if the Spectrum Access System ("SAS") or Environmental Sensing Capability network goes down or the governing SAS loses connectivity or becomes congested.

federal operations, but there is not a clear process for revisiting those models today. The R&D Plan should ensure that any co-existence models resulting from R&D do not become static.

Second, the CBRS band also demonstrates that additional R&D is needed to develop workable spectrum situational access and management tools. The Environmental Sensing Capability ("ESC") networks create large areas where networks cannot be deployed, even when no incumbent operations are present. This is problematic for a sharing framework that is intended to maximize efficient spectrum use. The R&D Plan should support the exploration of alternate solutions for identifying incumbent presence.

III. CONCLUSION.

We look forward to partnering with U.S. government stakeholders on R&D efforts that will advance spectrum access for full-power, wide-area, reliable commercial networks, as well as emerging technologies, while ensuring continued access to spectrum for federal operations.

Respectfully submitted,

/s/

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March 21, 2024

Federal Register Notice: 89 FR 12871, https://www.federalregister.gov/documents/2024/02/20/2024-03400/request-for-information-on-the-national-spectrum-research-and-development-plan, February 20, 2023.

Request for Information on the National Spectrum Research and Development Plan

Viasat, Inc.

Before the
NATIONAL SCIENCE FOUNDATION
Alexandria, VA 22314

In the Matter of	)	
	)	
National Spectrum Research and Development Plan	)	89 FR 12871
	)	
	)	
Request for Information	)	

COMMENTS OF VIASAT, INC.[1]

Viasat, Inc. ("Viasat") submits these comments in response to the Request for Information ("RFI") published by the National Science Foundation ("NSF") on February 20, 2024.[2] In the RFI, the NSF seeks public input to facilitate the development of a National Spectrum Research and Development Plan ("R&D Plan"). The R&D Plan is intended to organize and guide government investments in spectrum-related research and development ("R&D")—including by identifying recommended priority R&D areas.

Viasat is a global communications company that connects homes, businesses, governments, and militaries with high-speed broadband services and secure networking systems. Spectrum plays a critical role in allowing Viasat to offer these services to the public, and spectrum-related R&D likewise plays a critical role in allowing Viasat to improve these offerings and their underlying economics over time. Notably, Viasat's R&D investments have made it possible to exponentially increase the total throughput achievable over Viasat's satellite networks without a concomitant increase in required spectrum inputs. This has allowed Viasat to

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1 This document is approved for public dissemination. The document contains no business-proprietary or confidential information. Document contents may be reused by the government in the National Spectrum R&D Plan and associated documents without attribution.

2 *See National Spectrum Research and Development Plan*, Request for Information, 89 FR 12871 (2024).

offer higher speeds, dramatically increased capacity, and smaller end-user terminals—all at a much lower cost per bit than other technologies. As Viasat's experience demonstrates, a carefully crafted R&D strategy can drive substantial improvements in spectral efficiency and make possible the provision of innovative service offerings available to the public.

In short, Viasat understands the significant value that can be derived from spectrum-related R&D activities—provided they are appropriately targeted. Viasat therefore applauds the NSF's efforts to develop the R&D Plan, which should help to solidify U.S. leadership with respect to the management and use of spectrum resources. As it develops the R&D Plan, Viasat recommends that the NSF prioritize R&D efforts that will allow spectrum to be used more efficiently and effectively to support satellite use cases. As explained below, such efforts have the potential to significantly improve spectral efficiency while advancing other critical public policy objectives—including by facilitating greater competition and innovation, as well as more equitable access to spectrum resources.

I. THE R&D PLAN SHOULD PRIORITIZE R&D WITH THE POTENTIAL TO ENHANCE SPECTRUM USE BY SATELLITE NETWORKS

The RFI specifically solicits recommendations with respect to potential R&D related to spectrum efficiency and the shared use of spectrum resources. Viasat agrees that these are areas that should be explored, particularly as there are significant *in*efficiencies in how spectrum resources are currently being used to support satellite use cases. Indeed, substantial gains can be realized by exploring the technical bases for more efficient coexistence between satellite operators, as well as between satellite operators and terrestrial operators. Viasat more specifically recommends that the R&D Plan incorporate and prioritize work in the following areas of inquiry:

A. Default Criteria for GSO-NGSO Coexistence

Virtually all spectrum used by satellite operators is shared with other spectrum users. For example, the same spectrum is increasingly used by geostationary satellite orbit ("GSO") and nongeostationary satellite orbit ("NGSO") operators. In many bands, this sharing is facilitated by technical rules—including equivalent power-flux density ("EPFD") limits—which establish the "lanes of the highway" that allow GSO and NGSO operators to coexist and make productive use of spectrum resources.

However, not all bands are subject to EPFD limits or similar mechanisms. Rather, some bands are subject only to coordination requirements, which are often underspecified and subject to delay and abuse. Thus, in the absence of any default sharing criteria, there is a significant risk that the parties will not converge on a negotiated coexistence solution quickly, even where they enter into coordination negotiations in good faith. Furthermore, in the absence of default criteria, parties may have the ability and incentive to refuse to coordinate in good faith, and thus effectively block the other party from making *any* use of the relevant spectrum (creating significant hold-up risk). In both cases, spectrum is left underutilized and the public is denied the benefits that would otherwise flow from additional service offerings.

Viasat recommends that the R&D Plan prioritize the development of default GSO-NGSO sharing criteria in bands that currently lack such criteria, such as the 18.8-19.3 GHz and 28.6-29.1 GHz band segments. These default criteria would apply in the absence of a coordination agreement and would ensure that both GSO and NGSO operators have the spectrum access needed to offer a range of innovative, high-quality satellite communications services to consumers. This approach would also prevent any operator from blocking others from using shared spectrum by refusing to enter into meaningful, good-faith coordination. At the same time, it would preserve incentives to realize a coordinated outcome where possible, as one could be expected to provide the parties with additional flexibility and other benefits.

Critically, such default criteria would be beneficial regardless of which party is afforded "priority" in a given band—*e.g.,* by defining technical parameters within which parties without such priority would be permitted to operate, and specifying minimum standards that would need to be met by parties with such priority to facilitate shared spectrum use. Notably, this is how things work today in bands subject to EPFD limits; NGSO operators are able to deploy as long as they meet applicable EPFD limits, and GSO operators are required to design networks that tolerate interference levels consistent with those limits. In the 18.8-19.3 GHz and 28.6-29.1 GHz band segments (in which NGSO systems have priority), default sharing criteria could incorporate suitable default power density limits, and a simple requirement that NGSO systems employ satellite or earth station diversity to avoid signal transmissions that would intersect the GSO arc (NGSO operators generally take this approach anyway to facilitate coordination, without adversely impacting their systems given their system diversity).

B. Enabling GSO Use of Modern Antenna Technologies

The RFI appropriately recognizes the role that hardware can play in enabling efficient use of available spectrum resources. Viasat agrees that providing greater flexibility with respect to the deployment of additional hardware solutions can help to improve spectrum efficiency, including with respect to the operation of GSO networks. For example, applicable regulations currently require GSO operators to meet restrictive technical requirements that were developed decades ago based on the assumption that GSO networks would employ antenna technologies that are now outdated. These standards are not sufficiently flexible to allow GSO operators to take advantage of cutting-edge technologies (*e.g.,* flat-panel, phased-array antenna technologies) that would allow them to provide even more innovative, quality services to consumers at low cost.

In stark contrast, NGSO operators are *not* subject to these legacy antenna performance requirements. This does not reflect any reasoned evaluation of the respective risk posed by GSO and NGSO operations, or their respective ability to harness modern antenna technologies. Rather, this distinction reflects the historical fact that GSO networks were introduced decades earlier—at a time when far different assumptions were made about what was technically possible—and thus saddled with legacy regulations. But that historical fact hardly justifies the differential treatment of GSO networks and NGSO systems today, particularly when it limits the ability of GSO operators to make the most efficient and productive possible use of spectrum resources.

Viasat recommends that the R&D Plan correct this imbalance by prioritizing the development of liberalized antenna performance standards that allow both GSO and NGSO operators to utilize the most advanced technologies on a technology-neutral basis, and thereby enable the United States to increase spectrum utilization.

C. Refining Methodologies for Evaluating NGSO Interference Potential

The RFI identifies "modeling for coexistence analysis" as an area of interest for future R&D. Viasat agrees that there would be significant benefit in refining existing methodologies for modeling and evaluating interference potential—including in the satellite context. Of particular concern are widely acknowledged deficiencies in existing methodologies used to evaluate the interference potential into GSO satellite networks associated with proposed NGSO systems. Among other things, these methodologies do not adequately account for all relevant sources of interference (*e.g.,* sidelobe interference) and do not evaluate interference at even a potential representative sample of physical locations—and thus do not evaluate whether a given

NGSO system is reasonably likely to be able to comply with applicable limits *everywhere* as required by existing rules. In addition, these methodologies do not adequately account for the aggregate interference potential (or "joint effect") generated by multiple NGSO "systems"—whether deployed by the same or different NGSO operators.

Viasat recommends that the R&D Plan prioritize the development of higher-fidelity methodologies, which would help to understand and cabin interference risk and thus facilitate more effective shared use of spectrum resources by satellite operators.

D. Facilitating the Equitable Coexistence of Multiple NGSO Operators

The RFI notes that potential topics for R&D efforts include "economic-, market-, social-, and human-centric concerns" related to spectrum efficiency. Viasat agrees that spectrum efficiency is a multidimensional concept and should be treated as such. In Viasat's view, spectrum R&D that aims to improve efficiency should not blindly focus on maximizing throughput or some other technical metric alone, but rather should ensure that spectrum resources are most effectively harnessed to serve public policy objectives—including by making them available to multiple operators in an equitable fashion. Among other things, this approach would help to advance important policy objectives—including by promoting competition, innovation, and diversity in system architecture and offered services.

Viasat also recommends that the R&D Plan prioritize research into linkages between the physical use of space and the ability of multiple operators to access and use spectrum resources efficiently and equitably. These linkages are particularly pronounced in the NGSO-NGSO sharing context, as the geometric configuration of NGSO system architecture, the relative locations of satellites and earth stations in different systems, and the performance of NGSO antennas (*e.g.,* use of small antennas with wide beams) all can dictate whether and to what extent shared use of spectrum is feasible. These linkages also dictate the extent to which operators may reasonably be expected to design and deploy smaller systems that would provide greater spectral efficiency but for the fact that they cannot operate effectively in the face of larger, less spectrally efficient NGSO systems.

This unfortunate dynamic is produced by the existing regulatory framework in the United States, which (by default) requires NGSO operators to "split" available spectrum resources in the event of an in-line interference event between their systems. Within this framework, large NGSO systems are able to "blanket the sky," causing multiple in-line interference events that effectively prevent smaller systems from accessing shared spectrum resources on an efficient or equitable basis. Indeed, analysis has shown that the use of "band-splitting" can reduce the capacity available to smaller systems by 50-100% in some cases. Critically, though, larger systems are not similarly impacted by the use of "band-splitting," as they simply reroute affected communications through a different satellite.

Viasat recommends that the R&D Plan prioritize research into alternatives that ensure that spectrum is shared on an equitable basis, regardless of the respective sizes of the relevant NGSO systems. Such R&D could include evaluation of approaches based on the use of "angle-splitting" during in-line interference events in lieu of "band-splitting," and suitable NGSO antenna performance requirements. Under an "angle-splitting" approach, each system involved in an in-line event would be allowed to use available spectrum to communicate to and from satellites within a portion of space visible from a given area on Earth (*e.g.,* one system might operate with satellites to the East of a given point, and the other system might operate with satellites to the West of a given point). Available resources (and look angles) would be divided equally among relevant systems, without regard to the number of satellites in each such system.

Consequently, this approach would not subject smaller operators to a competitive disadvantage simply because they deploy fewer satellites.

E. Enabling Satellite-Based Direct-to-Device Services

The RFI suggests that R&D with respect to spectrum efficiency might productively focus on "[b]usiness and economic models." Viasat agrees that spectrum efficiency can be improved through the exploration of additional applications and use cases that can be supported by spectrum that is already available to operators—including satellite operators. For example, Viasat and other satellite operators are exploring innovative approaches to using mobile-satellite service ("MSS") spectrum to support direct-to-device ("D2D") offerings. The ability to provide D2D in MSS spectrum is among the most substantial growth opportunities for the satellite industry, and one of the most effective paths for realizing gains in spectral efficiency. The introduction of D2D offerings promises not only to make the use of MSS spectrum by satellite operators more efficient, but also to harness MSS spectrum to provide a level of capabilities to mobile handsets not otherwise possible today.

Viasat recommends that the R&D Plan prioritize efforts to facilitate the introduction of D2D services—*e.g.,* by supporting ongoing standards development, as well as the development of effective approaches that allow existing MSS service providers to support emerging D2D applications. Notably, Viasat is already working with other major players in the industry (directly and through the Mobile Satellite Services Association) to ensure that emerging D2D technologies are reflected in 3GPP standards. It is critical that the R&D Plan *not* undermine that important work that is already underway by and between industry participants.

F. Facilitating More Efficient Satellite Use of Certain Bands

In the United States, satellite operators are able to access and use certain band segments only on a heavily restricted basis due to the perception that those restrictions are necessary to protect wireless operations. For example, satellite operators wishing to access the 27.5-28.35 GHz portion of the Ka band are subject to extensive regulations limiting their deployment to certain rural and remote counties, and further limiting the number, nature, and location of the earth-station facilities that can be deployed in those counties. Recent experience under this framework confirms that these restrictions are unduly conservative; they *over*protect terrestrial systems (particularly given their limited deployments in the band segment) and prevent satellite operators from using this spectrum in ways that would not pose any interference risk to terrestrial operators. Consequently, the framework undermines spectral efficiency objectives.

Viasat recommends that the R&D Plan prioritize the exploration of alternative sharing approaches that would enable expanded use of that part of the Ka band by satellite networks. The R&D Plan should also explore whether additional spectrum bands (particularly in millimeter wave bands and above) could be made available for satellite use, subject to appropriate restrictions to protect terrestrial use. For example, there may be opportunities for satellite services to use additional spectrum bands in the Earth-to-space direction without posing any interference risk to terrestrial networks.

II. THE NSF SHOULD ESTABLISH A PROCESS FOR REGULARLY UPDATING THE R&D PLAN

The RFI seeks comment with respect to the creation of "a process to refine and enhance the R&D plan on an ongoing basis." Viasat believes that such a process is essential to account for the results of ongoing R&D efforts, as well as the evolution of national priorities over time. Viasat recommends that the NSF establish a process through which the R&D Plan would be periodically updated (*e.g.,* every two years) following a public consultation process. As part of this process, the NSF could solicit input from a wide variety of stakeholders, including industry, government, and academia, providing transparency and allowing the R&D Plan to benefit from the knowledge and expertise of stakeholders actively involved in spectrum use and research.

* * * * *

The R&D Plan provides an opportunity for the United States to prioritize spectrum policy goals for the next decade and beyond. Satellite operators continue to play an essential role in providing critical connectivity to the public, and targeted R&D would enable satellite networks to be even more effective in this respect. Viasat therefore recommends that the NSF develop an R&D Plan that prioritizes spectrum-related R&D in support of satellite applications and use cases, so as to allow satellite operators to meet customer demands and continue to innovate.

Respectfully submitted,

/s/

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March 21, 2024

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Request for Information on the National Spectrum Research and Development Plan

WifiForward

Before the
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Request for Information

on the

National Spectrum Research and Development Plan

Comments of WifiFoward

WifiForward is a broad coalition of entities that innovate, use and deliver services over Wi-Fi and other unlicensed spectrum technologies.[1] WifiForward filed comments with the National Telecommunications and Information Administration (NTIA) on the National Spectrum Strategy (NSS), and on the NSS Implementation Plan adopted this month.[2] We are pleased to provide brief comments to the Networking and Information Technology Research and Development (NITRD) National Coordination Office, as you shape federally-directed research and development in support of the NSS. Per the Federal Register Notice requirements,

[1] Additional information about WifiForward is available at www.wififorward.org

[2] See https://www.ntia.gov/issues/national-spectrum-strategy/stakeholder-engagement/received-comments.

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WifiForward is a strong proponent of policies that enable and support coexistence in spectrum utilization. The organization is focused on Wi-Fi technology, which was by design meant to politely contend for common spectrum resources. For the spectrum bands in which it operates today, Wi-Fi must yield to other radio systems that have superior claim to the band. The tools and techniques developed to enable this have allowed Wi-Fi to become a tremendous success story. Based on that success, the participants in WifiForward view coexistence as both a technology and business strategy to ensure that the United States can provide multiple systems and multiple users access to the spectrum they need to make the U.S. a spectrum leader. The use of coexistence-based approaches across a broad range of systems and users also supports the diversity and experimentation that drive innovation for the future. WifiForward believes the NITRD working group's efforts can play an important role in supporting the future use of radio spectrum by building upon successful coexistence technologies and developing increasingly efficient ways to share scarce spectrum resources.

We offer four insights as you plan your research and development approach.

1. <u>It is important that the work in the R&D Plan does not conflict with or duplicate efforts that are already underway through the NSS.</u> In its Implementation Plan, NTIA has distinguished the shorter term work it is progressing on the 3 GHz, 5 GHz, 7/8 GHz and 37 GHz bands from the work it will do to stand up a longer-term spectrum planning process. The research and development work under the umbrella of the R&D Plan will be most valuable if used to inform and support NTIA's long term planning where new challenges will arise.

2. <u>Further technical investigation of existing sharing mechanisms available in the commercial marketplace is not necessary for them to be useful in meeting short-term needs</u>. Coexistence mechanisms that are operating in the market have been evaluated and discussed repeatedly. For example, a comprehensive discussion of the existing

mechanisms at use now and available for many bands in the near term was recently authored by Michael Calabrese for the Dynamic Spectrum Alliance.[3] Stakeholders with vested interests in the successful deployment of these coexistence techniques and tools are best positioned to work with Federal stakeholders on their use in the near term for bands of interest.

3. The R&D Plan should be focused on the next generation of coexistence techniques and tools. For example, one of the key aspects of coexistence that continues to be under-developed is a sophisticated understanding of signal propagation. Existing propagation models are outdated and lead to overly conservative results. An improved understanding of propagation would use more modern tools to better account for things like clutter from buildings and foliage, especially as they relate to signals from lower-site and indoor transmitters, rather than only the higher-site, outdoor transmitters that characterize traditional wide area networks. Another area of longer-term investigation could be the use of artificial intelligence in propagation modeling.

   Advancements in this area would enable different systems to operate on the same frequencies – whether in the same geography or in directly adjacent geographies – and would be enormously beneficial as policymakers evaluate how to more efficiently allocate federal and commercial resources, and transition away from exclusive use radio silos. We recommend the NITRD working group coordinate its sponsored work in this area with other government organizations so as not to overlap efforts. Those are: NTIA's ITS lab – which has propagation expertise – as well as NIST, whose Wireless Networks

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[3] Calabrese, Michael, "Solving the Spectrum Crunch: Dynamic Spectrum Management Systems," October 2023 available at: https://www.dynamicspectrumalliance.org/solving-the-spectrum-crunch.pdf. IEEE DySPAN, as the National Science Foundation is well aware, has also been a forum for presentations of various aspects of sharing and coexistence mechanisms over the years, as well as generated standards in this area. See https://standards.ieee.org/ieee/1900.5.1/5348/. Similarly, the Dynamic Spectrum Alliance has also completed a research report on Automated Frequency Coordination solutions for 6 GHz unlicensed devices. DSA, "Automated Frequency Coordination: An Established Tool for Modern Spectrum Management," March 2019 available at: https://dynamicspectrumalliance.org/wp-content/uploads/2019/03/DSA_DB-Report_Final_03122019.pdf.

Division also has done technical work in this area. The working group might also consult with the FCC Lab, which may have views on particular issues in the current application of propagation models that would be useful to tackle. Potential areas of investigation might include – building entry loss, short range propagation in urban and suburban environments, or use of artificial intelligence in propagation modelling.

4. The NITRD working group's effort also would be well served by understanding the work that will be assigned to NTIA's Commerce Spectrum Management Advisory Committee (CSMAC),[4] which will launch a new two-year term this year. CSMAC is expected to provide advice to NTIA on standing up long term spectrum planning, and the CSMAC work may help the working group better target its science and technology-based research program to meet the future needs of policymakers.

Thank you for the opportunity to provide comments on the R&D Plan.

[4] See https://www.ntia.gov/category/csmac.