



Picasso Panel – Thinking Beyond 5 G



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National Science Foundation

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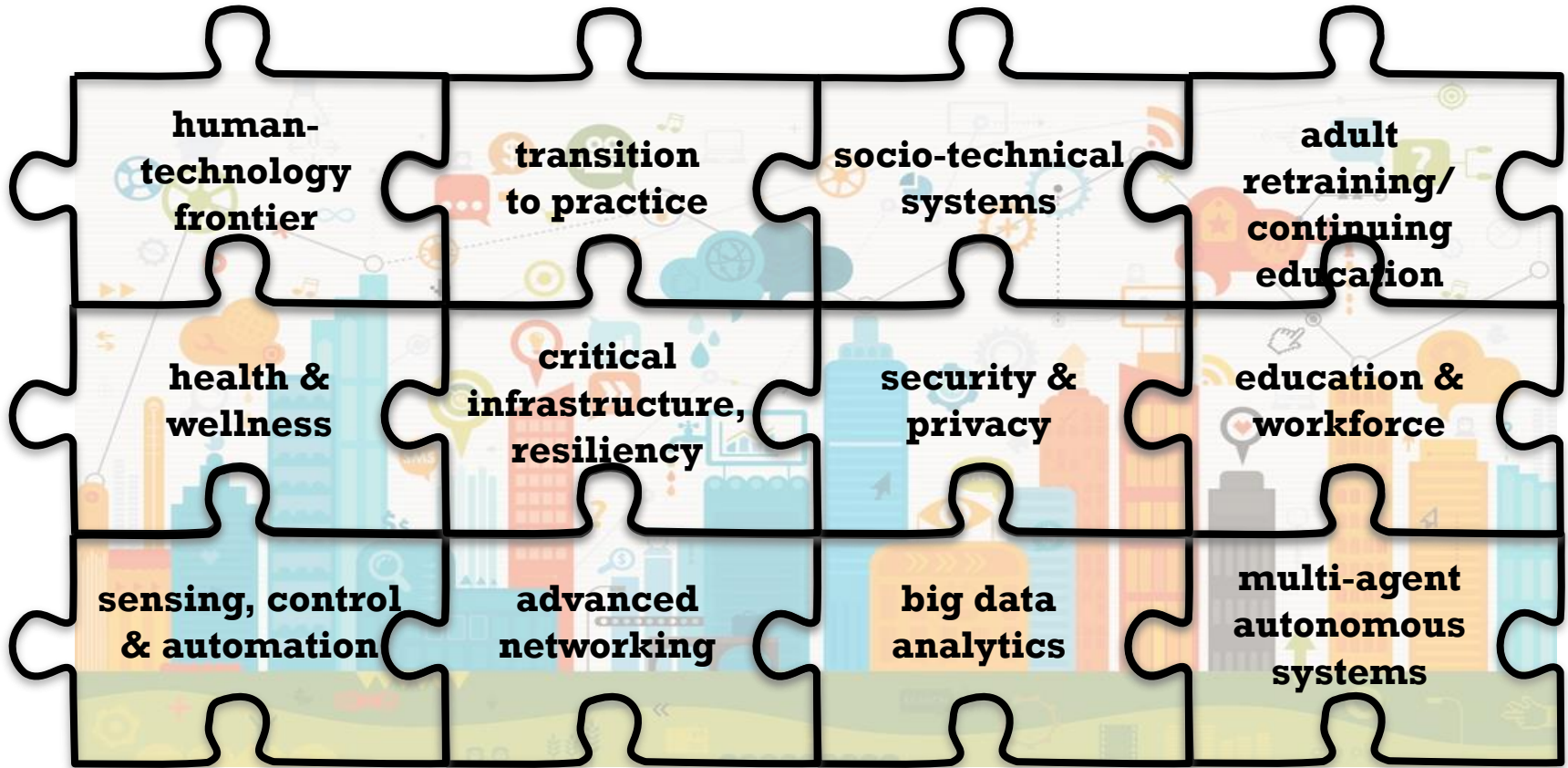


Some Motivation: Toward Smart and Connected Communities (S&CC):



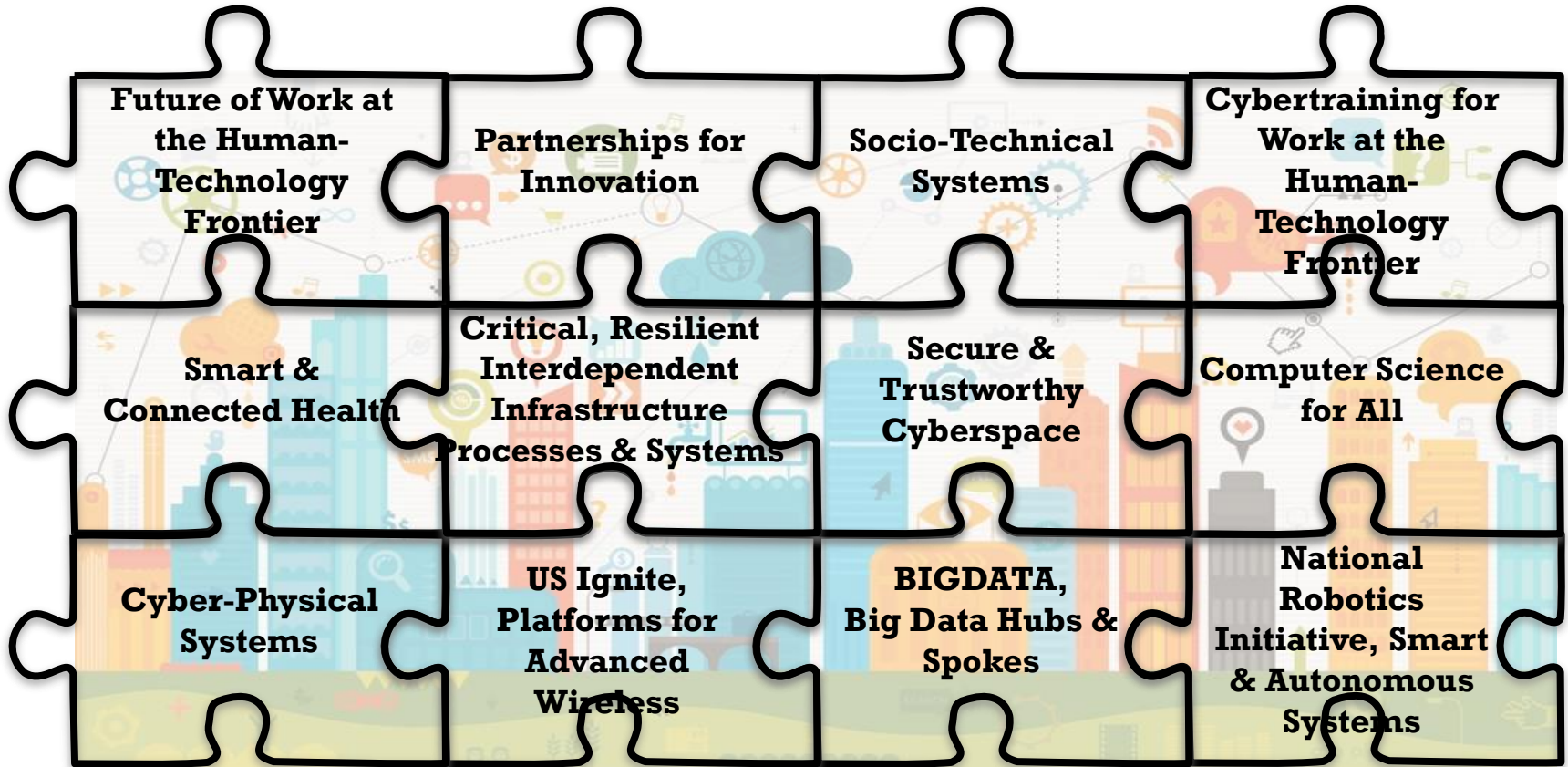


NSF is addressing current and future needs of communities...





...through investments in a range of programs



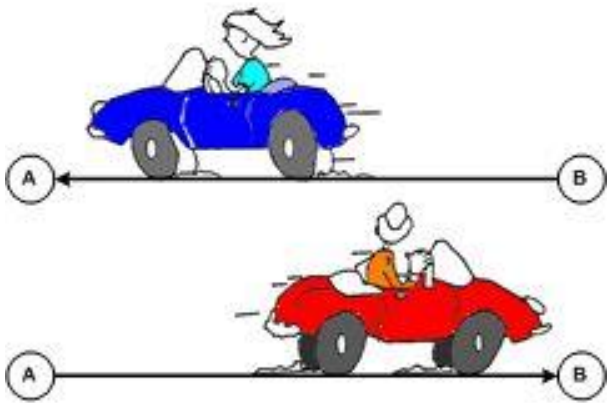


Wireless Networking at the National Science Foundation

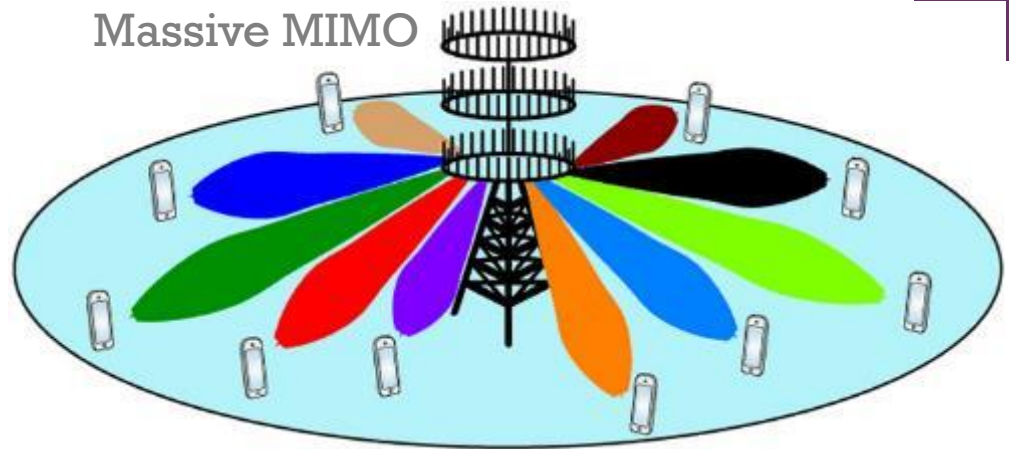
- Five distinct research programs at the NSF addressing aspects of wireless communications research
 - Theory, Circuits, Spectrum, Systems and Infrastructure
- Total research investment of over \$75M/year in 2017
- Investments fundamental to much of the work published today
- Multiple startups and tech transfers to industry

+ Theory to practice

Full-Duplex



Massive MIMO



Spectrum Sharing

+ Platforms for Advanced Wireless Research (PAWR)



PAWR Project Office

+ Fidelity and methodology issues

Toy Datasets

Measurement &
subject bias

No Null
Hypothesis testing

No blinded
experiments

Lack of support to
publish negative
results

- Hypothesize based on observations
 - Observe to conform with your hypothesis → Selective discarding of data that does not conform → Bad Science

+ Public Private Partnership

PAWR



Industry Consortium
<\$+ In-Kind=\$50M>

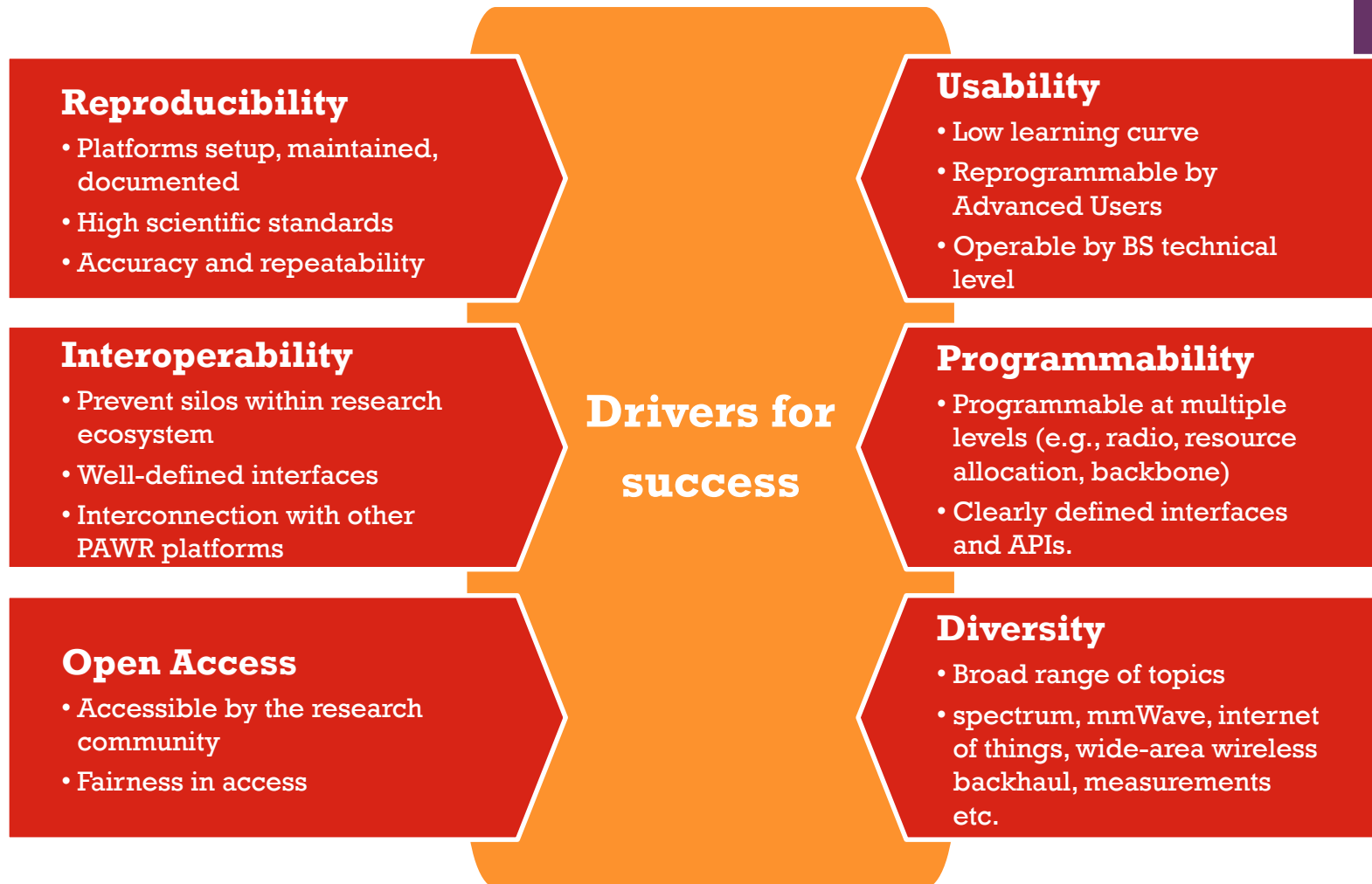
**National Science
Foundation**
<\$50M>

+ Charter Members

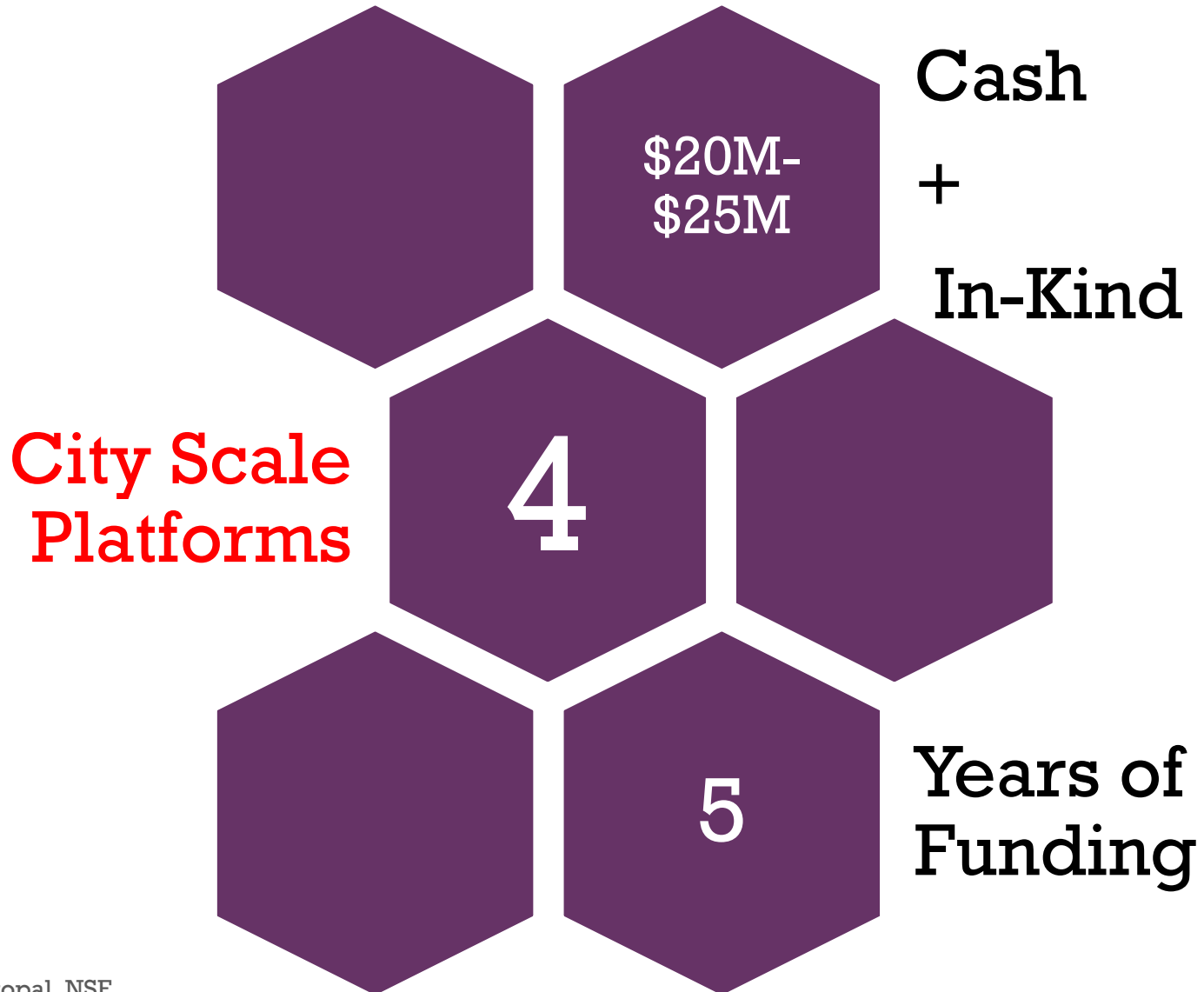


More Industry Partners are welcome....

+ PAWR Guiding Principles

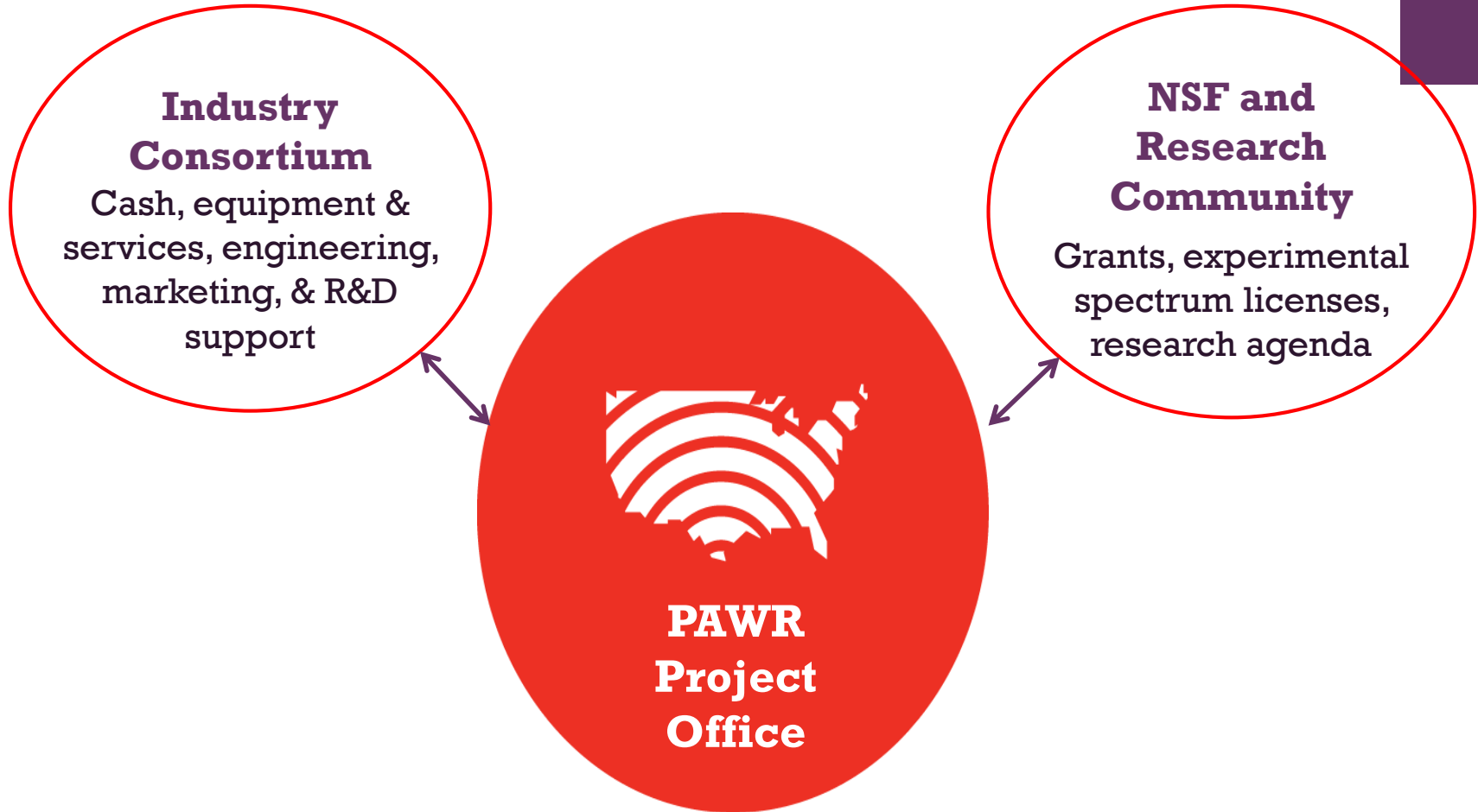


+ Key Figures





PAWR Project Office (PPO)



+ From Press Release

- The PAWR platforms will enable early-stage research that will push forward robust, new wireless devices, techniques, protocols and services. In addition, these research platforms will allow promising technologies to move quickly to market, provide hands-on practical training to a new generation of students, increase job opportunities, and support overall U.S. economic vitality. The overarching goal is to revolutionize the wireless ecosystem and maintain U.S. leadership in the sector for decades to come.

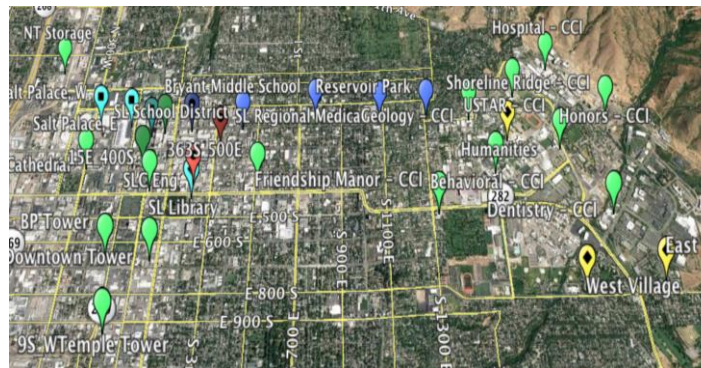
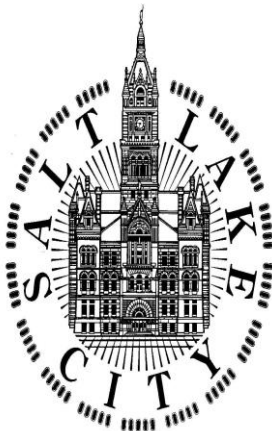
+ POWDER: Platform for Open Wireless Data-driven Experimental Research

- Next Generation Wireless Architecture
- Dynamic Spectrum Sharing
- Distinct environments: a dense urban downtown and a hilly campus environment.

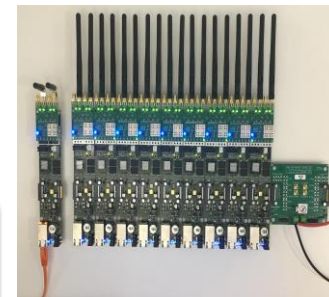
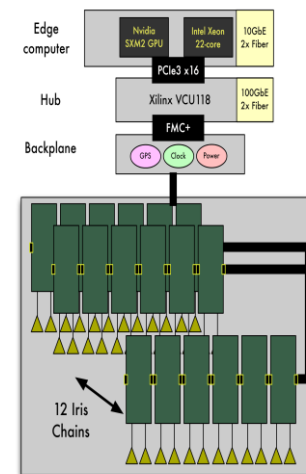


RENEW: A Reconfigurable Ecosystem for Next-gen End-to-end Wireless

- Massive MIMO base station (200+ antenna elements)
- End-to-End Programmable
- Diverse Spectrum Access 50 MHz-3.8GHz



Deployment Area: UofU Campus + Downtown SLC + Connected Corridor



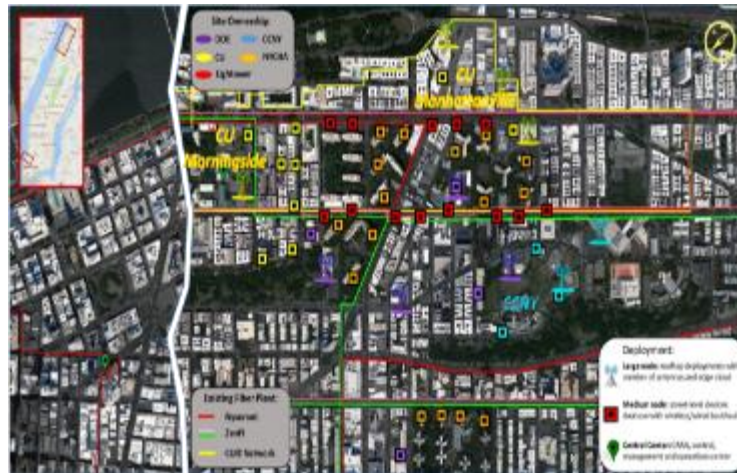
IRIS software-defined radio modules

Architectural view of RENEW base station

<https://powderwireless.net/>

+ COSMOS: Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment

- Dense population – complex urban RF environment
- Integrated dynamic optical switching + mm-wave comms
- Wideband radio signal processing (with bandwidths of ~500 MHz or more)
- Radio-over-fiber interfaces for ultra-low latency connections
- A multi-layered computing system with an RF thin client; flexible signal processing



Deployment Area: West Manhattan/Harlem

<http://cosmos-lab.org/>

RUTGERS

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK



28GHz phased-array ICs and phased-array antenna modules (PAAM)

+ Application Driven Experimentation



MANUFACTURING



HEALTH



PUBLIC SAFETY



TRANSPORTATION



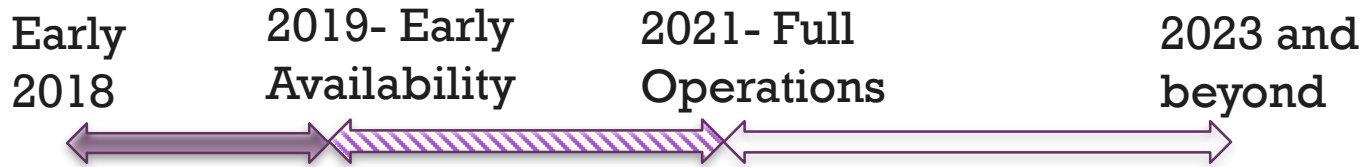
ENERGY



EXPERIMENTERS

+ Backup

+ Platform(s) Go-Live Timeline



+ POWDER Feature Set

Tech Area 1

- **Sub-6GHz multi-frequency, multi-radio, multi-antenna, fixed and mobile SDRs**
- Custom programmable massive MIMO
- Multi-cell interference, dynamic spectrum access, multi-RAT
- FDD and network- Massive MIMO

Tech Area 2

- **Low-latency, high capacity fronthaul/backhaul network**
- Distributed (edge, near-edge, metro) and heterogeneous (CPU, GPU, FPGA) compute
- Next-generation RAN and core mobile network
- Multi-access (mobile) edge cloud
- Management and operation of virtualized mobile networks

Tech Area 3

- **Diverse mobility and BYOD capabilities**
- User mobility and densification impact
- Custom and commercial equipment evaluation

+ COSMOS Feature Set

Tech Area 1

- Optical Networking with passive WDM switch fabrics
- Multiple sliceable and configurable topologies, splits between fronthauling/midhauling/backhauling and arbitrary higher layer protocols

Tech Area 2

- mmWave and Sub 6 GHz
- High-bandwidth, low latency, SDR-based, beamforming (at mmWave) and distributed MIMO
- Full-Duplex

Tech Area 3

- Edge and Core Cloud
- Low latency cloud RAN with heterogeneous and distributed FPGA/CPU/GPU processing

+ Who are the users?

- All of us !
 - Academics
 - Industry
 - Government
- Tackle the major issues in wireless communications research
- Research community also has to step up its game
 - Develop standards for experiment specifications
 - Incentivize higher standards for research
 - Shared development of common tools, repositories
 - Determine what standards of reproducibility meets needs

+ What's in it for You?

Research at-scale

Using Highly instrumented end-to-end Platforms to explore wireless, edge and cloud research topics independently or together; benchmarks; quick validation

Industry Opportunity

Critical gap between demand pattern and supply; move away from legacy infrastructure; rapid development, interoperability

International Scope

Federation between international platforms, shared learning, data and operational best practices