5G-ENABLED ENERGY INNOVATION

ADVANCED WIRELESS NETWORKS WORKSHOP FOR SCIENCE

PETE BECKMAN
Workshop Chair
Argonne National Laboratory

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Transforming Science with Advanced Wireless Technologies

Digital wireless communication has become a foundational technology for the nation. The U.S. Department of Energy's Office of Science (DOE-SC) is the Nation's largest supporter of basic research in the physical sciences discovering new materials, designing advanced microelectronics, and understanding the physics of radio frequency signaling.

The expanding national rollout of a new fifth-generation (5G) mobile network, coupled with the torrent of scientific data generated by next-generation devices such as battery-powered Internet of Things (IoT) sensors, has created an urgent need to enhance cutting-edge wireless technology. Breakthroughs in the deployment, integration, security, and operational range of wireless networking can provide new scientific capabilities for the next decade—from autonomous mobile instruments for scientific user facilities to intelligent sensors networks distributed over thousands of kilometers to study environmental processes. To realize this promise, however, we must continue to drive innovations in computing, artificial intelligence (AI), advanced materials, high-speed networking, and microelectronics.

In March 2020, the DOE-SC convened a workshop to identify the potential opportunities and explore the scientific challenges of advanced wireless technologies. The workshop was arranged in ten technical focus areas:

- **Advancing science missions**
- **Cybersecurity**
- **Critical infrastructure**
- **Extreme environments**
- **Scientific user facilities**
- **Edge computing**
- **Distributed instruments**
- **New science exploration paradigms**
- **Software architectures**
- **Data management.**

Workshop participants also submitted white papers that were discussed in breakout sessions organized around the focus areas. Plenary sessions were used for keynote presentations to frame scientific opportunities and present roadmaps for future technologies. On the second day, focus area leaders facilitated discussion groups that identified five Priority Research Directions (PRDs), detailed in the following pages. The full workshop report will be available from https://www.osti.gov/ at DOI: 10.2172/1606538.

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Priority Research Directions

Revolutionize wireless communication in extreme environments through advances in materials science and physics

Key Questions: How can we combine physics, advanced materials, and novel architectures to overcome the current limitations of 5G wireless technology in extreme environments? What innovations can increase the coverage, density, and reliability of sensors by orders of magnitude beyond today's solutions?

Wireless in the terahertz regime can revolutionize experimental science under severe conditions, such as radiation, corrosive agents, or extreme temperature. To realize this potential, we need coordinated research in physics, materials science, and device architectures to provide novel materials with targeted electronic and magnetic properties. Advanced models are needed to predict performance and support integration into advanced wireless platforms.

Reinvent scientific instrumentation and critical national infrastructure with wireless technology to provide rapid, AI-driven adaptation

Key Questions: How can we create scientific sensing networks that provide near-real-time feedback across a wide range of deployment conditions? What new AI-driven algorithms and methods are needed to assimilate heterogeneous data streams and autonomously control critical infrastructure and scientific instruments?

Leveraging advanced wireless, such as 5G, can enable new architectures that support a dynamic, near-real-time end-to-end fabric that predicts and responds to measurement conditions, thus dramatically improving the value of collected data. Likewise, critical infrastructure must respond to a continuously evolving environment. Breakthroughs in wireless instrumentation architectures are required in order to provide dynamic, robust, reliable, and repeatable operations.

Reinvent the digital continuum linking the wireless edge to advanced scientific user facilities, data analysis, and high-performance computing

Key Questions: What novel programming frameworks will enable fast, secure data movement and *in situ* analysis to span the continuum from wireless to cloud computing, scientific user facilities and supercomputers? What AI techniques can learn from and then automatically optimize and operate end-to-end infrastructure?

To effectively integrate the torrents of data from advanced wireless sensors, new computational tool sets must provide end-to-end services such as data movement and caching, data analysis and integrity, and automated performance optimization. New methods, algorithms, and microelectronic devices must address the challenges of mobile endpoints and unreliable links, to build a programmable digital continuum for science.

Revolutionize AI-enabled edge computing for advanced wireless

Key Questions: Using a co-design approach, how can we optimize computer architecture for power, precision, and programmability to support scientific AI at the edge for 5G? What novel software architectures can leverage network slicing and provide energy-efficient computation and scalability across heterogeneous edge resources?

The research community and computer industry are rapidly developing new hardware and software architectures for machine learning at the edge. Current limitations on electrical power and computing efficiency for scientific workloads can be overcome with a co-design methodology that links advanced wireless providers, scientific applications developers, and computer scientists, creating novel hardware and software architectures.

Accelerate innovation: Use community testbeds to explore advanced wireless for science

Key Questions: How does advanced wireless interact with scientific instrumentation? How can we develop scalable deployments for 5G-enabled science, test integration with new or existing scientific infrastructure, and benchmark the real-world performance of wireless sensors for scientific instruments and facilities?

Building an open wireless testbed with a capable wired backhaul to DOE scientific user facilities is foundational for developing next-generation applications and new hardware and software architectures, and for testing new scientific instruments. Such a testbed can ensure innovative research can successfully transition from concept to practice and also provide insight into resilience, performance, and security.

Summary

Wireless networks can enable scientific facilities to become more mobile, autonomous, and distributed. Breakthroughs in new materials and microelectronics are needed to broaden and extend those wireless networks into the harsh and extreme environments of new scientific domains. Furthermore, innovations in machine learning, edge computing, autonomous control systems, and smart scientific instrumentation, combined with advancements in software and tools for reliably moving and managing data across the digital continuum from the edge to data centers, will usher in new forms of end-to-end science platforms. The new platforms will be designed to automate the search for the most valuable data or unknown properties. By leveraging next-generation advanced wireless technology, we can build the infrastructure needed to explore, understand, and harness new scientific discoveries.

Workshop Chair: Pete Beckman, Argonne National Laboratory
DOE Lead: Robinson Pino, Office of Science, Advanced Scientific Computing Research
Chicago, IL
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Contributors: Aaron Tremaine, SLAC; Andrew Wiedlea, LBNL; Andy Nonaka, LBNL; Angel Yanguas-Gil, ANL; Arden Warner, FNAL; Arupjyoti Bhuyan, INL; Barney Maccabe, ORNL; Caleb Phillips, NREL; Charlie Catlett, ANL; Draguna Vrabie, PNNL; Elena Peterson, PNNL; Eric Schwegler, LLNL; Greg Tchilinguirian, PPPL; Harinarayan Krishnan, LBNL; Jason Fields, NREL; Jerome Lauret, BNL; Johnathan Cree, PNNL; Keith Tracey, SNL; Kevin Brown, BNL; Klaehn Burkes, SRNL; Kurt Sorensen, SNL; Luke Gosink, PNNL; Mark Bryden, AMES ; Matt Bickley, JLAB; Mike Ritsche, ANL; Peter Barnes, LLNL; Peter Fuhr, ORNL; Prasanna Date, ORNL; Scott Collis, ANL; Tammy Chang, LLNL; Theresa Windus, AMES; Thomas Potok, ORNL ; Valerie Taylor, ANL

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