Resilient & Intelligent NextG Systems (RINGS)

NSF

Federal Agency Partners:
DOD, NIST

Industry Partners: Apple, Ericsson, Google, IBM, Intel, Microsoft, Nokia, Qualcomm, VMware

RINGS
Resilient and Intelligent NextG Systems

NSF 21-581

National Science Foundation

Webinar Welcome

Schedule

- Welcome
- Partners Introductions
- Background
- Summary of the RINGS solicitation
- Q&A related to the RINGS solicitation

Webinar Welcome

- Margaret Martonosi – NSF Assistant Director for CISE
- Erwin Gianchandani – Senior Advisor, Office of the Director
- Gurdip Singh - Division Director, CNS

NSF Team

- Erwin Gianchandani
- Joydip Kundu
- Joyce Lee
- Graciela Narcho
- Gurdip Singh
- Thyaga Nandagopal
- Shekhar Bhansali
- Rance Cleaveland
- Alexander Sprintson, CISE/CNS
- Murat Torlak, CISE/CNS
- Mohammod Ali, ENG/ECCS
- Erik Brunvand, CISE/CNS
- Phillip A. Regalia, CISE/CCF
- Zhengdao Wang, ENG/ECCS

Partners

- Sumit Roy and Dan Massey (DoD)
- Nada Golmie (NIST)
- Ayman Naguib (Apple)
- Ali Khayrallah (Ericsson)
- Ankur Jain and David Culler (Google)
- Dinesh Verma (IBM)
- Shilpa Talwar, Christian Maciocco, Lily Yang, Nageen Himayat (Intel)
- Ranveer Chandra and Micaela Giuhat (Microsoft)
- Harish Viswanathan and Peter Vetter (Nokia- Bell-Labs)
- Rajat Prakash, Kiran Mukkavilli, Gavin Horn, and John Smee (Qualcomm);
- Meryem Simsek and Chris Ramming (VMware)

Webinar Welcome

- Next Generation (NextG) systems, broadly defined
  - Networking
  - Sensing
  - Computing systems
  - Global-scale services
  - Applications (AR/VR)
- Emphasis on
  - resiliency (through security, adaptability and/or autonomy)
    - across all layers of the networking protocol and computation stacks
    - throughput, latency, and connection density.
  - Go beyond the current research portfolio

Partner Profile - OUSD R&E

Representatives: Sumit Roy, Program Lead, Innovate Beyond 5G, 5G-to-xG Initiative
Dan Massey, Program Lead, Operate Through, 5G-to-xG Initiative

Areas of interest: All aspects of Beyond 5G networks that achieve desired performance and resiliency metrics while operating through congested/contested environments

Why are you interested in this program?

OUSD is pleased to partner in RINGS in recognition of the importance of investing significantly in basic/applied research and prototyping needed to create new beyond 5G core technology components and systems concepts for next-gen wireless networks with desired properties in support of many DoD mission-critical use cases.

What do you expect the program to achieve?

Explore the confluence of new network components and architectures to identify and address problem space identified by RINGS, and potential transition to DoD testbeds.

What resources can you make available to the projects?

Facilitate access to DoD expertise and collaboration opportunities, identify prototype evaluation and maturation pathways.

Partner Profile - National Institute of Standards and Technology

Representative: Nada Golmie, nada.golmie@nist.gov

Areas of interest: mmWave– THz channel sounding and modeling, MIMO, spectrum agility & coexistence, wireless performance and machine learning, sensing, RF & communications ML datasets

Why are you interested in this program?

Further leverage existing partnerships with industry, federal agencies, and the research community to accelerate the work of the NextG Channel Model Alliance (https://www.nist.gov/ctl/nextg-channel-model-alliance).

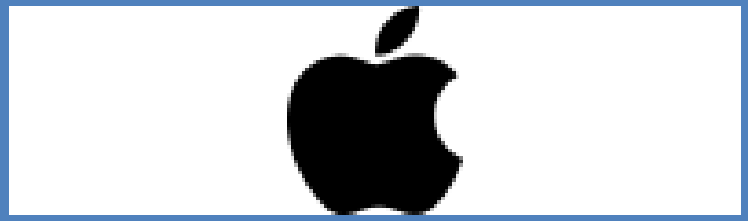
What do you expect the program to achieve?

Major advances in all aspects of next generation communication systems including RF circuits, antennas, spectrum management, network architecture, protocols and security.

What resources can you make available to the projects?

www.nist.gov/ctl/facilities in addition to measurements and datasets available here: 5gmm.nist.gov

Partner Profile – Apple Inc.



Representatives: Ayman Naguib, Wireless Technologies Research.

Areas of interest: Wireless Communications, Joint Communications and Sensing, Intelligent and Secure Spectrum Sharing, AI/DL Powered Air-Interface, Secure Communications and Computing

Why are you interested in this program?

This is a once per decade opportunity to shape the evolution of wireless communications. Participating in the RINGS program gives Apple another avenue to shape the and contribute to that evolution. We look forward to working with the awardees as well as other RINGS partners in shaping the future of wireless communications.

What do you expect the program to achieve?

We expect the program to accelerate the research and establish the foundation for the next generation of wireless networks and mobile computing platforms.

What resources can you make available to the projects?

Apple has a large R&D activity that spans all aspects of mobile computing and wireless communications and we are very interested in offering Apple's technical guidance as well as collaboration with supported projects, providing internships to involved graduate students.

Partner Profile - Ericsson

Representatives: Ali Khayrallah, Ericsson Research, Santa Clara, CA

Areas of interest: all the RINGS themes are of high interest to Ericsson

Why are you interested in this program?

We believe it is crucial to provide a long runway for research towards Next G networks. It is also necessary to foster the open environment for academia and industry to interact in meaningful ways and learn from one another. RINGS is an opportunity for both.

What do you expect the program to achieve?

We expect RINGS to lay the foundation and develop the breakthroughs that will mature into Next G technologies. We are also keen on supporting projects that truly embrace the system flavor of the program, emphasized by the solicitation structure.

What resources can you make available to the projects?

Ericsson has a large research organization with experts covering all aspects of RINGS. We are very interested in collaborating with the supported projects. We also have resources that can support experimental work, such as our D-15 labs in Santa Clara or via the NSF PAWR program which we fund.

Partner Profile - Google

Representatives: Ankur Jain, David Culler

Areas of interest: Next Generation WiFi, satellite and cellular systems. Integration of low latency cloud edge networking and network virtualization. AI/ML Analytics and Automation. Building and operating secure, reliable and zero-touch large scale networks. Support of societal priorities in education, transportation, public health and safety, defense and critical infrastructure.

Why are you interested in this program?

At Google, we have a long history of fundamental research in networking and we are proud to continue our partnership with NSF to build a diverse and inclusive workforce.

What do you expect the program to achieve?

To modernize the next gen communication networks via the cloud.

What resources can you make available to the projects?

In addition NSF support, we plan offer expertise, research collaborations, infrastructure, and in-kind support for selected researchers and students as they advance knowledge and progress in the field.

Partner Profile - IBM

Representatives: Dinesh Verma

Areas of interest: Full Stack Security, Network Intelligence, Autonomy, Scalable edge-to-cloud continuum, Merging digital/physical/virtual worlds

Why are you interested in this program?

IBM is proud to support partnership across technology companies, academic institutions and government organizations to accelerate important scientific innovation and discovery.

What do you expect the program to achieve?

Advance next generation wireless systems, unlocking new technological capabilities for powering and protecting our communications networks.

What resources can you make available to the projects?

Potential access to IBM Research staff, IBM Hybrid Cloud, AI and Data Resources, Staff Rotation options.

Partner Profile – Intel Corporation

Representatives: Shilpa Talwar, Christian Maciocco, Lily Yang, Nageen Himayat, Richard Chow

Areas of interest: Reliable computing & networking platforms across the client-edge-cloud continuum that will become essential to the way we work and live.

Why are you interested in this program?

Intel and NSF have a long-term commitment to driving network transformation. We would like to accelerate network and system research focus on 1) increasing wireless network resiliency to support critical and essential services. 2) We understand the cross-disciplinary & challenging nature of this research across compute/communications/AI & sensing. We believe academia is great place to seed 6G research and generate innovative ideas.

What do you expect the program to achieve?

Innovation in reliable networking, compute & intelligence across distributed, heterogeneous, and disaggregated resources.

What resources can you make available to the projects?

Intel's expertise in this domain spans compute, communications and AI (across hardware and software). We're glad to provide access to Intel mentors in these areas as well as access to HW/SW research resources.

Partner Profile - Microsoft

Representatives: Dan Fay, Krishna Chintalapudi

Areas of interest: Full Stack Security, Intelligent Edge/Cloud, Merging digital/physical/virtual worlds, Spectrum management, resilience, industry applications including in supply chain, agriculture, and energy

Why are you interested in this program?

Microsoft has a long history of investing in basic research especially to advance networking and wireless technologies. We see the combination of academic and industry researchers as great mechanism to advance breakthroughs in delivering the Next G networks

What do you expect the program to achieve?

Push boundaries of software in the NextG network stack, Extremely reliable, pervasive, high-speed networks, Network-driven industry disruptions

What resources can you make available to the projects?

Access to Microsoft's offering around Azure: Azure Stack Edge, Azure Private Edge Zones, Azure ML, and other resources.
Access to Microsoft researchers and engineers working on relevant problems
Connections to Microsoft partners to work on real-world problems and potentially datasets.

Partner Profile - Nokia

Representatives: Harish Viswanathan, Peter Vetter

Areas of interest: Waveforms, new transceiver technologies, AI/ML for air-interface and networking, architecture innovation, cloudified networks, joint communication and sensing, spectrum sharing, security and trust

Why are you interested in this program?

Opportunity to collaborate with a diverse research community and share insights

What do you expect the program to achieve?

Fundamental research on foundational technologies paving the way for next generation standards

What resources can you make available to the projects?

Share Bell Labs research expertise and results, proof of concept platforms

Partner Profile - Qualcomm

Representatives: Kiran Mukkavilli, Rajat Prakash, Gavin Horn, John Smee
Wireless Research & Development

Areas of interest: Wireless Communications, Intelligent and Resilient Connected Systems including Automotive, IoT Devices, and Trusted Computing Platforms

Why are you interested in this program?

We are excited to embrace challenging projects to advance technology leadership in next generation wireless and mobile communications together with government agencies, academia, and industry. RINGS strongly aligns with Qualcomm's core values to foster strong collaborations that push technology boundaries into new directions. We are focused on inventing and building transformative, foundational wireless innovations that will further advance 5G and define 6G.

What do you expect the program to achieve?

We want the program to accelerate new research for innovative concepts and approaches that further models for collaboration between industry, government agencies, and academia. We expect to see the cross pollination of interesting ideas and research output across academia, government, and industry, and an increase pool of talented graduates in both existing and upcoming technologies for the future

What resources can you make available to the projects?

Technical leadership guidance for end to end system design, including wireless, edge computing, AI/ML, and security.
Assistance accessing relevant datasets for innovating models for real world use cases

Partner Profile - VMware

Representatives: David Tennenhouse, Kaniz Mahdi, Sujata Banerjee, Chris Ramming, **Meryem Simsek**

Areas of interest: Scalable Edge-to-Cloud Continuum, Security, Intelligence & Autonomy, Merging digital/virtual/physical

Why are you interested in this program?

Explore opportunities emerging out of the confluence of networking, wireless communications, and cloud sectors

What do you expect the program to achieve?

Exciting discoveries and insights that lay the groundwork for a vibrant NextG ecosystem that drives enormous social and economic benefits

What resources can you make available to the projects?

Collaboration opportunities with VMware researchers & practitioners

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https://www.nsf.gov/pubs/2021/nsf21581/nsf21581.htm

Questions? Contact the Program Team below:

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Why NextG is a disruptor

- Transition to Machine-to-Machine Communication
- Connecting Billions of IoT devices
- New players and stakeholders
- Convergence of multiple technologies
- Software-driven, Virtualization, and Edge-Cloud-centered
  - Software at the base station radio level
- Increasing flexibility in system design (e.g., the range of spectrum frequencies)
- Many plug and play applications

Next-Gen Systems are a Game Changer

- Increasing reliance on cellular networking infrastructure
  - Anywhere – anytime – reliability, performance, service assurance is expected
  - Transportation, Industrial applications, Safety and Defense
  - Large-scale consumer use (much more than what we anticipate today)
- Enabling new applications
  - AR/VR, Video analytics

Resilience as a Primary Consideration:

- Resistance and/or high tolerance to attacks, failures and service disruptions, with rapid identification of the root causes;
- Graceful degradation of service and rapid adaptability when resource availability is impacted by disruptive events; and/or
- Resiliency in computational capabilities spread across distributed, heterogeneous, and disaggregated resources.

RINGS Award Details

- Solicitation no.: 21-581
- Proposals due: July 29, 2021

- 36 – 48 projects awarded
- Each up to $1,000,000, Up to 3 years
- The budget should be commensurate with the scope of the proposed research.
- Anticipated Funding Amount: $37,500,000 to $40,000,000

- Limit on Number of Proposals per PI or Co-PI: 2

- Participating NSF Directorates and Divisions
  - CISE: CNS and CCF
  - ENG: ECCS

Eligibility

- **Submission of proposals**
  - **Institutions of Higher Education (IHEs) only**
- **Principal Investigators**
  - **a tenured or tenure-track position, or**
  - **a primary, full-time, paid appointment in a research or teaching position**
  - **Researchers from foreign academic institutions who contribute essential expertise to the project may participate as senior personnel or collaborators but may not receive NSF support.**

Guidelines for Individuals Affiliated with Partner Companies:

- Individuals affiliated with a partner company may participate in proposals to the program subject to certain limitations and allowances:

- Such individuals may not participate in their capacity with the company.
- Such individuals may participate if they
  - (i) hold a primary appointment at another organization not partnered on the program
  - (ii) do so strictly in their capacity at that other organization.

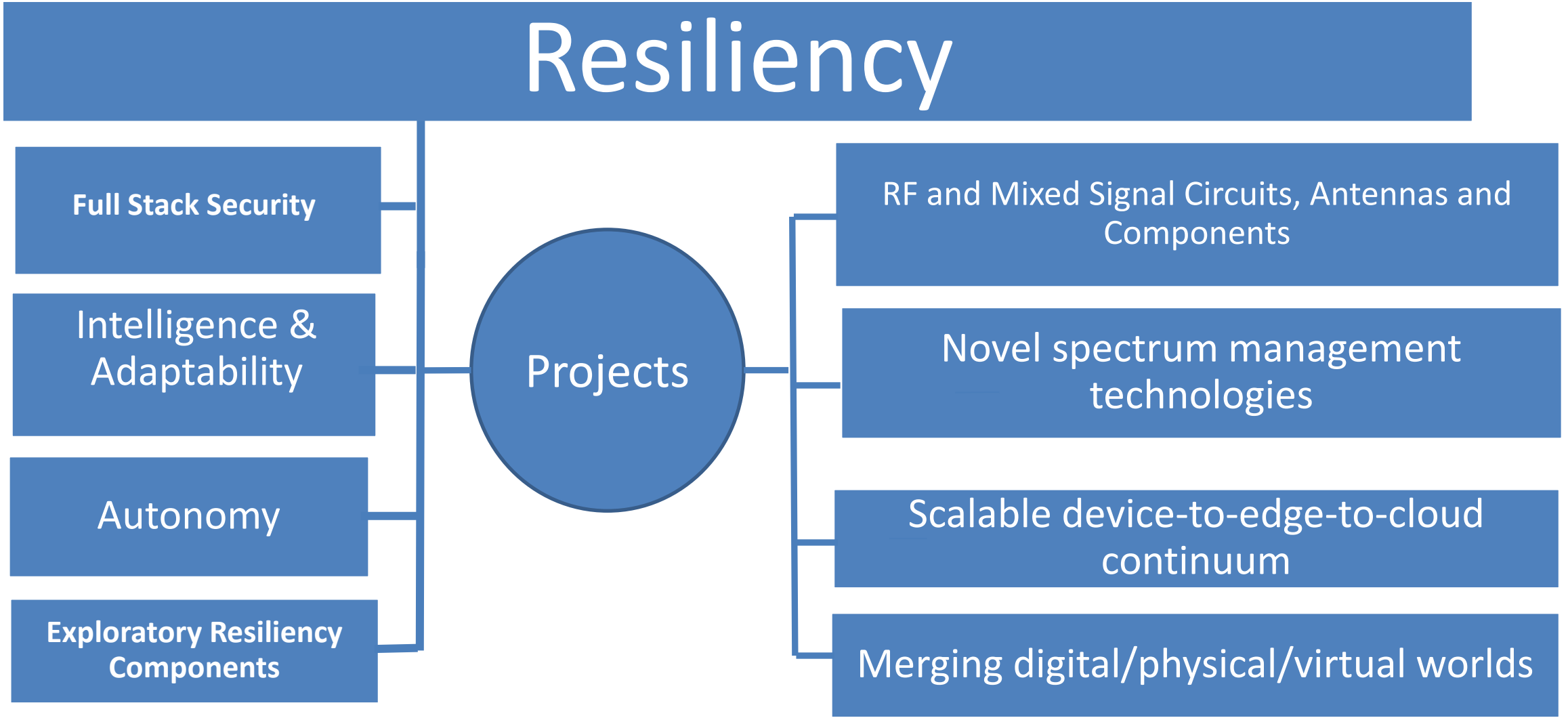
Additional Eligibility Info:

Refer to the Solicitation:

- Separately submitted collaborative proposals are not allowed.
- Support for non-lead collaborating organizations should be requested as subawards.
- Subawardee institutions are subject to the same eligibility restrictions as those noted above.

- Each proposal must include a PI and one or more co-PIs forming a team with complementary expertise.

RINGS Research Framework



RINGS Research Vectors

(pick at least one RV from each group)

Resilient Network Systems (Group A)

A.1 Full Stack Security

Advance a secure-by-design approach that enables the network designers and architects to eliminate entire categories of threats and address security requirements at the earliest stages of the design process. A secure-by-design approach can be coupled with a clean slate approach to ensure that system architects are not constrained by compatibility requirements with existing systems.

A.2 Network Intelligence & Adaptability

Robust and rapidly adaptable next generation architectures, protocols, and network system management that incorporate intelligence and agility across network system functions, components and services.

A.3 Autonomy

ability of the network to work at a highly functional level without human intervention even during disruptive events.

A4: Exploratory Resiliency Components:

New modalities that will ensure the resiliency of a NextG network system.

Enabling Technologies (Group B)

B1: RF and Mixed Signal Circuits, Antennas and Components

Fundamental innovations on the hardware and chip side (e.g., Widely tunable RF front ends; Novel RF circuits and electronics with high power-efficiency especially for millimeter-wave and beyond; Circuit and component resiliency for edge- and IoT-devices; Large-scale MIMO systems; Beamforming and multi-functional antennas; Advanced duplexing circuits and technologies)

B2: Novel spectrum management technologies:

Design of new waveforms, coding, and signal processing methods; At-scale signal processing and control for intelligent surfaces; New multi-band/multi-radio network design, leveraging disparate propagation and licensed/shared/unlicensed spectrum approaches; Advanced spectrum sensing, coordination and adaptation over short time-scales in a sustainable fashion;

B3: Scalable device-to-edge-to-cloud continuum:

Software architectures to support use of energy-efficient and heterogeneous programmable accelerators on end-devices; Software architectures to support edge-to-cloud disaggregation/virtualization; Accelerators and hardware architectures that work in conjunction with software to meet performance and resiliency requirements; Network & service interoperability / distribution / federation across the device-to-edge-to-cloud continuum.

B4: Merging digital/physical/virtual worlds

Enable advanced applications at-scale, including Augmented/Virtual/eXtended Reality (AR/VR/XR), autonomous driving, massive interactive real-time applications, advanced industrial/manufacturing and scientific user applications, and tele-health.

Solicitation-Specific Review Criteria

1. What is the potential for the project to advance impactful research in resilient NextG network systems?
2. How effectively does the proposed research ensure synergy between the Resiliency RVs (Group A) and Enabling Technology RVs (Group B)
3. Does the proposed research contain the required collaborative teaming to address resiliency challenges across the chosen enabling technologies?

Evaluation Resources: Examples

- Utilizing publicly available wireless- and cloud-related resources to evaluate or demonstrate your innovations.
- Leveraging wireless testbeds and collaborations through government labs or industry for evaluation of new technologies
- Using
  - NSF-funded platforms such as the NSFFutureCloudprojects (Chameleon Lab and CloudLab), FABRIC, and PAWR platforms
  - NIST testbeds and facilities, NIST-led NextG channel model alliance and data repository.

Cloud Computing Resources

- Consider using the cloud access entity (CloudBank) supported by NSF's (Cloud Access) program if cloud computing resources are needed.

- Check out examples of cloud computing resources: Amazon Web Services (AWS), Google Cloud Platform (GCP), IBM Cloud, and Microsoft Azure.
- Contact CloudBank (see https://www.cloudbank.org/faq) for consultation on estimating the costs for using cloud resources.

- Describe the cloud request in a Supplementary Document
- See instructions in Sections II.3 and V.A for preparing supplementary documents

RINGS : Additional Supplementary Documents

Letters of Support/Collaboration:

- Letters of support are **not** allowed.

- Letters of collaboration should follow the format specified in the PAPPG Chapter 2.C.2(j).

- Proposers must not include letters of collaboration from any of the participating organizations listed in this solicitation.

Follow guidelines in the latest Proposal and Award Policies and Procedures Guide (PAPPG):

https://www.nsf.gov/pubs/policydocs/pappg19_1/nsf19_1.pdf

RINGS Review Process

- Final selection for awards will be conducted by NSF in consultation with relevant funding partners.
- OUSD R&E and NIST program staff may act as observers in the review process.
- NSF may share with representatives of the partners the subset of proposals which are under consideration for funding by NSF, along with corresponding unattributed reviews and panel summaries.
- NSF will take into consideration the input of all funding partners in addition to feedback from the reviewers prior to making final funding decisions
- NSF retains final authority for making all award decisions.

RINGS: Budget and Funding

- Each proposal budget must include funding for a PI or co-PI and up to one other project participant to travel to and attend annual two-day PI meetings in the Washington, DC, area during the award period.

- Inclusion of voluntary committed cost sharing is prohibited.

RINGS: Program Management: PARTNER ENGAGEMENT

- Representatives may attend the annual PI meetings;
- Organization may provide software (prototypes or products), data sets, other computing infrastructure, and/or other such support to all awardees;
- Organization may separately offer to fund its own personnel as researchers to directly participate, part-time or full-time, with the funded awardees
- Optional deployment of one or more researchers will require mutual consent by the participating organization and the awardee for each award made under this program.

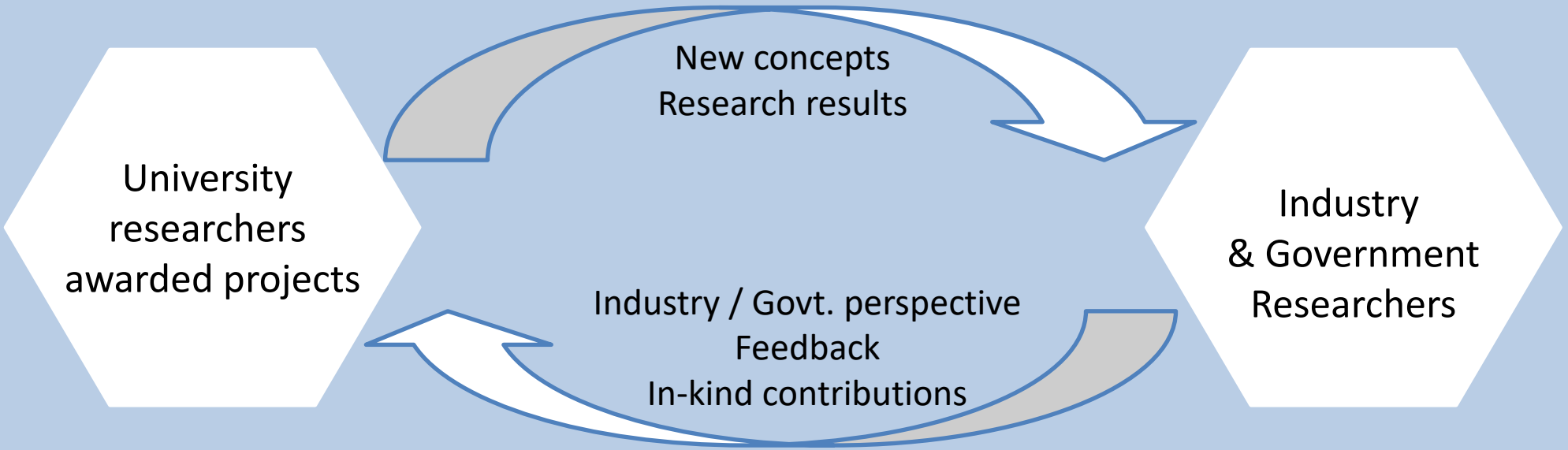
Coordination entity:

- Proposers should plan that NSF or a NSF-funded coordination entity and a virtual organization that will facilitate
  - research dissemination
  - workshops
  - collaborative engagements
- Awardees must engage with NSF and/or the coordination entity on these activities throughout the duration of the grant.

RINGS Industry Working Group (1/2)

Goal:

- Create an eminent US research community on Next Generation networks
- Enable meaningful sharing and collaboration
- Facilitate co-ordination to benefit all parties



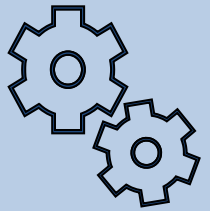
RINGS Industry Working Group (2/2)

Dissemination

- Technical RINGS Summits (1-2x /year)
  - ✓ Presentation and discussions on preliminary results for feedback
  - ✓ Industry/government talks on vision/perspective
- Webinars
- Common program site
  - ✓ Research papers and reports
  - ✓ Presentations, recordings of demos
  - ✓ Tools, data
  - ✓ Announcements

Collaboration

- Facilitate access to
  - ✓ Simulation tools, data, testbeds
  - ✓ Opensource projects
  - ✓ Industry prototypes / equipment
  - ✓ Industry experts
  - ✓ Internships / residency
- Identify
  - ✓ Voluntary collaboration
  - ✓ Clustering and teaming
  - ✓ Catalyst future projects
- Liaison with relevant industry or government initiatives



INTELLECTUAL PROPERTY:

- Awardees shall grant to the industry partners named in this solicitation a non-exclusive, worldwide, paid-up, non-transferable, royalty-free license to all intellectual property rights in any inventions or works of authorship.

- Such license shall not extend to awardees' background intellectual property;

- NSF shall neither enforce nor participate in any such negotiations between awardees and industry partners, nor will any funds provided by NSF to the awardee be contingent upon such negotiations.

- No rights or licenses are granted by the industry partners.

- Awardees may delay the publishing of data and software describing inventions to first permit the filing of patent applications. That said, NSF terms and conditions will require that awardees promptly publish all results, data, and software generated in performance of the research.

Teaming meeting

- Presented by the NeTS Virtual Organization
- Organizers: Katie Wilson and Arpit Gupta
- Will include Industry panel and lightning talks
- Tentative day – June 8
- More details at http://nets-vo.org

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- Zhengdao Wang, ENG/ECCS

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Thank you!

Questions

Webinar Q&A

Q&A

- Please enter your questions in the Q&A Box

Q&A

1. What kind of support would the partners provide? Does that include datasets, infrastructures, and evaluation testbeds?”

Q&A

- Q: I have been interacting with a NextG expert from a partner company for some time. I am wondering based on the wordings from the call, whether it would create a conflict if we mention this collaboration in the proposal. The call did mention no collaboration letters from partner.

Q&A

- Q: How do partners get involved in the proposals and/or funded projects?

Q&A

- Q: What is the role of listed partners in the call? Do we need to partner with anyone of them as part of the proposal submission?

Q&A

- Q: What is the definition of the term “work of authorship”

Q&A

- Q: Is there a particular priority between the focus areas communication, computation, sensing, and networking?

Q&A

- Q: Will the requirement to grant IP rights to industry partners prevent any open source release of software or hardware?

Q&A

- Q: Does this program require collaboration with the industry advisory board?

Q&A

- Q: Can funds be used to support participation in various community working groups, e.g., NextG Alliance, OpenWiFi, NSC, etc.?

Q&A

- Q: Do proposals need innovation in core wireless technologies, or broadly systems support for wireless systems?

Q&A

- Q: Does the scope include high-end high performance systems that could exhibit failures due to transients?

Q&A

- Q: What is the difference between this program and a regular core program in terms of requirements and expectations?

Q&A

- Q: Could you describe how this partnership came about? Why we these partners selected and not others?

Q&A

- Q: What is the TRL that the industry partners are looking for?

Q&A

- Q: To what degree will you involve application partners (i.e. in the healthcare and automotive/autonomous sectors)?

Q&A

- Q: What will make a proposal competitive?

Q&A

- Q: Is there more emphasis on theoretical foundation or practical applications and experimentation?

Q&A

- Q: Does the proposal need to be linked/applied to partners?

Q&A

- Q: Will the program have new calls later years?

Q&A

- Q: Does the fact that DoD and industry are involved in it make the review process different?

Q&A

- Q: Is there an interest in data privacy?

Q&A

- Q: Will industry partners be seeking licenses to patents aggressively, that is can we improve our odds of funding if we can produce IP?

Thank you!

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Resilient and Intelligent NextG Systems

Backup

A1: Full Stack Security

- An overarching goal of the network system is to provide end-to-end security, without which network applications cannot function in a reliable and predictable manner.
- NextG network systems will be used to enable and support essential and/or life-critical services.
- Any interruption in such services may lead to very significant societal consequences. Thus, an important goal for the NextG network systems is to achieve a drastic reduction in attack vectors compared to the current systems.
- This RV will advance a secure-by-design approach that enables the network designers and architects to eliminate entire categories of threats and address security requirements at the earliest stages of the design process.
- A secure-by-design approach can be coupled with a clean slate approach to ensure that system architects are not constrained by compatibility requirements with existing systems.

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A1: Examples of some research topics

- Composable and programmable security;
- Zero-trust security, covering design, operations and management involving untrustworthy components of the network system;
- Formal verification tools for protocol and stack implementations;
- Embedded device security & network verification architectures;
- Leveraging wireless channel and device properties to secure devices and networks;
- Multifaceted trust and configurable intrinsic security in federated and heterogeneous networks;
- Novel authentication, authorization, delegation and cryptographic mechanisms; including those that are resilient to quantum-algorithmic attacks; and/or
- End-to-end secure slice from the end devices through the RAN through the Mobile Core to services.

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A2: Network Intelligence/Adaptability

Design of robust and rapidly adaptable next generation

- architectures,
- protocols,
- network system management

that incorporate intelligence and agility across network system functions, components and services.

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A2: Examples of some research topics

- Multi-agent intelligence with distributed learning, inference & multi-agent federation, and interactive machine learning across the network, including RAN and end-devices;
- Privacy-preserving machine learning & joint design of distributed learning and networking;
- Dynamically composable networks and services configured and orchestrated on-demand;
- Rapidly identify and understand disruptive events through intelligent network forensics; and/or
- Adaptive edge networks that can maintain critical service support in the face of extreme disruption events.

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A3: Autonomy

- Focuses on the ability of the network to work at a highly functional level without human intervention even during disruptive events.

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A3: Examples of some research topics

- Zero-touch autonomous networks with data-driven communication methods and network system design;
- Seamless (and secure) orchestration for heterogeneous mobile-edge-cloud systems;
- Safe and predictable AI for networks – fair, transparent, explainable, robust and resilient to attacks;
- Rapid, autonomous adaption to reconstitute or reconfigure network functions in response to disruptive events; and/or
- Real time recovery post attack-detection to meet critical functionality and safety required within the networked system.

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A4: Exploratory Resiliency Components

- Proposers are free to suggest new modalities that will ensure the resiliency of a NextG network system beyond the three mentioned above.
- A proposer should make a compelling case for such alternatives in the proposal description.

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B1: RF and Mixed Signal Circuits, Antennas and Components:

- Resilient computing, communications, and networking operation for NextG network systems, fundamental innovations on the hardware and chip side will be required.
- Support many emerging applications spanning from MHz to THz.
  - Dynamic reconfiguration
  - Additional modalities such as operations in full duplex, low power, wide-band, and low-noise figure modes
  - Provide methods to alleviate path loss, signal blockage, and beam tracking with minimal energy consumption.
- Such innovations are needed for both high-capacity urban uses as well as for cost-efficient broadband services in under-served areas, such as rural communities.

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B1: Examples of some research topics

- Widely tunable RF front ends;
- Novel RF circuits and electronics with high power-efficiency especially for millimeter-wave and beyond;
- Circuit and component resiliency for edge- and IoT-devices;
- Large-scale MIMO systems;
- Beamforming and multi-functional antennas;
- Advanced duplexing circuits and technologies; and/or
- Novel Software Architectures for efficient processing of RF Signals.

RINGS

B2: Novel spectrum management technologies

- Waveform design;
- Source and channel coding;
- Signal processing;
- Advanced antenna technologies;
- Power-efficient spectrum sensing and negotiation protocols

B2: Examples of some research topics

- Design of new waveforms, coding, and signal processing methods;
- At-scale signal processing and control for intelligent surfaces;
- New multi-band/multi-radio network design, leveraging disparate propagation and licensed/shared/unlicensed spectrum approaches;
- Advanced spectrum sensing, coordination and adaptation over short time-scales in a sustainable fashion;
- Edge-to-cloud spectrum management systems for heterogenous networks; and/or
- Spectrum-aware systems to meet extreme performance requirements (e.g, stringent latency, reliability and localization precision in a manufacturing environment).

B3: Scalable device-to-edge-to-cloud continuum

- Edge resources provide an intermediary layer between multitude of diverse but constrained end-devices and the larger-scale cloud resources.
- Understanding how to navigate this device-to-edge-to-cloud continuum is a rich area for research, especially when resiliency, privacy, and multi-tenancy of shared and heterogeneous resources are considered.
- The network edge plays a vital role in enabling innovations in both network architectures and content-delivery services.

B3: Examples of some research topics

- Software architectures to support use of energy-efficient and heterogeneous programmable accelerators on end-devices;
- Software architectures to support edge-to-cloud disaggregation/virtualization;
- Accelerators and hardware architectures that work in conjunction with software to meet performance and resiliency requirements;
- Network & service interoperability / distribution / federation across the device-to-edge-to-cloud continuum;
- Systems that better understand data and computation placement as well as movement between tiers in the device-to-edge-to-cloud continuum to support resilient operations;
- Privacy and security of data, along with controlled data sharing and data isolation in the device-to-edge-to-cloud continuum;

B4: Merging digital/physical/virtual worlds

- There is a need to develop new integrative technology that is capable of supporting seamless deployment of such applications and meeting their stringent/unique demands.
- This will include supporting immersive interactions needed to take human augmentation to the next level, as well as developing ubiquitous, low power sensing to sustain real-time operations for long durations.
- Proposals targeting this particular RV must address the challenges faced in the network system context for such applications, and not the development of these applications in isolation.

B4: Examples of some research topics

- Characterizing the benefits of advanced communications and sensing techniques (e.g., multi-modal sensing, joint radar and communications architectures, low latency and high reliability communications);
- Networks offering AI computation and analytics services in support of advanced applications.
- Distributed authorization, privacy and provenance mechanisms for multi-agent control systems;
- Ubiquitous, low power sensing, and AI-assisted network-driven optimization of collaborative controls applications;
- Understanding temporal and computational aspects of delivering desired quality of experiences for users given limitations of the underlying communication and computation frameworks, including definition of appropriate metrics.