PAWR Project Office

Platforms for Advanced Wireless Research (PAWR):
Seeking Teams to design, deploy, and operate advanced wireless research platforms

REQUEST FOR PROPOSALS (RFP)

Key Dates:

Proposers' Day (attendance encouraged, but not required)
April 27, 2017
Hyatt Centric Arlington, VA Please register here: https://goo.gl/forms/tRzheVwF1zpGnAT22

Expression of Intent to Submit proposal (optional)
May 8, 2017
Please submit your team's intent to submit: http://bit.ly/Intenttosubmitproposal

Preliminary Proposal (required)
June 1, 2017
6pm Eastern Time

Full Proposal (required)
July 31, 2017
6pm Eastern Time

Finalists announced
No later than October 2017
Site visits to be completed by the end of 2017
Winner(s) announced during the first quarter of 2018

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IMPORTANT INFORMATION

Any proposal submitted in response to this RFP should be submitted in accordance with the PAWR Project Office (PPO) proposal guidelines outlined in the Supplementary Documents and Information section on Page 16 of this RFP Reference Guide.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title

Platforms for Advanced Wireless Research (PAWR): Seeking teams to design, deploy, and operate advanced wireless research platforms.

Synopsis of Program

The PAWR program aims to enable experimental wireless communications research across devices, communication techniques, networks, systems, and services conceived by the U.S. academic and industrial wireless research community and deployed in partnership with local communities. PAWR seeks to accelerate the Nation's wireless innovation ecosystem, thereby enhancing broadband connectivity, enabling the emerging Internet of Things (IoT), and next-generation cellular xG standards, as well as sustaining US leadership and economic competitiveness for decades to come. Each research platform conceived under the PAWR program will enable at-scale experimentation by supporting the geographic size, technical diversity, and user density representative of a small city/community.

The National Science Foundation's (NSF) Directorate for Computer and Information Science and Engineering (CISE) has established the PAWR Project Office (see http://advancedwireless.org/) to support the design, deployment, and operations of the research platforms. Working closely with the NSF and the wireless research community, the PPO has assumed responsibility for overseeing the design, deployment, and operations of a set of research platforms. Subject to

the availability of funds/contributions, the PPO will ultimately be soliciting proposals for up to four, at-scale platforms for advanced wireless research to be funded by $50 million in cash from NSF and approximately $50 million of in-kind and cash contributions from a PAWR Industry Consortium, for a total of approximately $100 million across all four platforms over seven years. This RFP is requesting proposals to award up to two of the four platforms envisioned in this first solicitation.

PPO Contacts

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Award Information

Anticipated Type of Award: Subaward Agreement

Estimated Number of Awards: Up to 2

Anticipated Funding Amount: Approximately $20,000,000 of in cash and in-kind contributions per platform over five years, subject to the availability of funds/contributions.

ELIGIBILITY INFORMATION

Who May Submit Proposals?

Proposals may only be submitted by the following:

Universities and Colleges

Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the U.S. acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.

Non-profit, non-academic organizations

Local governments, community-owned utilities, research labs, foundations, economic development organizations, research and startup incubators, professional societies and similar organizations in the U.S. associated with economic development, educational or research activities.

Academic institutions and non-profit organizations such as local governments are strongly encouraged to form teams to respond to this RFP to adequately achieve the goals of the PAWR program. Teams comprised of both academic institutions and local non-profit/municipal leadership will be considered the strongest and most sustainable teams. For-profit organizations that are not members of the PAWR Industry Consortium may also participate on

proposing teams, but may not submit or lead proposal teams.

Limit on Number of Proposals per Organization: 1

An organization may participate as a lead proposer in no more than one proposal submitted to this RFP, but may be listed as a subawardee in additional proposals. For collaborative proposals involving multiple institutions, the proposal should be submitted by only one institution, with funding for participating institutions made through subawards or subcontracts. *Proposals should not be submitted as separately submitted collaborative proposals.*

Who May Serve as Project Director and/or Principal Investigator (PI)?

Project Directors/Principal Investigators may be affiliated with universities/colleges or with non-profit, non-academic organizations as defined above.

Participation in any project by investigators from federal agencies beyond NSF and/or non-NSF-funded FFRDCs may be via a letter of participation indicating that those organizations will provide, at no cost, the services and research as indicated in the proposal.

Alternatively, Federal agencies beyond NSF and non-NSF-funded FFRDCs can participate as subawardees, provided that those organizations include in the proposal a letter from the responsible agency confirming that agency's financial support of the agency's or FFRDC's participation should the project be funded by the PPO.

An individual who is PI on one proposal may not participate in this role on any other proposal, but may participate in other proposals in another role, such as "senior personnel." **These eligibility constraints will be strictly enforced in order to treat everyone fairly and consistently**. In the event that an individual exceeds this limit, proposals received within the limit will be accepted based on earliest date and time of proposal submission. **No exceptions will be made.**

Additional Institutional Eligibility Information:

For U.S. universities and two- and four-year colleges with overseas campuses, this RFP restricts eligibility to research activities using the facilities, equipment, and other resources of the campus(es) located in the U.S. only.

INTRODUCTION

Wireless communication networks and applications have evolved to become a vital part of the Nation's economic growth and productivity. The number of smartphones, connected tablets, and wearable devices in use across the US today has doubled over the last decade. The burgeoning Internet of Things (IoT) and emerging next-generation broadband mobile wireless technologies are expected to add several billions of connected devices worldwide within the next 5 years. Devices will also continue to consume increasing amounts of data. To support this unparalleled growth in devices and traffic, ubiquitous wireless connectivity at speeds covering the range from megabits per second (Mbit/s) to gigabits per second (Gbit/s), improvements in coverage, reliability, and latency will be required.

In past generations of wireless technologies (e.g., 3G, 4G, WiFi), NSF-funded academic research in the US laid the foundations for the underlying technology [e.g., Code Division Multiple Access (CDMA) and Multiple Input Multiple Output (MIMO)]. Continuing this trend of research investments, NSF has in recent years supported fundamental research in Massive MIMO, full-duplex wireless, millimeter-wave networks, dynamic spectrum sharing, network virtualization, emergent wireless network architectures, software-defined and cognitive radios, wideband antennas, and dynamic tunable filters—all of which have been touted as critical components of the emerging standards in wireless technologies for both local- and wide-area networks.

Research in these topics has offered promising preliminary results in theory, simulations, and lab-scale prototypes of very small numbers of advanced wireless nodes. However, due to a lack of appropriately-sized resources available to the academic research community, it has been challenging to test these preliminary results at scale.

To meet this challenge, NSF, through the PAWR Project Office and in collaboration with the more than 25-member PAWR Industry Consortium, has formed a public-private partnership (i.e., the PAWR program) to support creation of four at-scale experimental platforms for advancing fundamental wireless research. These research platforms will enable pursuit of new research challenges, enhance education about wireless technologies and data networking, further academic-industry cooperative partnerships, and spur greater technology transfer from academia to industry, thereby maintaining US leadership in developing the next round of technological innovations. Importantly, these platforms for wireless research will further the capacity of the academic research community to help envision and shape next-generation wireless communication networks and services beyond '5G'.

The goal of the PAWR program is to support cutting-edge, multi-disciplinary experimental research on core wireless topics including, *but not limited to*: new physical layer and networking protocols, new antenna designs, software-defined radio transceivers, programmable radios, resource-sharing algorithms, spectrum sharing, cloud-enabled radio access networks, use of millimeter-wave spectrum bands for mobile applications, wireless network security, network planning, heterogeneous network architectures, end-to-end network quality of service (QoS), spectrum policy enforcement, end-user application performance, and spectrum data analytics and adaptability.

This effort will be accelerated by the fact that, in the last year, the United States has become the first country in the world to make vast quantities of both sub-6GHz and millimeter wave spectrum available for both licensed and unlicensed use. These newly available spectrum bands, in combination with other spectrum already available, promise to enable higher data rates and increased capacity in future wireless networks.

In the long term, these at-scale research platforms will collectively serve as a powerful research and development infrastructure that will support innovation in next-generation technologies broadly, giving rise to Smart & Connected Communities (S&CC) research and innovations of the future. Indeed, the proposed research platforms will benefit a multitude of research and education communities that are supported by ongoing NSF research programs (such as Networking Technology and Systems, Communications and Information Foundations, Communications, Circuits & Sensing-Systems, Computer Systems Research, Cyber-Physical

Systems, Secure and Trustworthy Cyberspace, and Smart and Connected Health, to name a few). Each research platform will be made available as a community resource in such a way that its operations can be sustained well beyond the platform deployment phase.

The success of the PAWR program ultimately rests on collaboration among three important stakeholders within the information technology innovation ecosystem: **university researchers, private sector companies, and local communities**. Participating university researchers will benefit by: gaining access to open, at-scale research platforms; receiving industry input earlier in the research process; and speeding up the transfer rate of disruptive ideas from university research to end users. Participating companies will benefit by: helping to sustain US industry leadership and economic competitiveness in wireless communications for the next decade and beyond; shaping the design of the research platforms; and securing cutting-edge research returns well in excess of initial investment. Participating local communities will benefit by: building core wireless capabilities through creative university partnerships; attracting government and corporate research funding and local wireless jobs; and utilizing advanced wireless capabilities to enhance community services and economic development.

PROGRAM DESCRIPTION

The PAWR program is a joint effort by NSF and a wireless Industry Consortium comprising over 25 companies and industry associations to create at-scale research platforms (i.e., at the scale of entire small cities/communities) to accelerate fundamental research on wireless communication and networking technologies. The PPO is managing this anticipated $100 million public-private partnership to stand up and oversee these eventual research platforms. The PPO is run jointly by US Ignite, Inc., and Northeastern University.

The PPO will work closely with NSF, the wireless research community, local communities, and industry in the design, deployment, and operations of the research platforms. PAWR will enable experimental exploration of robust new wireless devices, communication techniques, networks, systems, and services that will revolutionize the Nation's wireless ecosystem, thereby enhancing broadband connectivity, enabling the emerging Internet of Things (IoT) and next-generation cellular xG standards, as well as sustaining US leadership and economic competitiveness for decades to come.

The PPO, in conjunction with NSF and the PAWR Industry Consortium, has developed this Request for Proposals (RFP) that calls for teams of communities and research universities to propose the design, deployment, and operations of up to two platforms for advanced wireless research across the country. The PPO anticipates re-issuing the RFP annually on an as-needed basis and subject to the availability of funds/contributions to reflect the nature of the contributions from the PAWR Industry Consortium and planned investment by NSF.

The PPO will provide advice and share best practices on design, development, and overall project management with the winning platform(s). Once the platforms are up and running, the PPO will be responsible for providing common, centralized services and best-practice policies (e.g., related to financial management, sustainability, safety, data security, and researcher outreach) to avoid duplication across the platforms, including assistance in allocating and managing time for experimentation on the platforms. In addition, the PPO will design tools and

services to make the system easier to use. An initial set of services will be designed as part of a PPO shared services model. The PPO envisions designing and developing a single interoperable framework with well-defined APIs to manage services common across the platforms. The four PAWR platforms will then determine, in partnership with the PPO, where the implementation work for the services framework is most easily performed. In general, each platform will implement its unique service functions and will be capable of supporting experiments. Each platform will also consist of shared services plus some number of prototype and production services that it will control.

The PPO envisions that the resultant PPO services suite could be built using: existing testbed services, new services, or a federation of some or all of the above. The goal is to make the platforms accessible to the broadest set of researchers, industry and community members. Hence, the PPO will design services to support different types of experiments/users:

- Beginners as well as expert wireless researchers;
- Industry as well as Academic researchers;
- Wireless research experiments as well as services leveraging the new PAWR-enabled wireless system.

See the "Other Information" link at http://advancedwireless.org/rfp for a more detailed description of these services.

Research time on each platform will be allocated equally between industry and NSF-supported academic researchers; the two allocations should complement each other: allocations to NSF-supported researchers will advance fundamental knowledge in the long term, while allocations to industry researchers may seek to accelerate nearer-term research and development activities.

PAWR constitutes an unprecedented opportunity to create and grow an evidence-driven community of wireless networking experimenters with a shared culture and high standards, starting from undergraduate and graduate students in the field. For this to happen, the PPO seeks platforms that are aligned with and support the following principles:

- **Reproducibility.** Platforms must be set up, maintained, and documented to guarantee the highest scientific standards in terms of accuracy and reproducibility of the experiments.
- **Usability.** Too often research platforms that are in principle "open" require a learning curve and very specialized expertise that make them practically inaccessible to a vast portion of the research community. The guiding criteria of this effort will be the principle that, through well-defined interfaces, the platforms should be usable by any individual in the advanced stages of working towards a bachelor's degree in a technical or scientific subject. More advanced functionalities that require sophisticated reconfiguration or reprogramming of the platforms will be available to advanced users. For PAWR to fulfill the promise of becoming a nationwide, shared, innovation lab, the PPO will ensure that each city-/community-scale PAWR platform is designed, tested, and documented to guarantee true usability, predictability, repeatability, and statistical significance of the experiments.

- **Interoperability.** It is crucial to overcome the natural tendency of networking platforms to become isolated from the rest of the research ecosystem. The ability to use PAWR resources by leveraging existing management frameworks to extend experiments and federate a larger base of researchers is important. PAWR platforms will have to be based on well-defined management interfaces to ensure interoperability among the new city-/community-scale platforms, as well as interoperability with other NSF-funded large-scale platforms, including others created in this program.
- **Programmability.** Platforms should be programmable at multiple levels (e.g., radio, resource allocation, backbone) with clearly defined interfaces and APIs.
- **Open Access.** All platforms must be accessible by the research community at large, with true fairness in opportunities for researchers throughout the Nation. Data generated should be, whenever possible, made available to the community for comparison and further experimentation.
- **Diversity.** The combination of all PAWR platforms must cover a broad range of topics in wireless networking, including (but not limited to) dynamic wireless spectrum use, millimeter wave, network architecture, wide-area wireless backhaul, and network measurements.
- **Sustainability.** Equally as important, it is expected that collaboration among proposing teams of university researchers, local non-profit or municipal organizations, and/or local for-profit companies (i.e., not including members in the PAWR Industry Consortium) or proposing teams composed of non-profit organizations only will help to leverage NSF and Industry Consortium investments and enhance sustainability. For example, a community that facilitates low-cost access to wireless infrastructure such as low-cost real estate and backhaul while streamlining permitting processes will enable additional funds for the purchase of advanced wireless equipment as well as time for deployment and operation of the corresponding platforms.

PAWR Platform Design Elements

The advanced wireless research platforms should support a diverse community of researchers across the country, in both academia and industry, in the wireless communication and networking space. Winning platforms are free to focus on just one wireless technology area, but could be flexible enough to support multiple research areas, including but not limited to examples such as the following:

- Spectrum sensing and sharing, as well as spectrum measurements;
- Dynamic and shared spectrum experimentation;
- New and evolving communications architectures such as Software-defined Networking (SDN), Network Function Virtualization (NFV), Computing at the Edge architectures, Cloud-based Radio Access Networking (C-RAN);
- Higher bandwidth and lower latency schemes;
- Wireless network security and privacy;
- Interworking among cellular, WiFi, 802.X and emerging IoT, mmWave technologies;
- Mobile wireless infrastructure; and
- Network and user performance measurement, monitoring, and analytics.

The PPO envisions PAWR sites as the fundamental physical instantiation of wireless substrate, local computation, connectivity, and storage resources within the platform. These sites will be used for a wide variety of research experiments, including serving as programmable UE (User Equipment) radios, monitoring stations, base stations, local edge clouds and wireless backhaul all connected to central aggregation clouds. Each proposal should describe how at least 10-20 sites will be deployed over the initial five-year period-of-performance, in multiple locations, with at least 4 radio sites and 2 local cloud computation sites operational by 12 months after award and the complete build out including all sites and local cloud implementations operational by the third year of the award date.

Each radio site might consist of multiple base stations, suitable for virtualization, with high-speed fiber or wireless access to significant "sliceable" computation and storage, plus SDN-enabled switches to link them together in arbitrary topologies. It is desirable for a few sites to host white-box, radio functional components that are suitable for extensibility, re-configurability and programmability to support innovations primarily focusing on software reconfiguration of the radio/networking functionalities. Certain sites may also be proposed to support black-box radio systems that coexist within the platform for application development agnostic to radio layer. The early sites should be modular in development and tested, then expanded over fixed intervals of time throughout the deployment area at topologically significant points in the overall network with specific attention to dedicated connectivity with campus, community, and regional networks. The platforms are envisioned as end-to-end systems encompassing multiple radio-access technologies to support reproducible research and real-life application scenarios at scale. Proposers should use their creativity in deciding the technologies used in the radio unit, local cloud and access network. Proposers are free to decide whether all radio sites are fully populated end-to-end systems, or whether some sites will act as aggregation clouds, with all such decisions clearly documented and explained (see Appendix 1 for additional examples).

In their platform design description, proposers should demonstrate overall community commitment and the level of community facilities, resources and services made available for the project, including but not limited to campus or community IT support, fiber backhaul and power provided to the sites and expedited permitting for site deployment. Specifically, such support from each city/community/university's Chief Technology Officer (CTO), Chief Information Officer (CIO) or equivalent leader, as well as from researchers, corporate and community leaders should be explicitly documented via letters of support as described in the Supplementary Documents and Information section of this RFP. As part of their full proposal, proposers should also submit information about specific frequencies of operation available around the radio sites by consulting the FCC Program Experimental license website (see Appendix 2).

At-scale experimentation within the PAWR program is not just about the infrastructure: it requires users and usage scenarios as well. Proposed platforms should be designed to support a critical density of users complementing the focused research area. As an illustration, a spectrum-sharing research platform might require a small pool of users across a large geographical area whereas a low powered IoT radio platform might require a large pool of users in a building. Proposers are encouraged to articulate how user participation will be encouraged

on their platform. Institutional Review Board (IRB) considerations are paramount for any experimentation involving human subjects to safeguard personal identifiable information (PII) for experiments collecting radio-level or network-level data and making them available. A PAWR platform must permit researchers from other institutions to perform research on the PAWR infrastructure. Therefore, external researchers can agree to defer to a single IRB's assessment of the project by each countersigning an IRB Authorization Agreement (IAA) with the lead IRB at the institution hosting the PAWR infrastructure. This only applies for research exclusively using PAWR infrastructure (a guiding template can be found here: http://www.hhs.gov/ohrp/assurances/forms/irbauthagree.html).

Individual researchers will have to obtain approval from the researcher's Institutional Review Board (IRB) if the experiment is using resources other than just PAWR-provided infrastructure. Similarly, IP and licensing terms and conditions can be found in the "Other Information" link at http://advancedwireless.org/rfp.

It is expected that the technologies deployed on the platforms will enable creation of novel applications and distributed systems and demonstrate how such application areas and services are expected to benefit citizens in the community and overall economic development. Each proposed PAWR platform is asked to identify broad application areas in which it plans to focus. These PAWR research efforts have the potential to accelerate the deployment of a new generation of ultra-low latency, high-capacity networks that will enable breakthrough applications for consumers, smart cities/communities, and the Internet of Things. The next decade may bring specific applications such as the following:

- Mobile phones and tablets that can download full length HD movies in less than 5 seconds, 100 times faster than 4G (6 minutes), and ultimately exceed the capabilities of upcoming 5G capabilities.
- First responders and emergency room doctors who get live, real-time video and sensor data from police vehicles, ambulances, and drones, along with patient vitals and medical records—all before the patient arrives at the hospital door.
- Semi- or fully-autonomous vehicles that can communicate with the outside world and with each other to improve travel efficiency and safety.
- Factories equipped with always-connected smart manufacturing equipment that self-diagnose and repair themselves before they break.
- Gigabit-speed wireless broadband available in businesses, public transportation stations, stadiums, campuses, schools, malls, parks, and other public spaces.
- Virtual reality meetings in virtual spaces; training environments and simulators that allow entry-level workers to develop and demonstrate skills in high-demand fields like solar energy installation—anytime, from anywhere.
- Massive-scale sensor networks with very low-power consumption and cost, autonomous, remote deployment and operation, supporting use cases such as environmental and security monitoring, asset tracking, and agriculture.

PAWR Deployment Elements

Proposers will be required to develop a detailed deployment project plan as part of an overall

platform development plan or "PDP" that will clearly lay out timelines and costs associated with:

- Location and site plans and costs;
- Permitting, licensing, and other permissions necessary for deployment;
- Partners/vendors responsible for deployment, keeping in mind any federal or local requirements for open bidding and competition; and,
- Any risks and contingencies that might delay or alter the PDP in any way.

This deployment project plan must include detailed dates, resources needed, partners secured, and tasks associated with the deployment of the platforms. As previously stated, the PAWR program has been designed to produce coordination among three major groups of stakeholders: academic researchers, local non-profits and municipal governments, and industry partners. The ability and commitment of local partners to the deployment of a platform, and their willingness to lower costs or speed up deployment, will be considered when evaluating the feasibility and sustainability of a platform proposal. Proposers are encouraged to optimize end-to-end value by identifying available resources, facilities and services such as backhaul and site rentals at the time of the submission of the full proposal. The deployment project plan will not be required for preliminary proposals, but must be submitted as part of the full proposal.

The PPO, in consultation with the proposers, will incorporate in-kind contributions from the PAWR Industry Consortium, after potential finalists are selected based on the review process. For planning purposes, proposers should note that these contributions include equipment and services needed to deploy and operate a platform for advanced wireless research, such as: equipment at the radio site, at edge sites (e.g., IP aggregation equipment), at the core, supporting network testing, end-user devices, as well as engineering design services, cloud services, and deployment cost offsets at the radio site, edge, and network core (e.g., backhaul, site rental on a community-by-community basis). *However, during proposal preparation, proposers should not feel constrained to use only this set of equipment and services from the Consortium.* (See Appendix 3 for additional information on the types of contributions from the Industry Consortium.)

In addition, the PPO team expects to hold a technical negotiation with platform finalists in partnership with members of the PAWR Industry Consortium to identify feasible technology contributions, some of which may be proprietary and unknown to proposers before the final review stage.

PAWR Operations Elements

Sustainability of the platforms for the duration of the program and beyond is a critical factor in the success of the PAWR program. Thus, each platform, immediately prior to the issuance of an award, must provide a detailed Platform Operations Plan ("POP") that will outline the management and financial needs to ensure that the platform remains operational through and beyond the program duration. Such detailed POPs will not be required for preliminary proposals or full proposals, but will be required prior to award. Financial support for the operation of the platform must be included in the overall budget submitted in the platform proposal. Cash and in-kind support needed by the platform to support operations may be requested from among the NSF and industry contributions available. However, every effort should be made to secure

local corporate, municipal, or non-profit partners who can provide additional operational support that will increase the likelihood of long-term platform success. Some items that might be provided by a partner include but are not limited to:

- Dedicated Engineering or operations staff;
- Reduced or subsidized rental rates for locations and sites; and,
- Reduced or subsidized costs for utility services for network elements.

Proposers should also discuss in both their preliminary proposal and full proposal how their institutions and local community could support longer-term operation of the platform. Proposals that describe a plausible plan for sustainability (and usefulness) beyond NSF funding are strongly encouraged.

AWARD INFORMATION

Anticipated Type of Award

Subaward Agreement

Estimated number of Awards

Up to 2

Anticipated Funding Amount

Approximately $20,000,000 in cash and in-kind contributions per platform over five years for this RFP, subject to the availability of funds/contributions.

Over the next three years, additional platforms for advanced wireless research are anticipated, for a total of up to four such platforms. Subject to the availability of funds and quality of proposals received, NSF anticipates contributing $50 million in cash and the corporate members of the Industry Consortium anticipate contributing in-kind support of approximately $50 million.

PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

Proposal Preparation Instructions

Preliminary Proposal Preparation Instructions (required)

Preliminary proposals are required and must be submitted at http://advancedwireless.org/rfp. Submitters will receive feedback within 14 days indicating either **encourage** or **discourage**. An **encourage** finding generally indicates that the proposal appears to be responsive to the program guidelines and is a candidate for further development. A **discourage** finding generally indicates that the project is not responsive to this RFP, or has serious conceptual flaws that would not benefit from further development as a full proposal submission in this submission window. Submission of a Preliminary Proposal is required to be eligible to submit a Full Proposal. Preliminary proposals must be submitted, via http://advancedwireless.org/rfp, by 6 pm Eastern Time on June 1, 2017.

Required components and page limitations for the preliminary proposal are given below. Proposals with incomplete, incorrectly formatted or missing Project Description documents will be returned without review. The PPO reserves the right to request that proposers provide additional supplementary and other information documents during the review process.

The preliminary proposal should consist of two elements: Project Description and Team Qualifications. No other sections are required, nor should they be included in the preliminary proposal.

1. Project Description (8-page limit). The Project Description includes the following clearly labeled sections:
    a. Project title and lead organization's name placed at the top of each page.
    b. A concise description of the proposed platform in six sections (which correspond to the six merit review criteria): (i) **Vision and Technical Merit**, including a preliminary technical architecture design and a summary of novelty, technology topic areas, and end uses/applications (up to 2 pages); (ii) **Research Community** support and new research to be uniquely enabled by the platform (up to 2 pages); (iii) **Community Engagement**, with an emphasis on value contributed by the local community, and collaboration among university researchers, local companies, and the local community (up to 2 pages); (iv) **Alignment with the PAWR Vision** as noted (e.g., reproducibility, usability, etc.), (up to ½ page, or 350 words); and (v) **Preliminary Implementation Plan** (up to 1 page); and (vi) **Preliminary Sustainability Plan** (up to ½ page, or 350 words).
2. Team Qualifications (2-page limit per key personnel, including Project Director/PI, co-PIs, and other senior personnel, with a limit of three co-PIs/senior personnel). For the Project Director/PI, co-PIs, and other senior personnel, describe their qualifications and contributions that demonstrate relevant experience (e.g., ability to work effectively with wireless research community; experience with advanced networking infrastructure planning, deployment, and operations; effective management of large infrastructure projects; and experience working with multi-stakeholder partnerships).

Formatting Requirements

Proposal Pagination

Each proposal section should be paginated prior to upload to the electronic system.

Proposal Margin and Spacing Requirements

For all sections please use only one of the following typefaces identified below:

- Arial, Courier New, or Palatino Linotype at a font size of 11 points or larger;
- Times New Roman at a font size of 11 points or larger; or
- Computer Modern family of fonts at a font size of 11 points or larger.

No more than six lines of text within a vertical space of one inch. Margins, in all directions, must be at least an inch.

Page Formatting

Use a standard, single-column format for the text.

Full Proposal Preparation Instructions

Note: Full proposal preparation instructions are below. These instructions do not apply to the preliminary proposal stage.

Proposers must submit full proposals in response to this RFP by 6 pm Eastern Time on July 31, 2017 at http://advancedwireless.org/rfp.

A proposal title must begin with "PAWR Platform Full proposal: Your Project Name." Proposals with incomplete, incorrectly formatted or missing Project Description documents will be returned without review. The PPO reserves the right to request that proposers provide additional supplementary and other information documents during the review process. The Project Description section must not exceed 30 pages, including figures, charts, graphs, maps, photographs, and other pictorial representations. **Proposals exceeding this length will be returned without review**.

The Project Description **MUST** contain the following sections (i.e., Sections I – X) with the headings shown below. Page lengths for each section within the Project Description are suggested below, but only the 30-page total section limit will be enforced:

Section I: Platform vision (up to 3 pages)

In this section, proposers should outline the core characteristics and novelty of the proposed platform, as well as which disruptive, transformative technologies and applications will be pursued over the course of the effort. The proposed technologies and applications should represent the potential for significant acceleration of wireless technology advancement.

Section II: Platform Technical Architecture Design (up to 4 pages)

This section will describe the proposed architecture design to deliver on the platform vision, drawing on the design principles described in the PAWR Platform Design Phase of this RFP. Proposers should also review Appendix 1: PAWR Industry Consortium Architecture Examples for possible scenarios that could be accommodated within platform designs.

Section III: Description of research community support and new research to be uniquely enabled by the platform (up to 3 pages)

This section should document evidence of interest from the research community in the areas that the platform seeks to support. It should also describe how such research would be uniquely enabled by the proposed platform vision and technical architecture design.

Section IV: Description of engagement among academic researchers, industry, and the local community (up to 3 pages)

This section should describe how academic researchers, industry, and the local community will work together to achieve the vision of the PAWR program, including demonstrated evidence that links and commitments have been established among the groups. It will be particularly important to demonstrate how the local municipality is providing support for the proposed

platform, and their expectations of the platform in return. Detailed descriptions of support from these constituencies (university, industry and local community) including, but not limited to, backhaul, deployment sites, power supply, network operations support, and any steps being taken to expedite permitting and other regulatory approvals typically required to deploy wireless networks should be separately included in the **Facilities, Equipment, and Other Resources** section of the proposal.

Section V: Alignment with the PAWR vision (up to 3 pages)

The proposer should provide evidence that the platform will ensure: reproducibility of research, usability, interoperability with other platforms, programmability, open access, and diversity within the platform.

Section VI: Platform Development Plan (up to 6 pages)

The Platform Development Plan (PDP) is the document that describes activities, budget, and schedules for all design, deployment, and operations activities relating to the advanced wireless research platforms. Proposers should provide a Gantt chart identifying key milestones, major activities, deliverables, and resource assignments over the project period, and discuss the critical path from design and deployment to the operations phase of the project. The Gantt chart should be sure to include three critical elements – Platform Design, Deployment, and Operations Elements – in addition to other selected elements (e.g., documentation on research procedures for the platform). The schedule should show the sequencing of all major activities to be conducted in sufficient detail to justify and align with the proposed budget.

Note that a more detailed Platform Development Plan will be required from those finalists that proceed to the Site Visit phase of the review process (expected to be during the latter part of 2017). Finalists will be asked to provide a comprehensive, concise description of project management activities (i.e., to the level of Work Breakdown Structure Level 3), aligning these activities with the goals and milestones. They will also be asked to provide rationale for why these activities are identified; who will lead, facilitate, and participate in them (cite backgrounds, disciplines, sectors, etc., rather than specific participant names); and the methods/metrics that will be used to evaluate the platform's effectiveness in realizing them.

Section VII: Sustainability Plan (up to 2 pages)

Discuss how the platform will be sustained beyond the initial 5 years of operation, including but not limited to proposals to fund ongoing research via user fees, local company contributions, and/or community funding for economic development purposes. The proposed sustainability plan should explain key assumptions, commitments, and other factors that will ensure the platforms continued viability.

Section VIII: Risk Mitigation Plan (up to 1 page)

Discuss any risks associated with completing the PAWR platform design, deployment, and operations activities, including technical and organizational risks. Discuss lessons learned by the proposing team from past experiences, and how the project plan covering costs and schedule has been risk-adjusted.

Section IX: Management Plan, Organizational Structure, and Project Staffing (up to 3 pages)

Describe the platform's organizational and management structure. Describe the structure and processes to be used to provide effective leadership of the platform, including ensuring productive, collaborative interactions with the PPO, the PAWR Steering Council (on which each platform will have a representative), and the anticipated PAWR research community. Describe the approach to be used to identify and prioritize development activities, and the competitive process to be used in the selection of development and deployment sub-awardees and consultants.

Section X: Contributions of Key Personnel in the Past Five Years (up to 2 pages)

For the Principal Investigator, co-PIs, and other senior personnel, describe their qualifications and contributions made in the most recent five years that demonstrate (for the team, not for a single individual):

- An ability to work effectively with the US wireless research community;
- Experience with advanced networking infrastructure planning, deployment, and operations;
- Effective management of large infrastructure projects, including establishing project management control systems and usage of earned-value management methodology; and
- Experience working with multi-stakeholder partnerships (e.g., teams involving community, corporate, and university team members).

Reviewers will be asked to comment on the quality of the prior work described in this section of the proposal.

Supplementary Documents and Information (Pages in this section do not count against the 30-page limit for the Program Description above.)

***Biographical Sketch(es)* (see** https://www.nsf.gov/pubs/policydocs/pappg17_1/pappg_2.jsp#IIC2f) for description of content and format required for the full proposal phase of the PAWR program. Please limit each biographical sketch to 2 pages.

Budget and Budget Justification

Budget Form: Please see https://www.nsf.gov/pubs/policydocs/pappg17_1/pappg_2.jsp#IIC2g for cost category definitions. A Five-Year Budget Excel spreadsheet template will be made available at the time of full proposal preparation. Upload a document with one page for each year and for the cumulative total.

Budget Justification (up to 5 pages)

- The Budget Justification is narrative and must be no more than five pages.
- Each budget line item must be documented and justified in the Budget Justification as specified below.
- The proposal may request funds under any of the categories listed so long as the item and amount are considered necessary, reasonable, allocable, and allowable per 2 Code

of Federal Regulations (CFR) § 200, Subpart E. For-profit entities are subject to the cost principles contained in the Federal Acquisition Regulation, Part 31. Amounts and expenses budgeted also must be consistent with the proposing organization's policies and procedures and cost accounting practices used in accumulating and reporting costs.

Cost Sharing

Voluntary committed cost sharing is prohibited. Proposers and/or proposing partners (i.e., cities/communities, universities, and/or industry) may contribute resources to a given research platform, such as development facilities, backhaul, deployment sites, power supply, network operations support, and any capabilities needed to expedite permitting and other regulatory approvals typically required to deploy and operate wireless networks and support the broader goals outlined in this RFP for the PAWR program. These resources should not be included in the Budget or Budget Justification; instead, all such resources necessary for, and available to, a project must be clearly described in the "Facilities, Equipment and Other Resources" section of the proposal.

The Budget and Budget Justification proposed to the PPO should include the total request for funds, including the costs of all platform equipment and services to be covered by the award, and all applicable federally-negotiated indirect costs. After teams have been selected for the full proposal phase, the PPO will provide a document describing exact industry contributions and associated costs to proposers. Finalists selected for site visits will hold an in-depth technical negotiation with the PPO to secure exact details for proposed deployment and operation planning.

Once the PPO selects a PAWR proposal for possible award negotiations, the PPO and platform-proposer will work with the Industry Consortium to identify the specific equipment and services that the Consortium will contribute. Those contributions will be structured to complement the "Facilities, Equipment and Other Resources" section of the final awarded proposal.

The final awarded proposal will contain three parts:

1. Facilities, Equipment and Other Resources section specifying contributions from the proposer and/or proposing partners, along with in-kind contributions from the Industry Consortium meant to complement this section;
2. Budget for funding to be provided by NSF, including federally-negotiated indirect costs (note that voluntary committed cost-sharing is prohibited); and
3. Budget for funding to be provided by the Industry Consortium.

Facilities, Equipment and Other Resources Section (up to 10 pages)

Describe facilities and resources that are available to the proposing team to support the proposed platform, including, but not limited to, research and development facilities, backhaul, deployment sites, power supply, network operations support, and any capabilities needed to expedite permitting and other regulatory approvals typically required to deploy and operate wireless networks and support the broader goals outlined in this RFP for the PAWR program. Any community facilities, equipment, and other resources should be explicitly listed in this section.

Data Management Plan (up to 3 pages)

Proposals must include a supplementary document of no more than three pages labeled "Data Management Plan". This supplementary document should describe how the proposal will conform to the PPO Data Management Plan (see the "Other Information" link at http://advancedwireless.org/rfp) and any additional strategies for data management and research sharing. Information that should be considered includes:

1. The types of data, samples, physical collections, software, curriculum materials, and other materials to be produced in the course of the project;
2. The standards to be used for data and metadata format and content (where existing standards are absent or deemed inadequate, this should be documented along with any proposed solutions or remedies);
3. Policies for access and sharing including provisions for appropriate protection of privacy, confidentiality, security, intellectual property, or other rights or requirements;
4. Policies and provisions for re-use, re-distribution, and the production of derivatives; and
5. Plans for archiving data, samples, and other research products, and for preservation of access to them.

Proposals that include subawards are a single unified project and should include only one supplemental combined Data Management Plan, regardless of the number of subawards included.

Letters of Support (up to 2 pages each)

Documentation from each city/community/university's Chief Technology Officer (CTO), Chief Information Officer (CIO) or equivalent leader, as well as letters from researchers, corporate and community leaders must be included to document, precisely, the overall community commitment and level of community facilities, resources and services made available for the project, including but not limited to campus or community IT support, fiber backhaul and power provided to the sites and expedited permitting for site deployment. There are no limits on the number of such letters of support.

A list of Project Personnel and Partner Institutions:

Provide current, accurate information for all personnel and institutions involved in the project. Partner institutions listed should include any community or local company partners. PPO staff will use this information in the merit review process to manage conflicts of interest. The list **must** include all PIs, Co-PIs, Senior Personnel, paid/unpaid Consultants or Collaborators, Subawardees, Postdocs, and project-level advisory committee members. This list should be numbered and include (in this order) Full name, Organization(s), and Role in the project, with each item separated by a semi-colon. Each person listed should start a new numbered line. For example:

- Mary Smith; XYZ University; PI
- John Jones; University of PQR; Senior Personnel
- Jane Brown; XYZ University; Postdoc
- Bob Adams; ABC Community College; Paid Consultant

- Susan White; Welldone Institution; Unpaid Collaborator
- Tim Green; ZZZ University; Subawardee

Current and Pending Support Form

The information at http://www.northeastern.edu/research/raf/lifecycle/develop-my-proposal/nsf-specific-tools/proposal-elements-nsf/current-and-pending-support/ should be provided for each investigator and other senior personnel. This form requests information on current and pending NSF funding so that time commitments can be evaluated.

Formatting Requirements

Proposal Pagination

Each proposal section should be paginated prior to upload to the electronic system.

Proposal Margin and Spacing Requirements

For all sections, except figures, captions, tables and the Excel spreadsheet, please use only one of the following typefaces identified below:

- Arial, Courier New, or Palatino Linotype at a font size of 11 points or larger;
- Times New Roman at a font size of 11 points or larger; or
- Computer Modern family of fonts at a font size of 11 points or larger.

No more than six lines of text within a vertical space of one inch. Margins, in all directions, must be at least an inch.

Page Formatting

Use a standard, single-column format for the text.

Summary of Proposal Requirements	
Preliminary Proposal (due June 1, 2017)	**Full Proposal (due July 31, 2017)**
Project Description (up to 8 pages):	**Project Description (up to 30 pages):**
Vision and Technical Merit (up to 2 pages)	Platform vision (up to 3 pages)
Research Community (up to 2 pages)	Platform Technical Architecture Design (up to 4 pages)
Community Engagement (up to 2 pages)	Description of research community support and new research to be uniquely enabled by the platform (up to 3 pages)
Alignment with PAWR Vision (up to 1/2 page)	Description of engagement among academic researchers, industry, and the local community (up to 3 pages)
Preliminary Implementation Plan (up to 1 page)	Alignment with the PAWR vision (up to 3 pages)
Preliminary Sustainability Plan (up to 1/2 page)	Platform Development Plan (up to 6 pages)
	Sustainability Plan (up to 2 pages)
	Risk Mitigation Plan (up to 1 page)
	Management Plan, Organizational Structure,

Summary of Proposal Requirements	
	and Project Staffing (up to 3 pages)
	Contributions of Key Personnel in the Past Five Years (up to 2 pages)
Team Qualifications (2-pages per PI and co-PI/senior personnel – three co-PIs/senior personnel maximum)	**Supplemental and Other Information:**
	Biographical Sketches (up to 2 pages per individual)
	Budget Form
	Budget Justification (up to 5 pages)
	Facilities, Equipment and Other Resources Section (up to 10 pages)
	Data Management Plan (up to 3 pages)
	Letters of Support (up to 2 pages each)
	List of Project Personnel and Partner Institutions
	Current and Pending Support Form

PROPOSAL PROCESSING AND REVIEW PROCEDURES

The RFP has been written with a view to encourage deep collaborations among communities, academic institutions, local corporate partners, research nonprofits, and civic institutions such as Chambers of Commerce, startup accelerators, and innovation centers.

Merit Review Principles and Criteria

Like NSF, the PPO will rely on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing the nation's health, prosperity, and welfare. Accordingly, the PPO will conduct a fair, competitive, transparent merit review process for the selection of projects.

Merit Review Criteria

The following merit review criteria will be used by PPO staff during the Preliminary Proposal phase and by the Full Proposal Review Panels during the full proposal phase to evaluate proposals:

1. Vision and Technical Merit	• Is the research platform focused on disruptive, transformative technologies and applications instead of incremental approaches? • Is the platform design well motivated? • Do the proposers demonstrate awareness of existing academic and industry testbeds? • If so, does the platform complement such existing testbeds? • Is the platform development plan technically sound (required for Full Proposal only)?

2. Research Community	• Does the plan show commitment and evidence of capability to attract a broad and diverse group of academic and industry researchers in both the short and long term? • Is there broad research community support for the proposed platform? Who are the early users? • Will new transformative research be uniquely enabled by the proposed platform? • Does the platform balance the competing needs of short-term vs long-term research of industry and academic researchers?
3. Community Engagement	• Is there close alignment with community and other local stakeholders? • Is there a detailed plan for regular coordination with key stakeholders? • Is the PAWR deployment connected to the broader innovation and economic development organizations and plans of the proposed region? • Does the platform development plan leverage local support for deployment and operations (e.g., contributed value) – required for Full Proposal only?
4. Alignment with PAWR Vision	• Does the proposal provide convincing evidence that the proposed platform will support: 1. Reproducibility of research; 2. Usability; 3. Interoperability; 4. Programmability; 5. Open Access; and, 6. Diversity
5. Implementation plan	• Does the project team have the right expertise and experience to implement the vision as well as details of the research platform? • Does the proposing team have a track record of operating experimental testbeds that can help assess their ability to manage this project? • Does the plan follow the timeline suggested by the PPO, with sites operational as soon as possible and platform fully operational by year 3? • Is the deployment plan feasible, with clearly designed goals, timelines, and deliverables (required for Full Proposal only)?
6. Sustainability	• Are there long-term plans to evolve the platform beyond the 5 years of initial operations? • Is the operational model sound? Is it financially sustainable? How will research on the platform be funded (e.g., user fees, local financial support)?

Review and Selection Process

Once preliminary proposals have been received, the PPO staff will conduct an internal review process based on the review criteria above with the goal of securing proposals that align with the quality and goals of the PAWR program.

Once full proposals have been received, one or more review panels will be convened, based on well-established NSF merit review procedures. Reviewers will be drawn from academia,

industry, and the government sector. Reviewer names will not be released beyond the PPO. Reviewers will be assigned to each proposal based on expertise and pursuant to conflict-of-interest rules. Reviewers will provide recommendations to the PPO Project Director, who will collaborate with PPO staff to put forward site visit candidates to NSF and the Industry Consortium.

The PPO team will work with the finalists and the PAWR Industry Consortium during the site visits to identify feasible technology contributions, some of which may be proprietary and unknown to proposers before this final stage. Based on these site visits and additional technical negotiations with the finalists, up to two winning proposals will be selected and appropriate subawards of cash and in-kind contributions will be administered.

AWARD ADMINISTRATION INFORMATION

Notification of the Award

Notification of the award is made to the submitting organization by the PPO. Organizations whose proposals are declined will be advised as promptly as possible by the PPO. Verbatim copies of reviews, not including the identity of the reviewer, will be provided to the Principal Investigator.

Award Conditions for Winning Platforms

An award from the PPO consists of:

1. An award agreement, which includes any special provisions applicable to the award and any numbered amendments thereto;
2. A budget, which indicates the amounts, by categories of expenses, on which the PPO has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); this budget will need to conform to NSF standards; once approved, funding will be provided incrementally based on satisfactory completion of project plan milestones;
3. The proposal referenced in the award notice;
4. Applicable award terms and conditions; and
5. Any announcement or other PPO issuance that may be incorporated by reference in the award notice.

Special Award Conditions

The PPO, in consultation with the cognizant NSF Program Officers and the PAWR Industry Consortium, will review and approve subawards and consultants. The agreement between the PPO and the awardee will specify additional award conditions.

Reporting Requirements

The winning platform must submit on a monthly basis actual cost, schedule, and performance data consistent with the Project Plan. The Principal Investigator must submit an annual project report to the PPO via email no later than 90 days prior to the end of the current budget period. No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public posted on the PPO

website.

Failure to provide the required reports will delay PPO review and processing of any future funding increments.

The winning platform will be monitored by an independent evaluation team assigned by NSF, whose role will be to work with each platform and help it adhere to the requirements of this solicitation, provide NSF with an external independent assessment of platform activities and progress, and collect PPO-required performance data on a biannual basis. The platform is required to provide all necessary data and materials to the evaluation team in a timely fashion to enable the evaluators to fulfill their responsibilities.

The activities of the platform teams will also be monitored through quarterly interim progress reports. In lieu of a fourth-quarter report, an annual report on progress and plans will be submitted by the awardee to the appropriate PPO member. The PPO will provide the format for these reports within one month of the award date. Both quarterly and annual reports must address progress of the platform regarding the duties outlined in this solicitation.

PPO CONTACTS

General inquiries regarding this program should be made to:

- Bryan Mikesh, Project Director, PAWR Project Office, pawr@us-ignite.org
- Abhimanyu Gosain, Technical Program Director, PAWR Project Office, agosain@ece.northeastern.edu
- Tommaso Melodia, Research Director, PAWR Project Office, melodia@ece.northeastern.edu
- Kaushik Chowdhury, Academic Outreach Director, PAWR Project Office, krc@ece.northeastern.edu

For questions related to the use of the proposal submission system at http//advancedwireless.org/rfp, contact: **RFP365 Responding to an RFP Help Topics**

OTHER INFORMATION

This RFP Reference Guide and the PPO website (http://advancedwireless.org/) provide the most comprehensive source of information on the PAWR program. Please be sure to also examine supporting documents in the Appendix, including:

- Appendix 1: PAWR Industry Consortium Architecture Examples
- Appendix 2: FCC Experimental Spectrum Policies/Tools/Process
- Appendix 3: PAWR Industry Consortium In-kind Contributions

Other information can be found on the "Other Information" link at http://advancedwireless.org/rfp, including: Potential PPO Services; Data Management Plan; PPO Constituency Contributions and Benefits; Conflict of Interest Standards; IP and Licensing Guidelines; and NSF Workshop report on "Large-scale Networking Platforms Communities of Practice.".

ABOUT THE PAWR PROJECT OFFICE

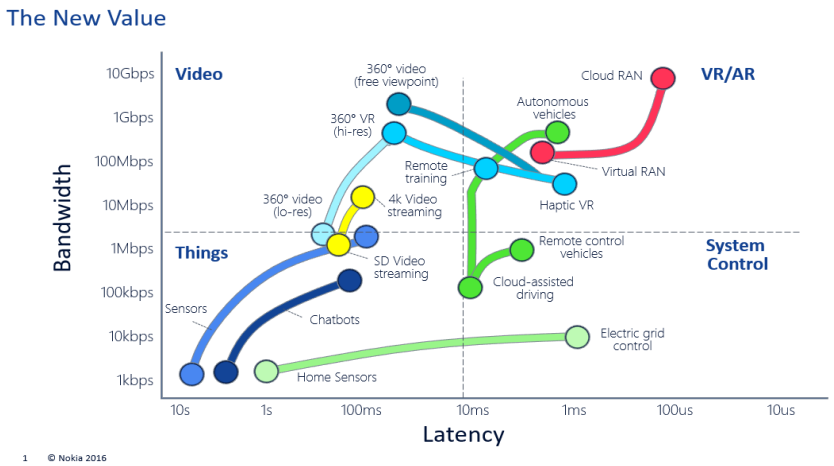
The PAWR Project Office is an independent non-profit organization led by US Ignite, Inc., and Northeastern University. Please see https://www.advancedwireless.org/ for a further description.

Appendix 1: PAWR Industry Consortium Architecture Examples

Note: *This document drafted by the PAWR Industry Consortium is designed to present examples of network architectures that may enable the types of applications and services proposed by PAWR platform teams. The architecture examples are therefore for illustrative purposes, and not meant to instruct or prescribe any part of a proposed PAWR platform solution. Rather, they represent potential foundations upon which even more creative, breakthrough architectures and applications can be developed.*

It is expected that each proposed PAWR platform will identify broad application areas in which it plans to focus. These PAWR research efforts have the potential to accelerate the deployment of a new generation of ultra-low latency, high-capacity networks that will enable breakthrough applications for consumers, smart cities/communities, and the Internet of Things that cannot even be imagined today. Exhibit 1 below outlines potential "new value" applications in the areas of video, virtual reality/augmented reality (VR/AR), "things," and systems control.

Exhibit 1



Example Architecture: Topology and Guiding Principles

The guiding principle for PAWR platforms is to provide flexibility to support the evolving needs of researchers, a variety of experiments, a large number of experiments, and the ability to re-program configurations rapidly and easily, while ensuring rigor and reproducibility of results. Radio technology will evolve rapidly, and additional or multiple frequency bands may be needed. Software will move toward the edge so CPU and memory will be available at all locations in the architecture. Cloud-based servers will allow for flexible configurations, local controllability, and ease of application integration. Networks will be designed to take advantage of software-defined networking (SDN) and network function virtualization (NFV) for agile, robust, interoperability among SDN elements.

Performance of the system (e.g., achieving low latency) will also be important, so the network edge will probably need to be located close to the radio layer. This will also provide flexibility in supporting multiple experiments by minimizing coordination across multiple PAWR platforms. Most changes for experiments will likely be needed at edge layer functionality. Computational resources and memory will be included at the radio site, edge location, and core location to support various software architectures that drive latency down.

It is essential that the network is built end-to-end for low latency and high throughput such that basic infrastructure does not impede experiments. This low-latency metric must be end-to-end, including backhaul, packet manipulation and security functions. Similar considerations also apply to the metric of end-to-end throughput. Experiments that measure and establish guidelines for these two metrics are TBD and will in general be application-specific.

Holding down network costs may be achieved by using cloud-based architectures, sharing core elements across the multiple PAWR locations, open source (non-licensed) software, contributions from Industry Consortium partners, and by creating a base layer of functionality that researchers can use.

Such shared infrastructures, with computing at less secure locations, and with diverse user communities bring special security challenges. It is essential that elements of the PAWR infrastructure are protected, communications are secured, and users authenticated. Ideally, the infrastructure should provide orchestrated, secure overlays, allowing for separation and isolation of different organizations. Prevention of DoS attacks – either malicious or just misbehaving elements–should be part of the basic security infrastructure. Furthermore, mobile-edge computing (MED) brings its own opportunities and challenges to security.

The PAWR network likely will not support legacy voice, PSTN- Circuit based services, or interconnect to those public or carrier based circuit based services. It is expected that the network will interconnect to the existing Internet and data networks with SDN switching capability and operate in a decentralized, heterogeneous fashion.

As the success of the PAWR platform depends in large part on enabling and attracting wireless researchers with easy access and validation capabilities, it is imperative that an open source data model along with a robust set of co-creation tools and APIs are made available.

A primary purpose of the PAWR initiative will be enabling research that provides breakthrough services to citizens. Therefore, measurement and data collection will play a key role. Measurement capability, measurement storage and analytic capability will be needed at each layer as described in sections below.

Radio Site Layer: The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

- **Configuration/Deployment flexibility:** PAWR sites could have physical configurations that allow for easy swapping or additions of radio technology. This may include enclosures that allow multiple radios, edge compute modules, sensors, common equipment, power, and weather protection.
- **Site locations:** Radio layer may be designed to have a variety of signal quality conditions to allow for the range of radio performance to be validated. Areas with excellent, good, poor (weak signal) and interference conditions may be created.
- **Radio Types:** Sites may choose to deploy combinations of traditional radio heads and SDR (open source and proprietary) radios.
- **Architecture:** Sites may propose a combination of programmable small cells and C-RAN, RF head ends and other emerging technologies as needed.
- **Virtual RAN:** V-RAN may be proposed to provide a Radio-as-a-Service (RaaS) fronthaul over IP service.
- **Antennas:** Radio layer may have sites with omni and directional antennas. Antennas to support multiple RF streams to support MIMO, beamforming and other interference mitigation techniques may also be made available. A single site may have directional and omni antennas as needed. Each radio will most likely be connected to a designated antenna (not combining multiple radios with one antenna).
- **Backhaul**: Radio layer may primarily have low-latency fiber connectivity, but also may have a number of sites capable of supporting wireless backhaul (for mmWave and NLOS). Microwave and/or Ethernet Backhaul may be used in places where fiber is not available, if appropriately designed. In-band wireless backhaul may also be pursued as an option for such transport, or as needed for research on self-backhaul / relay scenarios.
- **Mobile Sites:** Mobile base station sites using wireless/mmWave backhaul may also be proposed. The mobile site can also be used with Satellite/high altitude airborne platforms-based backhaul as needed. Extensions of this platform may include a higher number of mobile sites as needed to support research on ad-hoc mobile networks or connected vehicles.
- **Backhaul design** (radio site to Edge location) will be very dependent on local resources, transport providers, and available Industry Consortium Partners.
- **Measurement**: The Radio site will contain needed RF measurement/stimulus capability including but not limited to:
    - Spectrum Analysis capability;
    - Interference detection and generation;
    - Signal analysis capability;
    - If the baseband units are located at the radio site, CPRI and/or Ethernet data capture may be required;
    - If the radio site is separate from the baseband units (C-RAN), this capability may be located at the C-RAN site;

- The radio site might also need impairment generators to simulate packet/Frame loss, delay and jitter;
- All measurements should be time synchronized either with GPS or IEEE1588;
- Careful consideration must be given to the type of equipment used at radio sites. The most sensitive equipment may have stringent environmental requirements. It may be preferable to provide a protected lab environment for some types of tests;
- Consideration should be given to low cost/ruggedized sensors at radio or C-RAN sites with measurement data backhauled to either C-RAN, edge sites or the cloud for analysis; and,
- Since RF measurements may be needed at various spots other than the radio sites, thought should be given to portable or handheld spectrum analyzers.

Network Edge Site: The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

- **Edge Location:** Each PAWR platform may choose to propose an edge location to aggregate the traffic and provide low-latency capabilities. This meets performance and flexibility needs while minimizing duplicate costs (additional CPU instances and transport costs).
- **Shared Tenant Access:** The edge location may be located at "shared tenant" data centers that provide connectivity services to other networks (Internet, PSTN, local carriers, among others), as well as access or co-location with cloud service providers.
- **Host for Network Infrastructure:** Edge locations may provide network infrastructure functions, firewall and VPN functionality, equipment and experiment management, network performance tools, and application servers and hosting capability.
- **Edge-Distributed Computing Infrastructure:** The edge locations may provide computing and storage facilities for applications requiring low-latency, proximity, or specific location.
- **Transport Interface:** Transport network (Edge location to Core location connectivity) may be proposed from a number of providers at the Edge location. Various interfaces- at layer 1, 2 or 3 could be made available at the edge location to validate various technology/protocol designs. Cost minimization should be a design consideration, with flexibility built in as well through collaboration with partners.
- **Measurement:** Since most data at the edge sites will be digital (little RF measurement should be needed depending on the location of the edge site RF), Ethernet capture equipment and perhaps network impairment equipment will be sufficient. In addition, real-time, streaming telemetry will be increasingly important as more uses are found for network telemetry. Here again, open source data models and an open source ecosystem for telemetry collection may be valuable components. This also means data storage will be required along with appropriate analysis tools. All captures should be

accurately time stamped. Data storage must be provided for collecting data from element management systems. To reduce cost, consideration should be given to restricting data capture to edge sites and streaming it to the cloud for analysis.
If the Edge sites are relatively close to the radio sites, these may also be a good location for RF analysis capability, but these solutions will be determined as platform designs are completed. Finally, standardized active test measurements could be used including but not limited to TWAMP, Y.1564 and Y.1731.

User Equipment (UE): The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

The UE device radios are highly flexible, quickly tunable, and, when enhanced with modular hardware, can serve to enable a tremendous range of research experiments, of widely varying objectives, across frequency bands from 100 KHz to 60 GHz. It is also expected that the UEs will provide:

- **Deployment Flexibility:** Client devices and User UE form factor devices could be made available in stationary and/or mobile deployment scenarios to minimize barriers of use and add to the topological diversity for experiments.
- **Programmability**: UE devices may be proposed with architectures to abstract or represent the capabilities of the radio with a wide variety of (re)programmable components such as filters, RF chip, and baseband processors to investigate new paradigms for cost minimization, power requirements, and programming complexity.
- **Modularity**: UE's may be proposed with clean interfaces between digital (baseband) and analog (Radio Frequency unit). The devices should make it possible to insert special hardware for enhanced processing capabilities in the data path beyond just the RF frontend.
- **"Softwarization:"** An important tipping point in the maturity of many technologies is when their algorithms and data structures can be realized in software instead of hardware. UE devices should be flexible, versatile and future-proof with use of SDR-based or pre-commercial platform technologies

Example Architecture: Functionality

The examples provided below are for illustrative purposes, and not meant to instruct or prescribe any part of a proposed PAWR platform solution. Rather, they represent potential foundations upon which even more creative, breakthrough architectures and applications can be developed.

Radio Site Functionality: The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

- **Software Configurable Options (Open Source and Proprietary):** With the combination of Open source and Proprietary models, partners may be able to validate various software stacks, integration models, protocol/interface compatibility, technology/hardware/software integration and performance measures along with many other research areas.
- **Small Cells/C-RAN/Latency validation**: Platforms may propose to validate various latency and IP- related innovation to support various configurations on Small cells and C-RAN. With low-latency fiber connectivity, users would have the ability to run CPRI or Ethernet interface to validate various latency- sensitive applications such as timing, sync, failover, scheduler coordination, and interference mitigation.
- **Antenna Swap outs**: As sites will be built with various antenna configurations, partners may want to have the ability to swap out the antennas for the different radios that need to be tested.
- **Mobile edge compute capability (MEC):** This capability may be built into the SDR or a separate module for network functions or application layer. This would allow the research community to validate various applications such as congestion management, capacity management, traffic shaping or any other research areas as needed. Interfaces between application instances and the network would be protected by firewalls.
- **Performance Validation**: With various software configurable options and other capability built into the PAWR test site/cluster, a flexible RF layer/air interface may be made available. Single and multiband tests could be performed at the same time with the requisite UE configurations.
- **Equipment possibly available at a Radio Site such as:**
  - Software Defined Radios (SDR) per sector, omni configuration and other configurations as needed
  - Baseband controller (BBU)- Often built into the SDR
  - SDR Switches
  - Antenna- directional and omni (options with multiple ports for MIMO and beamforming)
  - Backhaul/Router: Dark fiber with termination options such as layer 1, Ethernet or others as needed.
  - Alternate Wireless backhaul: mmWave / NLOS controller and antenna
  - Security: Firewalls and IPsec VPN gateways.
  - Power
  - GPS source (or alternate clocking source/technology)
  - Cabling and brackets
  - Enclosure

Example Edge Site Functionality: The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

- **Aggregation capability**: Ability to aggregate traffic at the IP or layer 1 as needed. IP Aggregation location for PAWR radio site backhaul includes network equipment and connectivity to the provider of this local transport layer.
- **Peering**: Connectivity to other networks (internet, public data providers, carriers).
- **Physical Space:** Location for any owned network infrastructure equipment space (rack) leasing and ability to add any additional servers or equipment based on need.
- **Network Infrastructure Service-functions:** Packet routing, Security capabilities, Network Configuration management, Fault monitoring and Network management systems may be made available. The equipment at these locations usually includes Gateway routers, firewalls and VPN gateways, DNS, security, Element management systems etc. The equipment supports both IPv6 and legacy IPv4 transport.
- **Network resource-experiment management:** VLAN – network slice configuration, access control, policy definitions
- **Cloud Provider Services:** Application and storage services for applications, including analytics, third party, network performance, mobile edge compute functions, or User applications. Note that some network infrastructure services could be cloud provided.
- **Open Mobile Edge Cloud:** The mobile edge infrastructure supports open APIs that allow virtualized local services and research applications needing low latency or local data processing to access the infrastructure and the user data. It is important that local services present the same APIs and are managed as the larger cloud services complex. This way a simple, consistent service orchestration can be applied end-to-end.
- **Network Analytics:** Predictive analytics for capacity planning, including bandwidth, MEC CPU and memory, etc., as well as security, including anomaly detection and threat identification. These types of analytics can be partitioned between the Network Edge and Core, and may be the subject of experiments to determine the most useful metrics and analytical tools.
- **Network connectivity**-Infrastructure equipment will likely be owned equipment (provided by Industry Partners) located in leased rack space. This would provide the required configuration and security control and flexibility of software deployment that leasing network services may not allow. Application servers and storage can be leased-cloud based. This design point and functionality mapping will be done at the detailed design stage.

Example User Equipment (UE) Functionality: The descriptions below reflect some, but not all, possible means of supporting fundamental research from the point of view of the Industry Consortium.

- **Ad-Hoc Operation**: UE devices support both Infrastructure mode and device-to-device (D2D) operation. D2D enables localized services and applications that leverage proximity to other UE's as well as research areas such as interference management and shared spectrum access.

- **Application Ecosystem:** UE devices provide an emerging frontier for application researchers to provide the next-generation communications that underpin new applications and application approaches. Data communication is not an end in itself, but rather an enabling technology that allows the creation of novel applications and distributed systems that are realized only through the ability of different devices to exchange information.
- **Cross-Layer Optimization**: UE devices focus the communications challenges across upper-layer networking protocols at layers 3 and above. For instance, managing spectrum use is likely to be a multi-level collaborative activity, in which higher layer protocols mediate between incompatible layer 2 clusters. The UE also enables efforts in developing energy efficient MAC layer protocols, which are easily undone by "chatty" higher layer protocols as well as emerging ideas such as directional routing protocols to support beamforming antennas.

Appendix 2: FCC Experimental Spectrum Policies/Tools

Experimentation in Radio Frequency bands is subject to Federal Communications Commission (FCC) licensing rules. PAWR will leverage the FCC Program Experimental License to allow experimentation using qualified licensed spectrum on the research platform to enable technology evaluation and development of future capabilities. PAWR will also explore, along with winning proposers, other spectrum access strategies, including via licenses owned by PAWR Industry Consortium members.

Prospective PAWR platform awardees will be required to identify the spectrum that will be available for use in the geographical area(s) of their proposed deployment during the full proposal stage. The recently issued FCC public notice https://apps.fcc.gov/edocs_public/attachmatch/DA-17-362A1.pdf outlines the guidelines for this process.

Each final proposal selected for a reverse site visit will be required to complete the location authorization process https://apps.fcc.gov/els/ProgramExpLicensePurposeOption.do to pursue an "Innovation Zone" designation. The PPO will facilitate interactions between the teams and FCC representatives and will also assist proposers with other possible spectrum strategies.

Proposers must identify compliance personnel, develop management software and logging systems, and document emergency stop enforcement procedures and escalation processes to ensure consistent operation within the FCC rules. All such information must be submitted during the reverse site visit phase of the award process. The PPO will provide the interface with the FCC, campus CIOs and local safety officials to verify compliance and license the platforms as experimental zones.

RFP respondents are also encouraged to partner with educational or commercial institutions while looking for spectrum availability (an example would be the EBS/BRS band, if available).

Appendix 3: PAWR Industry Consortium In-kind Contributions

The industry consortium is contributing the following types of equipment/resources/services for the PAWR platforms. Proposers are encouraged to keep this availability in mind without attempting to discern the quantities, technical specs, and manufacturer. When preparing a full proposal, proposers should not be constrained to only using equipment from this listing.

Infrastructure:

1. Equipment:
    - Software defined radios, Radios and small cells in certain spectrum bands
    - Antennas and supporting structures, RF cabling, Cabinets
    - Connectivity platforms for fiber optics
2. UE (user equipment):
    - Mobile devices
    - IOT sensors
    - VR systems
    - Portable 5G mobile platform
    - Engineering (pre-commercial) equipment
3. Test Equipment and Analytics:
    - Server equipment for test & analytics for mmWave, Multi-antenna array, Steerable Beamforming, radio interface techniques and anchor booster architecture
    - Test platforms for Spectrum management, Bandwidth management, Hetnet and Backhaul
    - Test platforms for wireless networks, WLAN hardware and software
    - Test, Measurement, Assurance and Optimization platforms/solutions for next generation technologies like always connected society and IoT
4. Software:
    - Software and systems for Orchestration and Authentication of highly scalable and distributed IoT networks
    - Core network software for control, analytics and network orchestration
5. Tower Space: Space on the towers to mount research equipment
6. Backhaul: On site connectivity where applicable

Services:

1. Platform (test bed) design and engineering support
2. Technical expertise on Research design, Technology, Engineering and Testing
3. Platform expertise along with design and architecture support for orchestration and authentication
4. Wireless Consulting and Test support
5. Governance: framework for technology, platform creation and test