



An Overview of NSF's Support for NextG Research

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First IEEE Next G Summit

National Science Foundation

Advanced Wireless Research: 5G and Beyond

NSF-funded research enabling today's 5G networks:

- Three-tier CBRS spectrum sharing
- Use of mmwave spectrum for 5G
- 5G Network Architecture
- Massive MIMO Advances (Argos project)

NSF Investments in NextG

- ***\$100M annually and increasing, on average***

- <https://www.nsf.gov/cise/advancedwireless/>

- ***Foundational R&D***

- Core research, Cross-Programs (SWIFT)
- One-to-one Partnerships (e.g., DARPA, Intel, VMware)
- Multi-sector partnerships (e.g., RINGS, PAWR)

- ***Testing infrastructure***

- Platforms for Advanced Wireless Research (<https://beyond5g.org>)
- National Radio Dynamic Zone (NSF 22-579)

- ***Center-Scale Activities***

- SpectrumX: National Center for Wireless Spectrum Research
- NSF AI Institute for Future Edge Networks and Distributed Intelligence
- NSF AI Institute for Edge Computing Leveraging Next-generation Networks

Continued NSF investments for the long-term

- Next Generation research directions being explored
 - Not just 6G, but advanced Wi-Fi networks, advanced spectrum bands, wireless sensing, imaging
- Using spectrum efficiently and wisely
 - Sharing is imperative, and it can be done through novel means
 - We have explored only a few options, and there are many more to explore
 - Can unleash the power of shared public resource (spectrum) for greater public good while using it to ensure security, safety and science.



Building Blocks

- Artificial Intelligence
- Electromagnetic Spectrum
- Increased spectrum efficiency (higher data-speeds/Hz)
- Resilience and security
- Switching from hardware-heavy to software-heavy network
- Novel uses of wireless
- Non-terrestrial networks



Near Term

- Software-defined networking (SDN) ecosystems
- AI/ML for networking, spectrum sensing and access
- Enabling 6G and beyond systems (massive MIMO, mmWave)
- Mobile Edge computing
- Advanced wireless sensing, joint sensing/communication
- Free-space optical networks
- Large-scale MIMO
- Advanced duplexing
- Wireless measurements

Mid-term

- Fully programmable protocol stacks
- Ultra-low latency wireless links
- Ubiquitous wireless access
- Extremely low-power designs
- Zero-trust networking
- Meta-materials and intelligent surfaces
- “Security-by-design” and resilience
- On-demand spectrum sharing and access
- Widely tunable front ends.
- Energy efficient waveforms
- Intra-satellite communications

Long-term

- Quantum networks
- THz networking (new radio approaches)
- “Self-driving” networks
- Repeatable and verifiable research
- Holographic calls
- Tactile Internet
- Flying networks
- Metaverse



SWIFT

(ENG/CISE/
MPS/GEO)

FY'22
\$13M

SWIFT – Spectrum and Wireless Innovation enabled by Future Technologies

Three primary challenges

1. Spectrum Utilization (Efficiency, security)
2. On-Demand Spectrum Access and Resilient Coexistence
 - Resilient sharing, especially with passive users
 - Roadmap for possible adoption
3. Dark and Quiet Skies: Challenges to passive observations from spaceborne transmitters
 - Innovative satellite designs (e.g., to minimize apparent visual brightness, reduce radio footprint)
 - Ground-based mitigation techniques.



Support for the datasets

- Currently Available

- A Generic Deep Learning Dataset for Millimeter Wave and Massive MIMO Applications: www.DeepMIMO.net
- A Deep Learning Dataset Framework for Vision-Aided Wireless Communications: www.ViWi-dataset.net
- Cellular Network Information from Smartphones: <http://www.mobileinsight.net/>
- An Open Testbed for In-Phone Mobile Network Experimentation and Analytics at scale: <http://milab.cs.purdue.edu/>
- Testing video-streaming algorithms: <https://puffer.stanford.edu>
- Facility for experimenting on the future of wireless networking: <https://powderwireless.net/>
- Wireless coverage, throughput, and tower footprint map: <https://5gophers.umn.edu>
- Community Resource for Archiving Wireless Data: <https://crawdad.org/>
- RF Dataset of Radar Waveforms: <https://doi.org/10.18434/M32116>
- Radar Waveform Simulation Software: <https://doi.org/10.18434/M32229>

- Potential Future Datasets

- Massive MIMO
- SOC Operational Data: <https://researchsoc.iu.edu/services/data-for-researchers.html>
- Hacker Community Data (from exploit repositories and Deep Web Forums)
- RF physical layer and spectrum datasets using the POWDER platform
- Synthetic or remixed/replayed packet datasets
- Wireless spectrum samples from one rural and two urban locations between 54 MHz - 2.6GHz, at 20 MHz
- Wireless underground sensor network measurements from 3 years in a farm field

RFDataFactory Visit us at: <https://www.rfdatafactory.com>

- RFDataFactory is a platform for accessing and sharing RF-centric datasets, software application programming interfaces and tutorials for collecting and processing data from experimental testbeds and simulations.
- It is a community resource, welcoming of user contributions, and engagement.
- RFDataFactory is supported by the US National Science Foundation CISE Community Infrastructure (CCRI) Award #2120447.
- RFDataFactory welcomes open source contributions and thought leadership from industry partners.
 - You will hear from NVIDIA, NI, Interdigital and MITRE today!



12

Datasets



7

APIs



5

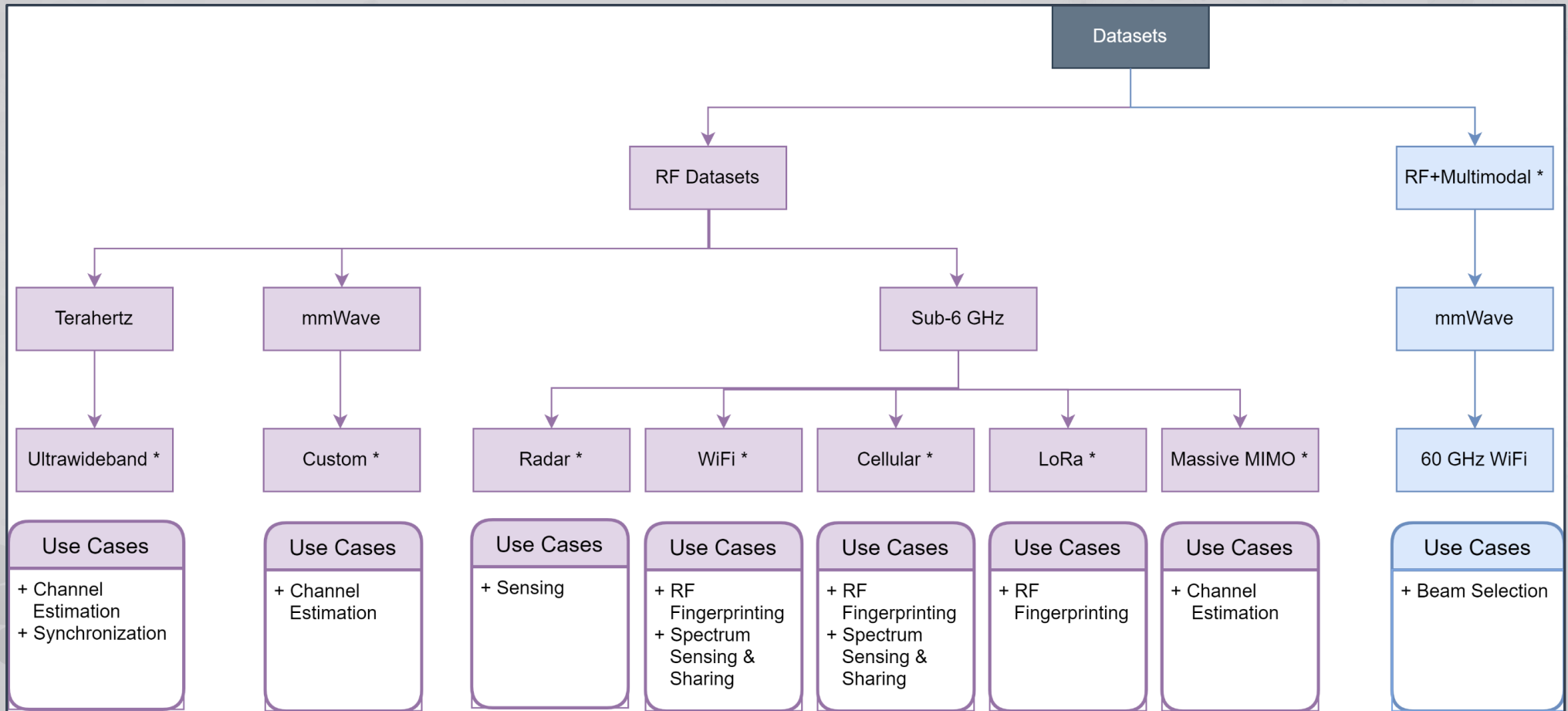
Tutorials



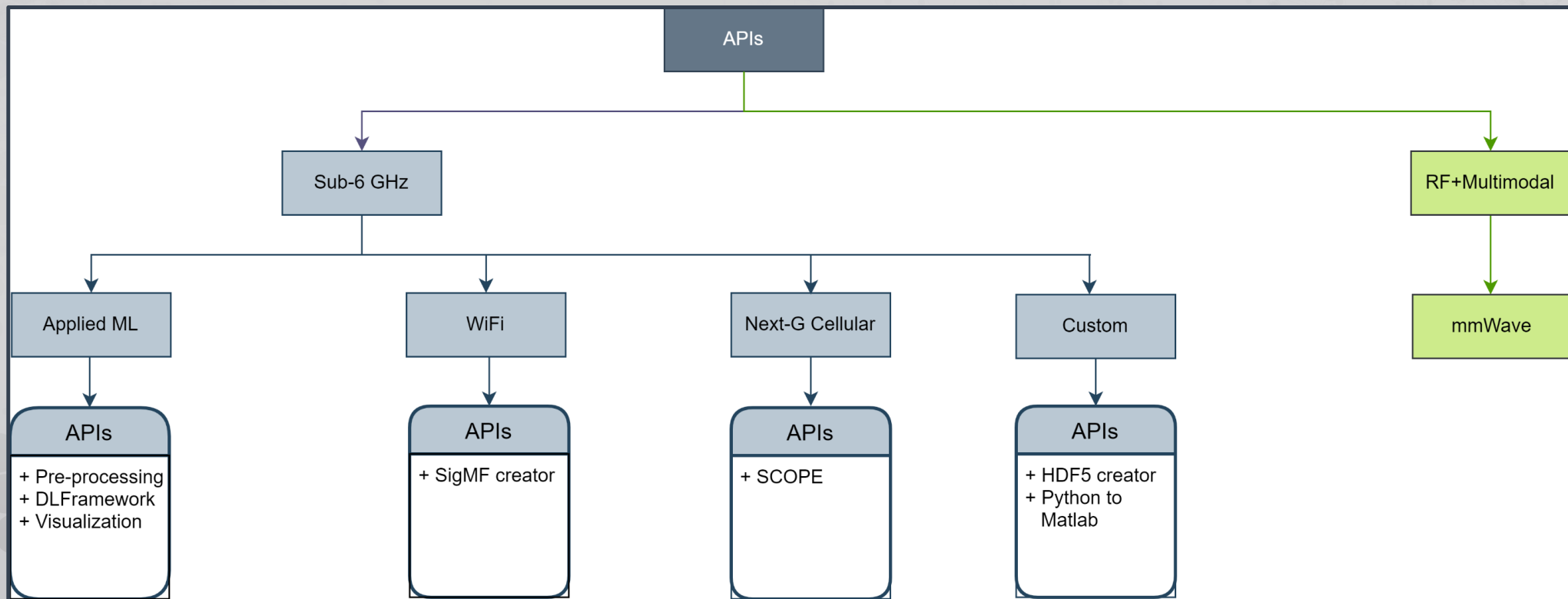
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Access Visits

What Datasets Are Available?



What APIs Are Available?



Platforms for Advanced Wireless Research (PAWR): Enabling At-scale Experimentation



POWDER

Salt Lake City, UT
Software defined
networks and massive
MIMO



COSMOS

West Harlem, NY
Millimeter wave and
backhaul research



AERPAW

Raleigh, NC
Unmanned aerial
vehicles and mobility



ARA

Ames, IA
Rural broadband

**\$100M public-private partnership with DOD, USDA NIFA, and >35 companies
accelerating beyond-5G wireless research**

AI Institute for Future Edge Networks and Distributed Intelligence

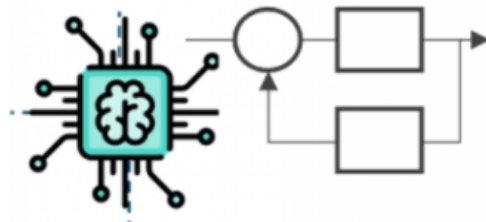
AI FOR NETWORKS

The astonishing success of AI provides a unique opportunity to design distributed intelligent efficient, self-healing, secure, and adaptive next generation edge networks. While the preliminary successes of AI for networks have been promising, developing AI/ML algorithms to networking with minimal or no human oversight poses many important research questions will be explored systematically and in depth.



Re-engineering the Physics/Constraints

Re-engineer the physical fabric for 6G+ wireless communications through AI, thus treating the fabric itself as a controllable entity.



AI Based Network Resource Allocation

Develop new AI techniques for the design and control of these next generation networks taking into account practical resource constraints.



Multi-agent Network Control

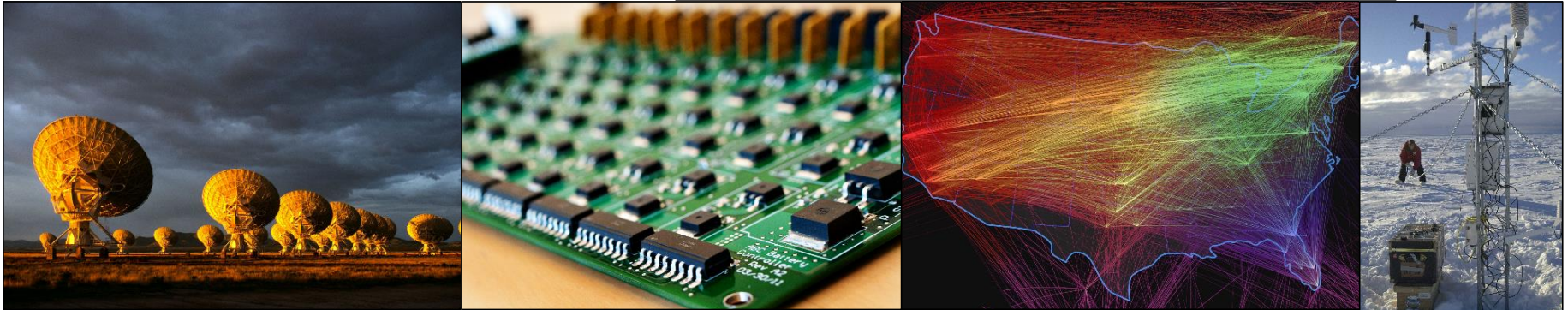
Develop multi-agent AI techniques for distributed intelligence and control across possibly non-cooperative, network entities.



AI Powered Network Security

Develop new AI tools and techniques to guarantee that the network is secure, intrusion free, and highly robust.

Spectrum Innovation Initiative (SII)



- I. National Radio Dynamic Zones
- II. National Center for Wireless Spectrum Research
- III. Spectrum Integrative Activities
- IV. Education and Workforce Development

***Includes all NSF directorates, plus FCC & NTIA via Memorandum of Agreement
Launched FY20***

\$17m/yr dedicated funding focused on spectrum



SII home page: https://nsf.gov/mps/oma/spectrum_innovation_initiative.jsp

MOA announcement: <https://docs.fcc.gov/public/attachments/DOC-369633A1.pdf>

MOA text: https://www.ntia.doc.gov/files/ntia/blogimages/sii_moa_fcc_nsf_ntia.pdf

Spectrum Innovation Initiative 4/2022 update

First U.S. National Center for Spectrum (SII-Center) kicked off 11/2021

“SpectrumX: An NSF Spectrum Innovation Center”

NSF will facilitate government interface with SpectrumX on an issue-by-issue basis

Upcoming: Center plenary in Boulder, CO (6/22), annual review (7/22)

SII National Radio Dynamic Zones (SII-NRDZ) solicitation released

\$10M FY22 solicitation; anticipated \$30M+ program investment

Goal: Advanced the use of dynamic spectrum sharing

At-scale field testing; operational deployments for facility spectrum access

e.g., radio telescopes sharing spectrum with surrounding users

First step towards a national user facility for research & experimentation on advanced wireless and spectrum management systems

Spectrum Workforce Development solicitation in process

Investigation of workforce composition and needs

Dedicated support via NSF undergrad & graduate fellowship programs

Internships and Visiting Scientist engagements with federal labs

Opportunities for Agencies

- Join interest list for SII announcements
- Attend SII-Center advisory meetings (2x/year)
- Provide 1-pager on lab opportunities for potential NSF-funded interns/visitors
- Join workforce development tiger team; other tiger teams in future
- Co-fund SII-Center, SII-NRDZ or workforce development activities of mutual interest

Email our team: esm@nsf.gov

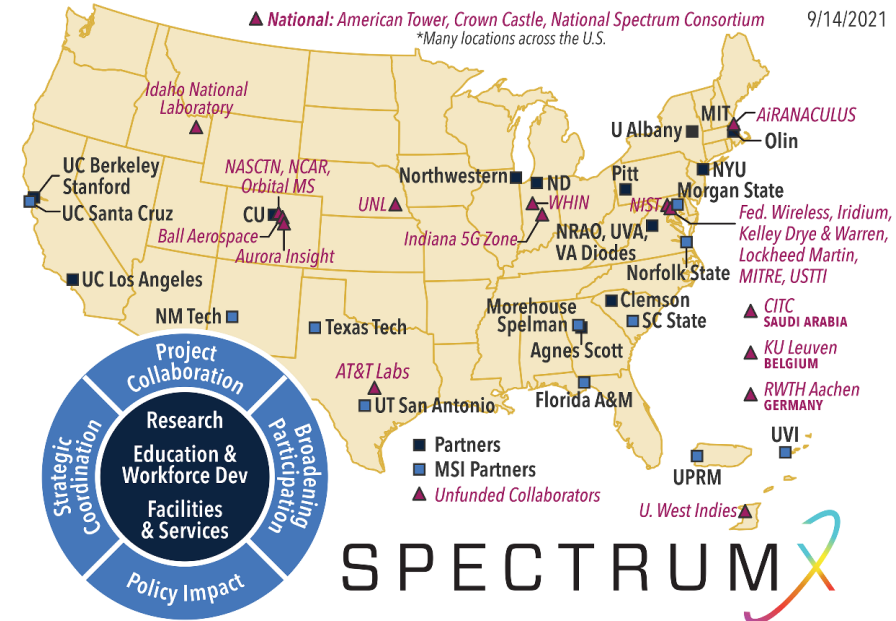
NSF PPSG rep: Linnea Avallone (lavallon@nsf.gov)

NSF IRAC rep: Jonathan Williams (jonwilli@nsf.gov)



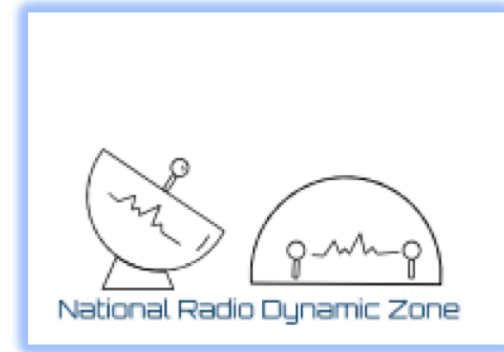
SpectrumX: An NSF Spectrum Innovation Center

- The first national center focused on the transformation of radio spectrum management
 - Research new ways to share and manage spectrum – flexible, automated, cloud-based
 - Collaboration a hub for researchers, industry, regulators, and others
 - Workforce develop the diverse workforce needed for growth
 - Maximize the benefits of the radio spectrum for society
 - A partnership on multiple levels
 - Sponsors: created jointly by NSF, NTIA, FCC
 - Participants: 27 institutions (12 minority serving)
 - grow into a hub for all stakeholders
 - Expertise: convergence across field boundaries
 - communications, passive science, sensing, radio technology, policy/economics, data science, control systems
 - Launched FY21, federal investment \$25m
-
- ▲ National: American Tower, Crown Castle, National Spectrum Consortium
*Many locations across the U.S.
- Idaho National Laboratory
- UC Berkeley
Stanford
UC Santa Cruz
- UC Los Angeles
- NM Tech
- Texas Tech
- UT San Antonio
- AT&T Labs
- UT San Antonio
- Florida A&M
- Agnes Scott
- Morehouse Spelman
- Clemson
- SC State
- Norfolk State
- Pitt
- NYU
- Morgan State
- Fed. Lock
- MITR
- UPRM
- Legend: ■ Partners ■ MSI Partners
- Strategic Innovation | Project Collaboration | Broadband Participation | Research Education & Workforce Dev

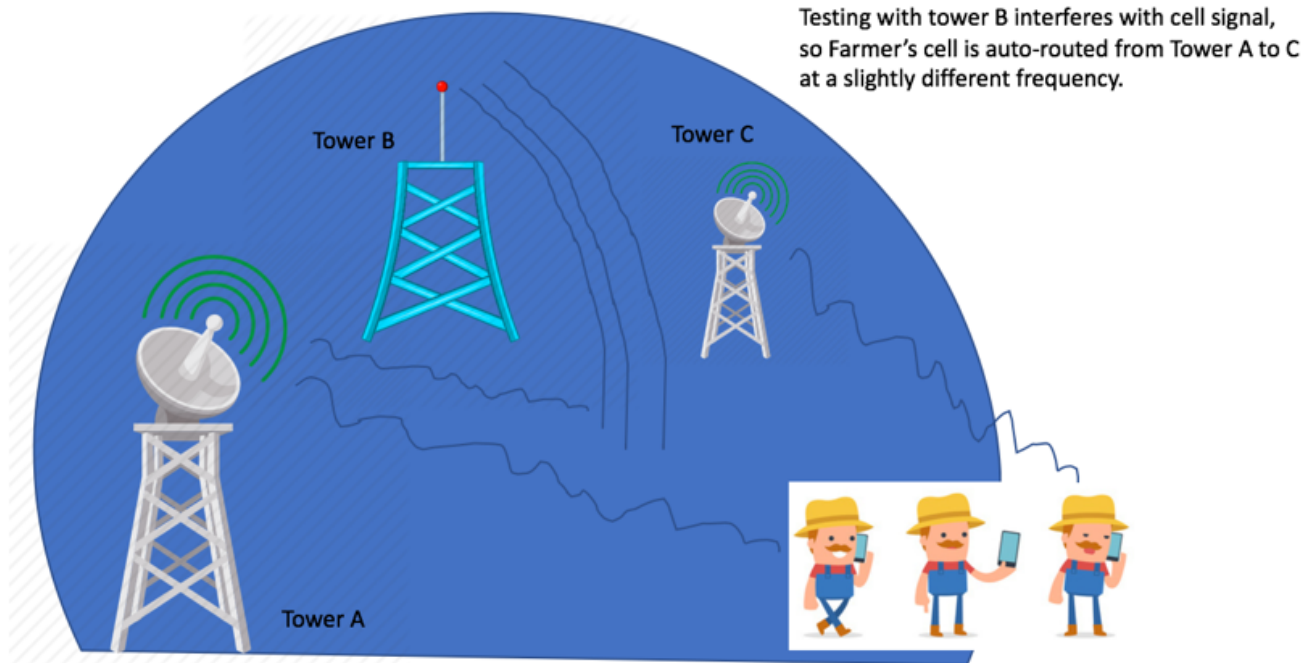


National Radio Dynamic Zones (NRDZ)

- Designate limited geographic areas to pilot innovative approaches in test beds
- RFI environmental sensing and waveform analysis (up to 115 GHz and beyond)
- Cognitive machine-to-machine frequency coordination leading to dynamic allocation and improved efficiency
- Bi-directional sharing / win-win



Expanding on NTIA/FCC's experience with CBRS to other frequencies...



Example of dynamic hopping within a National Radio Dynamic Zone Innovation Area to accommodate R&D testing with Tower B whereby cellular service is automatically routed to a different frequency that will not be impacted by Tower B's frequency.

International Collaboration

- US-Europe (ICE-T)
- US-Japan (JUNO 2)
- US- Ireland – DCL NSF 20-064
- US- Israel – DCL NSF 20-094
- US- Finland DCL NSF 21-035
- US- France (ANR) DCL 20-120
- US-Brazil
- For others, please check: <https://www.nsf.gov/od/aise/IntlCollaborations/index.jsp>

Why NextG is a disruptor

- *Transition to Machine to Machine Communication*
 - Supporting IoT
- *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*



NextG Wireless is a Game Changer

*Connecting billions of **IoT** devices*

Heterogeneous, low-cost, power-constrained, software-driven, bandwidth needs can vary depending on sensing type.

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, Metaverse, Video analytics



NextG is about:

Convergence

Wired and wireless, communications and sensing, het nets (6G, satellite, WiFi), compute and comms (mobile edge computing), software-driven communication systems

Spectrum sharing

Repurpose bands for optimal use, better sharing with trust

Resilience

Reliability, Adaptability and Security

Ultra-low latency

Enabling new novel applications

Wider broadband reach

low-cost backhaul, lowering cost of access, rural broadband

Intelligence



Resilient & Intelligent NextG Systems



- 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

RINGS Goals



- Create an eminent NextG US research community that brings together academia from awarded projects and expert researchers from sponsoring industry partners + govt. org (NIST, DoD, NSF).
- Enable communication and sharing between universities, industry and government
- Dissemination of results from awarded academic projects to co-funding industry partners.
- Industry context, recommendations and feedback on the direction of the research to improve the quality and relevance for US industry.
- Facilitate opportunities for internships and hiring
- Facilitate co-ordination to benefit all three parties (Academia, govt, industry)

RINGS program: Resilient & Intelligent NextG Systems

- \$40M effort in Phase 1
- Augments current investments in networking and computing research
- Resilience-motivated designs
- Diverse partnerships
- Ready-to-use city-scale testbeds
- Awards in early 2022



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 NextG Research Vectors

Resilient Network Systems (Group A)

Resiliency in the network as well as the associated service and computation architecture

Full Stack Security

Embedded & intrinsic Security, Multifaceted trust, Novel crypto mechanisms and Quantum-era security

Intelligence/Adaptability

Multi-Agent Intelligence systems, Privacy preserving ML, Adaptive edge networks

Autonomy

Zero-touch Autonomous networks, Safe AI for networks, Rapid & autonomous adaption

Other Resiliency Components

With justification to show how these create resilient network systems

Enabling Technologies (Group B)

Enabling components and technologies spanning from circuits to cloud

New radio approaches from MHz to THz

Waveforms, coding and signal processing, Intelligent surfaces, JCAS, large scale MIMO, and RF innovations

Spectrum utilization technologies

New multiband network design and Dynamic/adaptive coordination

Scalable Edge-to-Cloud Continuum

Software architectures, Network & service interoperability, and New dynamic/ad-hoc topologies

Merging digital/physical/virtual worlds

Interdisciplinary research for interactive human-machine applications within a specific industry vertical

RINGS: examples of spectrum capabilities investments

Resilience via pooling different spectrum bands and probabilistic guarantees (Northwestern)

https://www.nsf.gov/awardsearch/showAward?AWD_ID=2148183

Reconfigurable intelligent surfaces for wavefront control in high-reverb environments (UMD)

https://www.nsf.gov/awardsearch/showAward?AWD_ID=2148318

Secure adaptation of IoT communications, using low-power spectrum sensing (Northeastern)

https://www.nsf.gov/awardsearch/showAward?AWD_ID=2146754

Spectrum-agile tunable beamforming at mmWave for UAS air-to-air links (U. North Texas)

https://www.nsf.gov/awardsearch/showAward?AWD_ID=2148178

Thank you!

