5G Enabled Energy Innovation Workshop (5GEEIW)

Office of Science, U.S. Department of Energy

Where: Westin Michigan Avenue Hotel, 909 N Michigan Avenue, Chicago, IL 60611
Website: www.orau.gov/5GScience
When: March 10-12, 2020

Overview

Emerging advanced wireless networks such as fifth-generation (5G) cellular network technology offers potentially new opportunities and capabilities for the advancement of the U.S. Department of Energy (DOE) and Office of Science missions. In particular, 5G and its associated ecosystem technologies are expected to offer up to 20 Gbps connectivity with 1 ms latency. Initial discussions with DOE program managers and national laboratory scientists provided rationale and ideas for a workshop on energy innovations enabled by 5G technology as well as future technologies such as WiFi 6, 6G, and beyond for the advancement of existing and emerging scientific domains, infrastructure, and applications.

Objective: The workshop will deliver a community-based report highlighting 5G and beyond basic research, development, applications, technology transition, infrastructure, and demonstration opportunities in support of the U.S. DOE mission. The report will help the DOE Office of Science understand both the challenges and the opportunities offered by 5G and emerging advanced wireless technologies in the areas of basic research, development, and integration into scientific user facility operations.

Workshop Support: ORISE/ORAU will provide local management of the workshop website, hotel contracts, collection, processing and dissemination of materials as needed.

Participation

Participants: Interested participants are welcome to submit online a one- to two-page white paper providing technical material relevant to the workshop addressing a specific technical area. All submitted white papers will be reviewed by the program committee, technical area leads and co-chairs. A white paper must be submitted to only one technical area (no duplicative submissions); however, in the event a white paper overlaps with other technical areas, it must be indicated within the white paper at the bottom. Also, the review committee may re-assign/re-allocate white paper submissions to other areas. Participation in the workshop will be based on the relevance of the submitted white paper to the stated goals of the workshop. ***Any submitted materials may be made available for unlimited public distribution.***

- Whitepaper submission deadline: Jan. 31, 2020
- Whitepaper decision notification Feb. 7, 2020
- Registration deadline March 4, 2020

Communities: DOE, R&D Communities, Industry, and Academia

Organizing Committee

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Technical Focus Areas

The workshop will address a number of technical focus areas that span the scientific domains and activities where 5G technology could have the largest impact for the DOE. These technical focus areas will also form the basis for breakout group discussions and help organize the material in the workshop report. Each technical focus area will be chaired by a DOE lab employee and have co-chairs from the broader community.

Area:	**Chair(s)**	**Lab**	**Co-Chair**	**Organization**
Advancing Science Missions	Johnathan Cree	PNNL	Draguna Vrabie	PNNL
Cybersecurity	Arupjyoti Bhuyan	INL	Charmaine C. Sample, Elena Peterson	INL, PNNL
Critical infrastructure	Peter Fuhr	ORNL	Jason Fields	NREL
Extreme Environments	Paul Ohodnicki	NETL	Mauricio DaCunha	U. Maine
Scientific User Facilities	Scott Collis	ANL	Klaehn Burkes	SRNL
Edge Computing	Pete Beckman	ANL	Josiah David Hester	Northwestern University
Distributed Instruments	Greg Tchilinguirian	PPPL	Arden Warner, Tammy Chang	FNAL, LLNL
New Science Exploration Paradigms	Mark Bryden	AMES	Lin Zhou	AMES
Software Architectures	Pat McCormick	LANL	Jerome Lauret	BNL
Data Management	Andrew Wiedlea	LBNL	Harinarayan Krishnan / Esther Singer	NERSC / JGI

For each of the technical focus areas, background material and discussion questions will be provided both on the website and as read-ahead material.

The text below is a draft of that the background material that will be provided to participants to focus the workshop and breakout reports.

Advancing Science Missions

5G and advanced wireless communications will bring a technological revolution across disciplines by providing the ability to transfer massive amounts of data, with latencies comparable to wired, fiber optic networks and with the added benefit of mobility and ease of device deployment. Autonomous operations and embedded intelligence empowered by 5G will advance the nation's science missions in areas including advancing environmental monitoring, climate science, geosciences, and both natural and manmade hazards research. Smart monitoring networks, configured with artificial intelligence and able to react to measurements in real time, can be deployed in new areas and configurations, no longer limited by costly hardwired network infrastructure. 5G will enable monitoring at finer granularities, potentially making it feasible to study the thermal interfaces between the heat output of individual buildings and local climates. This technical focus area will identify how the capabilities of 5G can be harnessed to enhance scientific missions. Motivating questions include the following:

- What 5G enhancements will be critical to the mission space?
    - Latency, bandwidth, massive connectivity, mobility, power consumption, beamforming, network slicing?
- What experiments and demonstrations need to be performed now to guide future 5G integration in our scientific missions?
- Which 5G enabled technologies will be critical for enhancing science?
    - Edge computing, distributed and fieldable AI, real-world AV/VR
- Which technologies need to be incorporated into our experiments/demonstrations to enhance our scientific missions?
- What risks does 5G create to the science missions, and how can we mitigate them?
- How do we enable the deployment of 5G in areas necessary for our scientific missions?
- How can we harness the merger of 5G and AI to solve the challenges that our scientific missions face?

Cybersecurity

5G wireless technology is expected to provide enhanced cellular connectivity to power the exponential growth of wireless devices through faster data rates, lower latency, and higher device density compared with LTE/4G that is widely deployed now. Because a large number of applications – including the Industrial Internet of Things, connected vehicles, connected health, and augmented reality – will be enabled by 5G capabilities, a clear understanding of the security impacts associated with these capabilities is necessary in order to secure 5G use for work conducted by the DOE Office of Science.

This area on 5G cybersecurity will focus on (a) end-to-end security improvement introduced by 5G for the CIA triad of information security – confidentiality, integrity, and availability; (b) new security challenges that 5G brings along with its functional improvements; (c) current research that addresses the new security challenges as well as future needs; (d) operating in “zero trust” environments; (e) high-assurance communication with possible disruptions such as loss in network synchronization; and (f) use of machine learning and artificial intelligence, including convolutional neural networks to ensure secure 5G applications.

This technical focus area will also explore augmented reality as a 5G use case, including its possible use in security-related training and other relevant work in the DOE Office of Science.

Critical infrastructure

Numerous articles have stated the implications for 5G with respect to the nation’s critical infrastructure, which includes power generation, water treatment, roads, bridges, and other related municipal infrastructure. The 5G implications for infrastructure typically revolve around the high-bandwidth, low-latency benefits associated with multifrequency 5G implementations. Also meriting consideration are numerous applications such as 5G providing the communications fabric for wide adoption into the nation's infrastructure system of Internet of Things (IoT) sensors. The possibility of such a 5G fabric serving as the communications infrastructure that can allow connectivity of considerably more IoT (and related) devices – up to 1 million per square kilometer – means powerful increases in network processing but also significantly more network endpoints. A high density of 5G radio access points also provides the means for higher-resolution tracking – and therefore for asset management – of devices than current radio technologies.

These critical infrastructure topics will be explored in this technical focus area.

Extreme Environments
Emerging 5G technologies offer significant potential for dense sensor networks with unprecedented low latency and high data transfer rates to enable real-time monitoring and automated maintenance for a more reliable, resilient, and robust energy infrastructure. However, relevant environments for energy applications often involve high temperatures, high pressures, challenging chemical conditions, and potentially even radiation such that traditional instrumentation suffers severe challenges and may not be suitable. Examples of such extreme environments include fossil- and nuclear-based power generation systems as well as subsurface and undersea conditions relevant for carbon sequestration, unconventional oil and gas, offshore oil and gas, and geothermal resources. This technical focus area will explore opportunities for targeted fundamental research to enable extreme-environment 5G sensor instrumentation and robotics such as the following:

- Metrology and design of materials with unique high-frequency electromagnetic properties under extreme environments
- Device physics at 5G frequencies under high temperature and harsh environment conditions
- Extreme-environment-compatible antenna designs for 5G frequency ranges
- Electromagnetic radiation propagation and telemetry within confined metallic structures for energy system monitoring under extreme environmental conditions

Scientific User Facilities
The Science User Facilities for 5G group will identify key opportunities and challenges for future 5G integration with scientific user facility and other Office of Science funded research instrumentation, control, diagnostics and automation. The group will engage users of these facilities, the scientific community, and facility managers to investigate and highlight how 5G can accomplish the following:

- Improve and increase the deployment of user facility instrumentation in the environment, such as NEON and ARM
- Improve the control and monitoring of remote and/or dense network of instruments/systems.

- Decrease the latency in diagnostics and repair of remote and/or dense networks of instruments/systems
- Increase automation for remote and/or dense networks of instruments/systems
- Improve flexibility of sensors/instruments/systems within user facilities
- Increase the use of simulation tools

Edge Computing

Traditionally, data from sensors, scientific instruments, and large DOE experimental facilities is transported over computer networks to a centralized data repository for subsequent analysis. For many scientific questions, however, either the instrument produces too much data to be efficiently transported to a remote location for processing or a local latency-sensitive control system must act shortly after the data is available, enabling the sensing instrument to adapt to detected events and conditions. By moving the computation to the point of origin, scientific instruments can also become more autonomous, with the computing done *i*n situ. Over the past few years, advanced sensor systems and autonomous experimental systems have shifted to include accelerated computing platforms "at the edge," where the data is generated. One of the enabling technologies for this shift to edge computing has been the advancements in artificial intelligence and machine learning. In the DOE community, a large number of science and engineering use cases need edge computing and advances in AI in order to imbue sensors with real-time adaptive, autonomous capabilities. 5G technologies can support these new usage modalities. This technical focus area will explore how 5G can enable edge computing for DOE science applications and will identify the gaps and barriers to adoption, the research challenges, and the opportunities for scientific discovery. We expect the 5G community and the DOE science community to have the following areas of mutual interest:

- What is the programming model for the edge? Can we develop in a standard environment and deploy across a wide range of infrastructure within a 5G network?
- How will resources be managed at the edge? Computing and networking are often scarce resources for scientific instruments. What is the notion of "edge resource management, including prioritization and goal-based optimization" for 5G networks with embedded support for edge computing?
- How will authentication and authorization in 5G networks that support edge computing interact with the infrastructures already in place for scientific instrumentation and computing?
- What will the convergence of "customer" networking and ML-optimized hardware architectures for edge computing and 5G networks look like?

Distributed Instruments

5G technology has the potential to change the way DOE facilities use data gathered from their experimental facilities. In the past, instrumentation systems have required vast amounts of infrastructure to support power, connectivity, isolation, and supporting staff and software to reliably support experimental and operational objectives. Even when deployed, these large systems have had substantial maintenance and power requirements and do not always measure as much data as desired. The use of smaller, distributed measurements tools throughout DOE research facilities could provide a means to increase the breadth of data gathering activities as well as deploy new sensors to areas of interest quickly. This technical focus area involves the use of distributed instruments as a means to further instrument existing experiments and decentralize data acquisition and control. Questions to be explored include the following:

- Will 5G technology lead to reduced instrumentation infrastructure requirements? If so, can it reduce our physical footprint and impact to areas that we perform research?
- Will 5G technology lower the cost of doing research? Will reduced complexity expedite our ability to react more quickly to research opportunities?
- Will using 5G technology reduce our power consumption at our research sites?
- Does the reduced size and infrastructure requirements of 5G enabled equipment allow for more dense instrumentation of our experiments? What are the limits of the technology in this space?

New Science Exploration Paradigms

The 5G-enabled convergence of IoT/edge devices, software, cloud computing, AI/ML, and other emerging technologies is creating a rich computational fabric in which 5G is the essential thread holding the fabric together. This new computational fabric will enable the creation of new scientific tools; provide new ways of integrating knowledge; and lower the cost and time of exploration, learning, and innovation. The New Science Explorations Paradigms group will investigate how scientific exploration, learning, and innovation can and will change the software and hardware architectures needed to support these changes. As a part of this investigation the group will engage the experimental design, AI/ML, information technology, and modeling communities as well as the DOE laboratory science community to address issues such as the following:

- The current paradigm is that WiFi provides stationary wireless communication and cellular (4G …) provides mobile wireless communication. Breaking this paradigm will require that 5G provide significant improvements over WiFi 6. How pervasive will the reach of 5G be? How extensive and capable will the proposed private/local 5G (or 5g/WiFi hybrid) networks be? Will they be able to support new scientific workflows and paradigms within a laboratory setting?
- This computational fabric will enable the development of new hybrid scientific tools that incorporate concepts such as live digital twins, cyber-physical science, and visualization as an instrument. What types of scientific instrumentation will be possible, and how will this instrumentation help drive the Science mission?
- 5G-enabled sensor networks will enable moderate-scale computing in a hybrid computing environment where edge computing and cloud computing work in tandem. This will create an interconnected intelligent edge and intelligent cloud in which computing at the edge device level enables intelligent data collection and reduction, real-time cloud-based machine learning enables a better understanding of the data collected, and cloud-based modeling enables live exploration of the data within the larger context of the question being asked. How will this capability be used in scientific exploration and provide faster, more flexible scientific workflows?

Software Architectures

The software stack plays a key role in successfully enabling the effective and efficient use of computing resources for the design, implementation, evaluation, and optimization of mission-critical applications. This is true for computational and data-centric workloads and any number of complexities introduced by the supporting infrastructure (e.g., communication networks, data storage, computer system architectural details). In general, the goal is to create a set of abstractions that enable utilizing the power of the underlying hardware architecture components and lower-level software layers, while improving the overall productivity of end-users. The related design and implementation choices have a direct and lasting impact on the ability to create agile and flexible components that assist in establishing a timely and productive scientific workflow. In addition, a growing diversity of scientific software developers has a significant impact on both the set of abstractions and the need to compose unique and tailored software components for a particular scientific instrument, unique communication capabilities such as 5G, or even a set tailored to the unique needs of a specific experiment. This workshop will focus on the design, capabilities, and flexibility of the software stack -- all of which can have a direct impact on productivity, the overall time to solution, and the rate of scientific discoveries by the DOE Office of Science community.

Data Management

The data management technical focus area will identify key opportunities and challenges for future 5G-enabled scientific data retrieval, flow, analysis, and storage capabilities. The group will engage the scientific networking, experimental design, 5G R&D, and data management communities to characterize fundamental technology and infrastructure issues of mutual interest, such as the following:

- How will science workflows involving 5G-enabled sensor networks adapt their data management methods across distributed compute (edge and HPC) as well as new network capabilities such as caching and stream processing and deal with the tremendous growth in amounts, types, and schema complexity of data gathered?
- What convergence of network and compute capabilities will make it possible to meet expected demands for scientific data reliability as well as coupled services demands for performance and responsiveness? For example, as 5G enables ever closer coupling between scientific sensor and instrument control systems, how will models for data management capabilities (transport, storage, processing) adapt?
- How will scientific data pipelines leverage the physical and logical topology flexibilities offered by 5G, distributed compute “cloud” and software-defined neteworking technology? How will these topologies address inflexible features such as national computing center allocations and priorities, data storage and access limitations, and funding-use constraints?
- How will data management techniques need to be architected so they can integrate with distributed, federated machine learning approaches?
- Where will the bottlenecks arise for scientific data management, and how will users manage the dependencies between scientific experiment requirements and multipurpose 5G network infrastructure priorities?