



RESEARCH AND DEVELOPMENT PRIORITIES FOR AMERICAN LEADERSHIP IN WIRELESS COMMUNICATIONS

May 2019

Mr. President:

In your October 25, 2018 *Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future*, you directed The White House Office of Science and Technology Policy with providing recommendations for prioritizing R&D to advance radio frequency spectrum access and efficiency. The attached report is a product of interagency collaboration, led by the National Science and Technology Council's Wireless Spectrum R&D Interagency Working Group (WSRD), and highlights key priorities for spectrum R&D going forward.

Wireless spectrum is an essential resource to the economic prosperity, national security, and public safety of our Nation. The successful management and allocation of electromagnetic spectrum bands and wavelengths is crucial to ensuring that this resource is used in the most efficient way possible, maximizing the benefits of technologies that rely on such bands. New and innovative methods of utilizing spectrum, such as the identification of new bands that may provide benefit to certain technologies, or improved spectrum sharing technologies that allow better and more efficient use of identified bands, are key to our Nations near and long-term success.

While Federal and Commercial investment paved the way to 4G and provided a tremendous enhancement in services and capabilities, current networks are not sufficient to support the industries of the future. The United States must invest in state-of-the-art means and methods to use spectrum efficiently and reap the benefits of the advanced technologies that 5G will support: autonomous vehicles, telemedicine, emergency communications, and untold next-generation technologies that will result from increased data capacity and connectivity. Research and development (R&D) efforts are vital to ensuring that the United States maintains a strategic purpose and intent in navigating the wireless spectrum environment and ensuring the efficient and timely adoption of 5G networks.

In this report, WSRD has identified three spectrum R&D priorities: (1) pursue spectrum flexibility and agility to use multiple bands and new waveforms, (2) improve near real-time spectrum awareness, and (3) increase spectrum efficiency and effectiveness through secure autonomous spectrum decision making. Each plan lays out near and long-term recommendations that, if adopted, will position the United States to be a wireless technology leader.

The effort to invest in R&D recognizes that the future of public- and private-sector spectrum use must be flexible, focus on better awareness of spectrum use and spectrum congestion, and spectrum decision-making must be autonomous. By achieving these goals and leveraging collaborative public-private partnerships, our Nation will lead in next generation wireless technology through development of robust, dynamic, and flexible spectrum environments.

Sincerely,



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Key Takeaways

This report on recommendations for national spectrum research and development (R&D) priorities sets a vision to improve the national economic impact of electromagnetic spectrum for an increasingly wide range of communications, networking, location, and other applications while preserving and protecting national security and public safety. This priorities report is one step in defining an overall approach to position the United States as a world leader in next-generation spectrum technologies that more effectively leverage time, frequency, space, code, waveform, and networks.

The report recommendations identify R&D actions in three priority areas that can increase the effectiveness and efficiency of spectrum utilization through (1) spectrum agility, (2) near real-time spectrum awareness, and (3) adaptive spectrum decision making. The Wireless Spectrum R&D (WSRD) Interagency Working Group (IWG) recommends a whole-of-government approach to electromagnetic spectrum R&D and advocates public-private partnerships to achieve these priorities.

Background

Purpose and Scope

This report responds to the October 25, 2018, Presidential Memorandum on *Developing a Sustainable Spectrum Strategy for America's Future* and contains recommendations for prioritizing R&D to advance radio frequency spectrum access and efficiency, as called for in Section 2(c) of the Memorandum.¹ The report focuses on R&D efforts to create a flexible R&D environment that advances spectrum technologies to meet current and future spectrum requirements for the broad communications needs of the Nation.

This report supports Administration spectrum goals by identifying spectrum R&D priorities across Federal and private sectors for ongoing, increased, and new R&D investments in both the near term (5-10 years) and the long term (greater than 10 years). The priorities report looks beyond only mobile and broadband communications to examine the entire spectrum ecosystem, including science and meteorological observations, radar, radiolocation, and

Strategic R&D to Advance Spectrum Technologies

The investments and research made by Federal and commercial partners paved the way for the United States to lead the world in the 4th generation (4G) cellular network that most U.S. customers use today. The results of this research, in turn, spurred an explosion of services and capabilities that have provided an economic benefit to the Nation while fundamentally changing expectations by businesses and individuals on where and how they share and access digital data. Consumers are demonstrating an almost insatiable appetite for more capacity, lower latency, and higher data rates. Customer demand combined with using wireless networks in new areas such as autonomous vehicles, telemedicine, emergency communications, and the prospect of connecting billions of Internet of Things devices will exceed the limits of 4G networks. To meet these requirements and maintain U.S. technological leadership, the Federal Government and commercial partnerships are once again actively researching new technologies to support more devices, higher data rates, increased security, and greater mobility, which will be needed in the next (5G) evolution of cellular systems. Research in massive multiple-input multiple-output (MIMO) antennas, small cells using adaptive antenna beam forming and steering, and cognitive (self-adjusting) radios operating at higher frequencies offer the potential for better security while being able to access data 100 times (or more) faster than today's 4G networks. Advances that separate outdoor and indoor use allow leveraging technologies like WiFi for indoor devices to support better connectivity while significantly reducing energy requirements.

¹ <https://www.govinfo.gov/content/pkg/FR-2018-10-30/pdf/2018-23839.pdf>

navigation. The report considers the impact of R&D across the electromagnetic spectrum, as well as emerging network architectures and application domains expected in the future that will rely on the existence of a reliable wireless communication system.

This priorities report is the product of the Networking and Information Technology Research and Development (NITRD) Program's Wireless Spectrum Research and Development (WSRD) Interagency Working Group (IWG). A part of the National Science and Technology Council, the WSRD IWG coordinates spectrum sharing technologies and systems R&D activities across the Federal Government.² Through its coordination activities, the WSRD IWG has access to a wide body of knowledge in ongoing and emerging spectrum R&D, in both private and Federal domains, that has enabled the identification of the priorities in this report.

This priorities report addresses near-term and long-term spectrum R&D challenges. The report applies to Federal agencies and private entities using spectrum, especially those pursuing spectrum R&D, by aligning these efforts with national priorities.

Assumptions

The following assumptions were used as a basis for creating this spectrum R&D priorities report:

- The electromagnetic spectrum is fundamental to the Nation's security and prosperity and requires a "whole-spectrum solution" approach that encompasses and addresses scientific research, technology, policy, legislation, and operations in key United States economic sectors.
- The number of high-bandwidth, mission-critical, and day-to-day wireless applications and services is on the rise. In addition, wireless applications and services are increasing in the intensity of use, data throughput, complexity of operations, and need for flexibility.
- The spectrum environment includes many different types of systems besides wireless data networking, and both terrestrial and satellite systems can be used to advance 5G deployment.
- Using current spectrum technology and spectrum management processes, the spectrum below 6 GHz is oversubscribed.
- Densification (the ability to support more wireless services, capacity, and users in the same physical and/or spectrum space) is critical to increasing spectrum utilization. The ability to densify networks and systems will vary depending on network type and intended use.
- There is a need to protect and improve existing, and create new, technologies and management processes to ensure effective and efficient spectrum utilization. This applies both to the higher frequencies that many wireless services are moving into and the lower frequencies that are being used more efficiently as a result.
- Spectrum decision making must be fast, dynamic, adaptive, autonomous, flexible, and secure.
- Spectrum awareness at various scales is necessary to support dynamic use of the spectrum.
- A single application or system could use a combination of low-, medium-, and high-frequency bands and different data transmission modalities.
- The use of airborne and space based networked systems such as drones and satellites expand the use of spectrum beyond two dimensions.

² https://www.nitrd.gov/nitrdgroups/index.php?title=Wireless_Spectrum_Research_and_Development

Guidance

This spectrum R&D priorities report directly supports the October 25, 2018, Presidential Memorandum on spectrum strategy. This report also is shaped by the following Federal documents:

- *The National Security Strategy of the United States of America* (December 2017),³ which seeks to improve connectivity and improve digital infrastructure through the deployment of the secure 5G capability nationwide that is critical to supporting United States future growth.
- *The Office of Science and Technology Policy Memorandum M-18-22 on FY 2020 Administration Research and Development Budget Priorities* (July 2018),⁴ which emphasizes the importance of next generation wireless networks to an increasingly connected society. These networks will support public safety, national security, economic growth, job creation, technology advancement, and maintaining United States leadership in strategic computing.
- *National Institute of Standards and Technology Special Publication 1219, Future Generation Wireless Research and Development Gaps Report* (February 2018),⁵ which provides in-depth research on gaps within various components of the wireless industry and on the major R&D challenges facing the broad research community.

Spectrum R&D Priorities

This report identifies three overarching spectrum R&D priorities:

- Priority 1: Pursue spectrum flexibility and agility to use multiple bands and new waveforms.
- Priority 2: Improve near real-time spectrum awareness.
- Priority 3: Increase spectrum efficiency and effectiveness through secure autonomous spectrum decision making.

The report's spectrum R&D priorities and amplifying recommendations are organized into near term (5-10 years) and long term (greater than 10 years) categories. They address technology gaps and describe areas of needed R&D emphasis without defining specific technology solutions. They also look beyond the current spectrum R&D focus on cellular technologies to encompass broader spectrum systems, services, and technologies.

Priority 1: Pursue spectrum flexibility and agility to use multiple bands and new waveforms

Spectrum R&D is needed to improve the temporal use of Federal and commercial spectrum. Wireless systems need new and improved radio frequency technologies that support the flexibility to use multiple bands. Careful evaluation of incumbent systems and assets should be pursued to ensure safe and reliable sharing of spectrum bands.

³ <https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf>, pp. 18–19.

⁴ <https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf>, p. 2.

⁵ Available at <https://doi.org/10.6028/NIST.SP.1219>.

Near-term recommendations

- Develop advanced antenna arrays and algorithms (e.g., massive multiple-input multiple-output [MIMO] antennas, beam forming and steering, antenna nulling, and conformal arrays) for all frequency bands of interest.
- Develop advanced standards for receivers to incorporate new technologies that support new waveforms and multiple bands and reduce susceptibility to out-of-band emissions.
- Exploit available degrees of freedom (e.g., frequency, waveform, power, spatial orientation, location, and time) to create new spectrum access technologies.
- Improve dynamic spectrum access for a larger class of wireless systems and frequencies, incorporating both local-to-the-radio and cognitive multidomain, network-centric dynamic spectrum access.
- Identify spectrum bands that have utility for new technologies and designate the appropriate level of protection for incumbent systems through technical analysis.
- Properly evaluate and protect radio frequency emissions and interference to Federal assets in order to increase the interference tolerance and flexible spectrum access of space-based systems, where feasible.
- Develop technologies and techniques to better control emissions, including out-of-band emissions, thus enabling flexible and agile operations.
- Quantify spectrum need decreases resulting from emerging spectral efficiency technology.

Long-term recommendations

- Pursue advanced spectrum communication and radar technologies that support national spectrum interests for national security and economic growth.
- Establish United States leadership in the next generation of cellular standards beyond fifth-generation (5G) high-capacity wireless networks. Ensure that the United States is prepared to be a spectrum technology leader and benefit from new spectrum technologies.
- Expand United States involvement in international spectrum standards bodies to advance all technology priorities of the Administration.
- Expand flexible and dynamic spectrum access through continued exploitation of degrees of freedom to create new spectrum technologies.
- Develop systems that incorporate multifunction and multi-mission capabilities to address and avoid frequency conflict.

Priority 2: Improve near real-time spectrum awareness

As the spectrum environment continues to become more congested and contested, R&D is needed to improve spectrum awareness, such as near real-time network sensing and monitoring, in a manner that is secure and preserves privacy. In addition to providing more up-to-date information on network and spectrum environment changes, monitoring also supports enhanced interference detection and resolution to prevent degradation of systems or services provided. The increased use of lower-power and highly directional antennas presents a challenge as well as an opportunity in realizing spectrum awareness capabilities.

Near-term recommendations

- Develop systems and devices that actively monitor their spectrum environments (e.g., signal strength, interference, directional information, and noise floor) and support adapting operations, frequency bands, and delivery systems (satellite, terrestrial wireless, and WiFi) in near real-time.
- Identify flexible and quantitative measures for defining and mitigating interference that incorporate new spectrum sharing technologies.
- Develop the capability to securely share spectrum environment, system status, and network sensing information across heterogeneous devices, systems, and bands.
- Develop capabilities to securely fuse crowd-sourced network sensing information with Federal sensing, monitoring, and enforcement systems, ensuring appropriate levels of privacy. This will require the ability to identify and/or verify the pedigree and provenance of crowd-sourced data and correlate that to a level of trust.

Long-term recommendations

- Increase the speed of information sharing for faster collaboration between heterogeneous spectrum systems (e.g., wireless, radiolocation, radar, meteorological, and science systems), while maintaining privacy and security.
- Continue development of improved sensing and monitoring systems for heterogeneous and adaptive wireless systems.
- Automate qualitative measurement and analysis of interference coupled with automated reporting of spectrum state information by cognitive wideband and multi-band systems.

Priority 3: Increase spectrum efficiency and effectiveness through secure autonomous spectrum decision making

The current methods of spectrum decision making and spectrum sharing need to evolve to support the future spectrum ecosystem. Future wireless networks are likely to be more decentralized and better able to react to changing environmental conditions. The spectrum ecosystem will benefit from systems that can make decisions in near real-time, autonomously and securely, and coordinated with other disparate wireless systems over a wide frequency range in the same geographic area, while balancing efficient use of spectrum with effectiveness of Federal and private missions.

Near-term recommendations

- Develop tools that perform autonomous spectrum decision making based on the current spectrum environment, operational risk assessment, risk management, and business management processes (e.g., cost benefit analysis, security, opportunity costs, national security, public safety, and national economic growth).
- Develop tools that assess spectrum utilization technologies from the perspective of spectrum efficiency and mission effectiveness to support adaptive Federal and private spectrum allocations in place of static spectrum allocations and/or assignments to avoid degradation of systems or services.
- Develop tools, processes, and procedures that foster closer collaboration and coordination within and between the government and industry on spectrum decision making.

Long-term recommendations

- Develop automation to support agile, flexible, and adaptive spectrum sharing for all passive and active users. Automation should integrate mission requirements and operationally focused decision making into new spectrum technologies that improve sensor performance while mitigating interference. Automation should also support dynamically assigning and allocating spectrum while minimizing human intervention or action.
- Automate spectrum management tools and capabilities to be more efficient, flexible, and adaptive to take advantage of temporary spectrum allocations and unlicensed spectrum.
- Continue investments in secure autonomous, dynamic network configurations and operations. Increase decentralized spectrum decision making and spectrum sharing between wireless systems in complex, heterogeneous, and congested or contested wireless environments.
- Create better models for characterizing propagation in multiple potential operating conditions (e.g., frequency, waveform, location, modality and propagation environment).
- Protect existing and future improvements in scientific uses of the spectrum to ensure the United States is a leader in scientific discoveries and environmental sensing information.

Conclusion

The electromagnetic spectrum is a critical national resource. The recommendations for spectrum R&D priorities described in this report, if adopted, will position the United States to be a wireless technology leader. Through using and improving public-private partnerships, the United States can provide a robust, dynamic, and flexible spectrum environment that supports economic growth, scientific progress, national security, and public safety.

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development enterprise. A primary objective of the NSTC is to ensure that science and technology policy decisions and programs are consistent with the President's stated goals. The NSTC prepares research and development strategies that are coordinated across Federal agencies aimed at accomplishing multiple national goals. The work of the NSTC is organized under committees that oversee subcommittees and working groups focused on different aspects of science and technology. More information is available at <https://www.whitehouse.gov/ostp/nstc>.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976 to provide the President and others within the Executive Office of the President with advice on the scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, the environment, and the technological recovery and use of resources, among other topics. OSTP leads interagency science and technology policy coordination efforts, assists the Office of Management and Budget with an annual review and analysis of Federal research and development in budgets, and serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the Federal Government. More information is available at <https://www.whitehouse.gov/ostp>.

About the Subcommittee on Networking & Information Technology Research & Development

The Networking and Information Technology Research and Development (NITRD) Program is the Nation's primary source of federally funded work on pioneering information technologies (IT) in computing, networking, and software. The NITRD Subcommittee of the NSTC Committee on Science and Technology Enterprise guides the multiagency NITRD Program in its work to provide the research and development (R&D) foundations for assuring continued United States technological leadership and meeting the needs of the Nation for advanced IT. The National Coordination Office (NCO) supports the NITRD Subcommittee and the Interagency Working Groups (IWGs) that report to it. More information is available at <https://www.nitrd.gov/about/>.

About the Wireless Spectrum Research and Development Interagency Working Group

Federal agency members of the Wireless Spectrum Research and Development (WSRD) Interagency Working Group work together to coordinate spectrum-related research and development activities both across the Federal Government and with the private sector and academia under the auspices of the NITRD Subcommittee. The group's purpose is to facilitate efficient and effective investment in the advancement of spectrum-sharing technologies and systems, consistent with the WSRD IWG's guiding principles, which are transparency, smart investment, and solicitation of opportunities for technology transfer across and beyond the Federal Government. More information is available at <https://www.nitrd.gov/groups/wsrld>.

About this Document

The recommendations in this report for spectrum research and development priorities set a vision to improve the national economic impact of spectrum while preserving and protecting the national security, scientific, and public safety use of spectrum. The report is one step in the overall approach to position the United States as a world leader in next-generation spectrum technologies. The priorities report identifies research and development actions that can increase the effectiveness and efficiency of spectrum utilization through spectrum agility, near real-time spectrum awareness, and adaptive spectrum decision making.

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