RADIO RECEIVER SYSTEMS R&D: INNOVATION NEEDS AND IMPACTS ON TECHNOLOGY AND POLICY

WORKSHOP SUMMARY

Prepared by the

WIRELESS SPECTRUM R&D INTERAGENCY WORKING GROUP

NETWORKING & INFORMATION TECHNOLOGY
RESEARCH & DEVELOPMENT SUBCOMMITTEE

COMMITTEE ON S&T ENTERPRISE

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About the Wireless Spectrum R&D Interagency Working Group

Federal agency members of the Wireless Spectrum R&D (WSRD) Interagency Working Group (IWG) work together to coordinate spectrum-related R&D activities both across the Federal government and with the private sector and academia under the auspices of the Networking and Information Technology Research and Development (NITRD) Subcommittee of the NSTC's Committee on Science and Technology Enterprise. 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://nitrd.gov/groups/wsrd.

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Key Takeaways

The Wireless Spectrum R&D (WSRD) Interagency Working Group (IWG) held a workshop, *Radio Receiver Systems: R&D Innovation Needs and Impacts on Technology and Policy*, on May 5, 2017, in Washington, D.C. At this workshop, Federal, private, and academic stakeholders discussed their individual views regarding the need for innovation in radio receiver systems in the following key areas:

- The current spectrum environment increases receiver performance requirements and adds complexity to everything from receiver design to regulatory policy.
- New metrics are required to guide development of receiver design, requirements, and regulations.
- Designers must balance complexity and efficiency. There is a recognized need for receiver systems to facilitate spectrum agility (i.e., the ability to scan and analyze wider frequency ranges), to provide spectrum sensing, and to enable data sharing and distribution.
- Regulatory policies must strive for a balance of standardization and flexibility to incentivize adoption of new technologies and keep up with the rapid development cycle.

Background

Spectrum rule-making by the Federal Government aims to regulate intended transmission power and unwanted emissions from transmitters; it generally does not regulate receiver performance. Receiver standards are not used in the United States because receivers are not considered the source of interference. In addition, transmitter-related interference effects can be measured fairly easily, whereas understanding the complex internal operations of a receiver is necessary to determine its interference-mitigation performance. However, receivers, not transmitters, experience the adverse impacts of interference, which, in turn, adversely affects overall system-level performance in both receivers and transmitters. In contrast to U.S. practice, European regulators, without directly dictating receiver designs, take the approach that harmful interference claims can be made only after demonstration that the receiver system meets interference tolerance levels set by policy.

The NITRD Wireless Spectrum R&D Interagency Working Group, which is co-chaired by the National Telecommunications and Information Administration and the National Science Foundation, organized this workshop to share insights and build relationships across Federal agencies and between the public, private, and academic sectors. The 35 workshop participants represented a balanced cross-section of stakeholders involved in, or impacted by, this area of research.[1]

Event Focus

The workshop was organized around the following three topics:

1. Characteristics Needed in Radio Receiver Systems

Traditional receiver designs use filters to prevent overload of the receiver front end and the system as a whole. An important function of the filters is to prevent the various received signals from mixing together and producing unwanted harmonics and intermodulation products that degrade receiver performance. As systems are designed with wider bandwidth, the interference due to these effects

[1] More workshop information is available at https://nitrd.gov/nitrdgroups/index.php?title=WSRD_Workshop_IX.

becomes more significant. While narrowband filters could solve this issue, they also lock the system design into a specific frequency allocation and limit system capabilities.

The standards of measuring receiver performance are impacted by receiver complexity, which has increased over the years (both functionally and operationally), and by system-level performance characteristics. The current spectrum environment requires new metrics to guide improved receiver design. While each parameter involves various trade-offs to arrive at an optimal design for a particular radio environment and mission, discussions identified the following key characteristics for next-generation receivers:

- High sensitivity
- Adaptive interference mitigation
- Spurious response and image rejection
- Intermodulation rejection (second-order and third-order intermodulation products)
- Channel sounding and equalization
- Agile frequency assignment (adaptive spectrum control)
- High dynamic range
- Cooperative or non-cooperative interference avoidance
- Adaptive harm claim thresholds
- Noise shaping (prior to analog-to-digital conversion)
- Antenna directivity
- Adaptive antenna polarization
- Selective signal modulations
- Modular front ends
- Variable sampling rates (as a function of noise level)
- Variable data rates
- Networking (among cooperative devices)
- System figure-of-merit indicators
- Variable-gain antenna

2. Advancing Next-Generation Radio Receiver Systems

Radio receiver systems are constantly evolving to meet changing needs, including operating in multiple frequency bands, implementing new and varied policies, and addressing new and expanding application environments such as the IoT (internet of things) receiver requirements. The medical area is an example of an environment experiencing rapid expansion of wireless technologies and products, in particular, those that monitor patients and provide data that help determine care and treatment. As the number of devices increases, so does the likelihood of harmful congestion and interference. Improvements in the following key areas will require innovative solutions:

1. *Agile frequency selectivity for both transmitter and receiver systems* with the ability to scan and probe wider dynamic frequency ranges and advanced tunable filters; this will require spectrum sensing in dynamic environments, with distributed antenna systems as needed.
2. *Multifunction and multi-mission systems capabilities* to address and avoid frequency conflicts, taking into consideration the trade-offs between wideband technology and system functional requirements such as spectrum-monitoring capabilities.
3. *The use of artificial intelligence and machine learning* (i.e., advanced deep learning) to process large amounts of data and improve channel prediction.
4. *Situational awareness and the sharing of information* by increasing flexibility and functionality (i.e., sharing sensing information with other radio systems).
5. *Quality of service and reliability* by establishing harm claims thresholds, moving toward multiband access systems, system-on-a-chip designs, and improving media access control and application layer solutions.

6. *Antenna systems* with dynamic beamforming, using antenna-nulling techniques, and improving software architecture and reuse.
7. *Receiver architecture* to support wideband operations, address legacy design limitations, focus on end-to-end system solutions, develop smart lower-layer protocols for channelization, and lower power consumption.
8. Implementation of active circulator technology to reduce cost and complexity.
9. *Design for data-centric services* to allow systems engineering tradeoffs for desired latency and quality of service needs to be balanced against the evolutionary shift from voice requirements toward data-centric services (including video, music, etc.).
10. *Testing infrastructure* to test and integrate innovative receiver systems, develop and validate modern receiver models, standardize test procedures, improve measurement, and provide access to performance data.

3. Implementation and Adoption Challenges of New Radio Receiver Technologies

Innovative receiver systems will require well-thought-out incentives to overcome implementation and adoption challenges. Participants examined current engineering and institutional tools, from explicit receiver specifications to trustworthy coexistence rules and discussed the following actions that would be helpful:

1. *Reduce cost and systems complexity* by investigating modularized and open architectures along with incremental roll-outs of receiver system features.
2. *Establish receiver architecture standards* that can evolve along with the rapid design cycle and facilitate increased coordination between manufacturers.
3. *Leverage work done in specific domains* such as the medical field and autonomous vehicles that involve a wide variety of technologies and frequency regions and face unique challenges in data processing, system infrastructure, and spectrum resources.
4. *Develop better metrics* that can be applied to a broad range of unique systems and applications (e.g., radars, commercial cellular, medical devices, etc.) and can assist in predicting the utilization of spectrum allocations.
5. *Improve proactive management of spectrum allocations* by collecting best practices that can be used across multiple bands, and by studying the move from a static to a dynamic frequency assignment, spectrum convergence and the ability to adapt to various applications (i.e., IoT), and methods for characterizing and testing receivers.
6. *Manage security and privacy issues* by identifying the risks and researching secure information transfer and solutions to privacy issues.
7. *Regulate receivers* to improve coexistence between transmitters (currently regulated) and receivers (currently not regulated). The concept of adjacent channel interference ratio is a good starting point for policy discussions in this area and is already used in many cellular systems to improve quality of service.
8. *Improve policy development* by exploring standard categories of interference consequences and agreeing on performance and "benchmark" goals for coexistence.
9. *Explore the need for policy flexibility* as standards change and evolve and for coexistence of "similar" systems and "dissimilar" systems.
10. *Improve information sharing* across receiver systems. Innovative methods are needed to improve performance and assure secure and private information transfer.

Conclusion

This workshop report outlines research topics that were discussed by a cross-section of experts with the goal of improving radio receiver systems. Past efforts to achieve better performance and more efficient spectrum use have focused on frequency-division and time-division allocations, but the explosion of wireless data service applications is driving the need for innovative changes in modern radio systems. Many systems are moving to wideband performance characteristics to increase their capabilities and performance. This reliance on wideband spectrum in the lower spectrum bands and the high-frequency millimeter wave bands requires designing and developing radio systems with increased functionality in both the transmitters and receivers. Improving overall system performance depends heavily on receivers being designed and built to deal with increased spectrum congestion and interference. Receiver design also needs to consider the full radio system to fully characterize and quantify performance. Upfront system engineering is needed for improved coexistence approaches that reduce overall interference. In addition, designers must balance performance metrics (e.g., sensitivity, selectivity, and efficiency) against costs, and policymakers must find ways to facilitate improved performance and information exchange that is both secure and private.