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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

In the matter of	)	
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Request for Information on the National	)	89 FR 12871
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.

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[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, OpenAirInterface (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:
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> - 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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