NSF's Platforms for Advanced Wireless Research (PAWR):

Fueling the next generation of wireless systems

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State of the wireless world today

- 5G is rolling out, in sub-6 GHz (massive MIMO) and mmWave bands.
- LTE-LAA is being deployed with carrier aggregation in 5 GHz.
- 5G NR-U being specified.
- Wi-Fi 6 is being certified by WFA and will operate in 6 GHz as well, once rules are finalized.
- 802.11ay (60 GHz) is being finalized
- DSRC and C-V2X being developed for 5.9 GHz
- A number of LPWAN systems in operation: LoRa, Sigfox, etc….
- Drones, satellites etc..
- New applications fueled by ubiquitous computing at the edge and low latency

What is the future?

- Fundamental issues still need to be addressed in making mmWave robust.
- Spectrum sharing and coexistence in new bands: e.g 6 GHz, mmWave
- V2X is still an open problem: DSRC or C-V2X or both or something else?
- Latency of 1 ms is still unrealized: will 5G NR deliver?
- Higher mmWave into THz: pushing towards higher bandwidths.
- AI/ML for network optimization, spectrum management, PHY/MAC protocol development.
- New applications, e.g. AR/VR, Industrial IOT and others that are yet to be imagined.

Plenty of research still to be done: theoretical and experimental, across the entire stack, from RF front ends to applications. Needs industry, academia and government to work together.

Platforms For Advanced Wireless Research

PAWR

Kick-Off: April 2017

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

NSF
<$>
$50M

NSF

The PAWR Vision

Drivers for success

Reproducibility
- Platforms setup, maintained, documented
- High scientific standards
- Accuracy and repeatability

Interoperability
- Prevent silos within research ecosystem
- Well-defined interfaces
- Interconnection with other PAWR platforms

Open Access
- Accessible by the research community
- Fairness in access

Usability
- Low learning curve, even if "open"
- Operable by BS technical level
- Reprogrammed by Advanced Users

Programmability
- Programmable at multiple levels (e.g., radio, resource allocation, backbone)
- Clearly defined interfaces and APIs.

Diversity
- Broad range of topics
- Spectrum, mmWave, Internet of Things, wide-area wireless backhaul, measurements etc.

Charter Members

PAWR

NOKIA Bell Labs · SAMSUNG · KEYSIGHT TECHNOLOGIES · NATIONAL INSTRUMENTS · Sprint · ORACLE · JUNIPER NETWORKS

COMMSCOPE · VIAVI · INTERDIGITAL · intel · QUALCOMM · AT&T · T-Mobile

verizon · ctia Everything Wireless · htc · SSC · CARLSON WIRELESS TECHNOLOGIES · atis · TIA ADVANCING GLOBAL COMMUNICATIONS

ERICSSON · Anritsu · BLACK & VEATCH · CROWN CASTLE · Polaris Networks 5G - Connecting the Future · JOHNS HOPKINS APPLIED PHYSICS LABORATORY · TELECOM INFRA PROJECT

MathWorks · Vapor · sigfox

Looking for new industry partners

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The PAWR Approach

Attribute	Approach
Problem Definition	Enhanced efforts of ~400 university researchers who need mid-scale testing capabilities to ensure success
Early Industry Involvement	Multi-use research platforms with "pre-competitive" research topic areas selected bottom-up by university PIs, with industry input
Research Scope	Mid-sized areas within cities, experimental platforms, 10-20 antenna sites, backhaul, SDRs
Flexibility and Speed	1 - 2 platforms per year in years 1,2 and 3
Streamlined governance, deployment, and operation	One governance consortium focused on upfront research and policy; city/university teams propose how to streamline deployment and ops

Initial topic areas to be enabled

mmWave/THz R&D and systems testing at the millimeter-wave bands that are about 28GHz, 60GHz with a target of 100 Gbps in data rates for small-cell networks that cover a few city blocks.

Network Slicing to focus on the providing differential isolated Micro services to multiple users from RAN to Network slicing .

NFV MANO provide support for ETSI and other MANO implementations to orchestrate end-to-end VM,container, VNF deployment in a cloud native environment including radio resources that operate on the wireless edge.

Microservices Architecture assembling, controlling, and composing services. PAWR provides a service control plane that is layered on top of a diverse collection of back-end service implementations, including VM-hosted VNFs, container-based micro-services, and SDN-based control programs that embed functionality in white-box switches

Massive MIMO 2.5-2.7GHz and 3.5-3.7GHz 128 antenna element fully programmable radio to allow PHY/MAC/network FDD, full duplex research to design, build and demonstrate high bandwidth connectivity to multiple users simultaneously.

RAN CU-DU Split to advance capabilities of baseband-RRH and other functional splits being debated n different communities e.g.eCPRI, OTN backhaul, O-RAN.

Applications/Services in later years – Platforms will serve as examples of Smart and Connected Community networks that demonstrate potential applications/services including Cyber-Physical Systems, Cyber-Security, Internet of Things, Robotics, Smart and Connected Health, and Big Data.

Where is PAWR today?

PAWR

Three platforms funded:

- Round I: Announced April 09, 2018
  - POWDER/RENEW: at University of Utah
  - COSMOS: at Columbia University
- Round II: Announced September 18, 2019
  - AERPAW: at NCSU
- Round III: RFP on rural broadband technologies

and

Colosseum: belongs to the PAWR family, at Northeastern University

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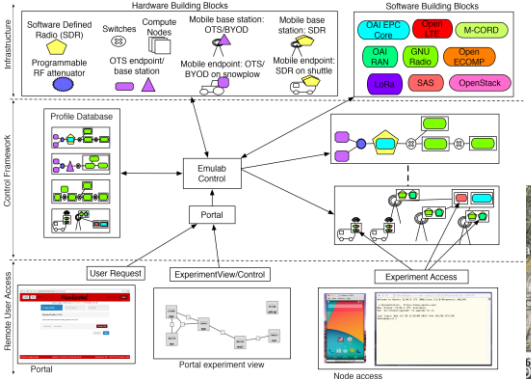
POWDER/RENEW

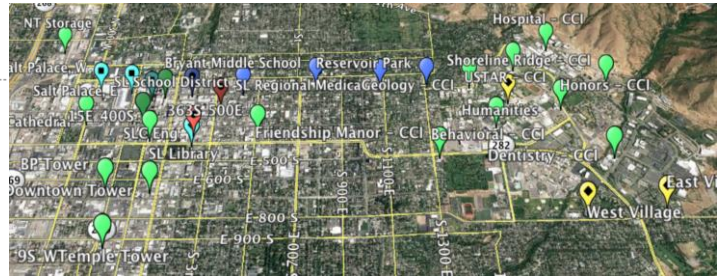
POWDER: Platform for Open Wireless Data-driven Experimental Research

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



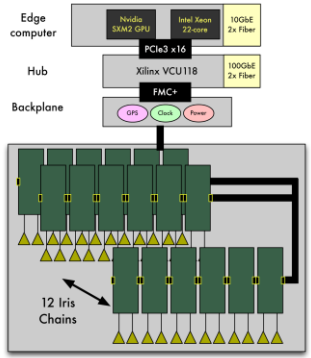
Control Framework with Hardware + Software Building Blocks

Deployment Area: UofU Campus +Downtown SLC + Connected Corridor



RENEW: A Reconfigurable Eco-system for Next-generation End-to-end Wireless

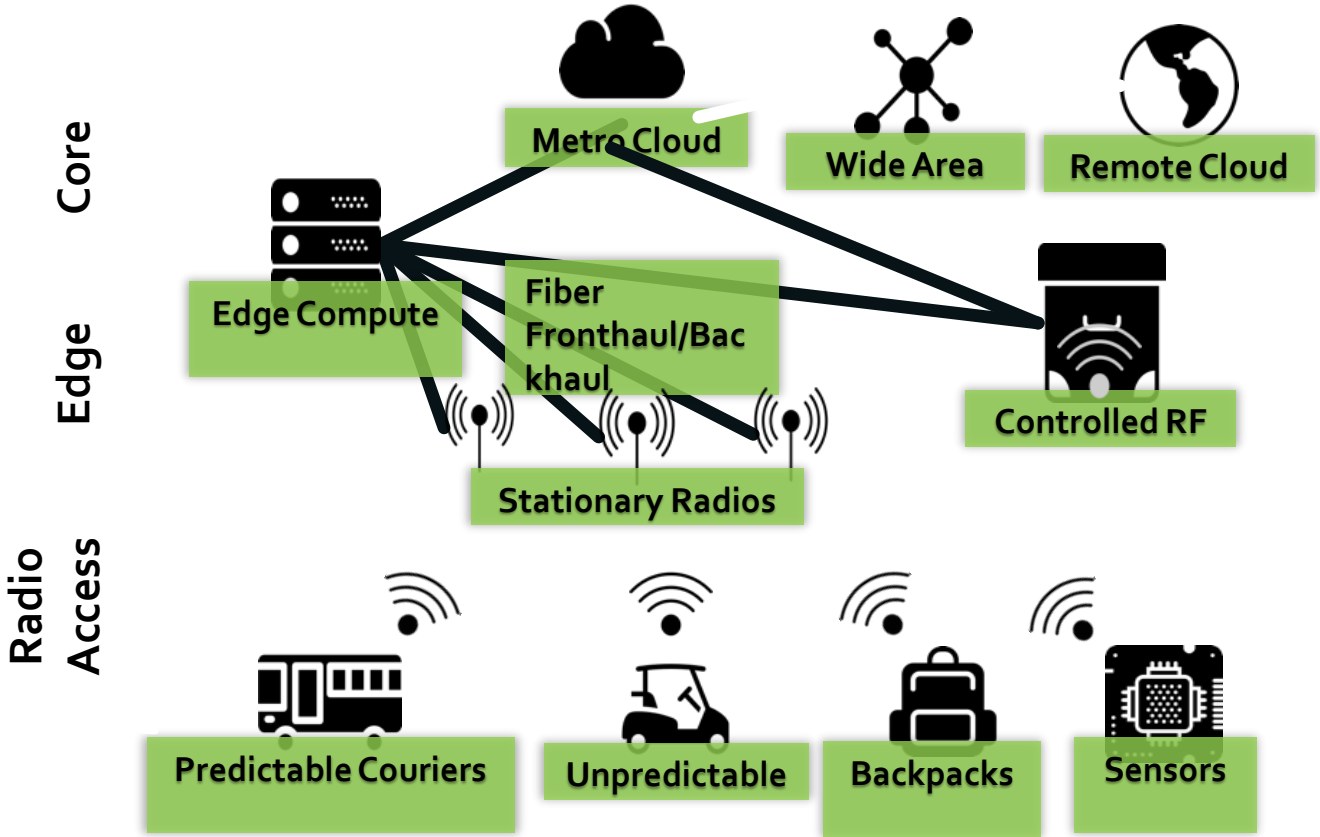
- RENEW Massive MIMO base station
- End-to-End Programmable
- Diverse Spectrum Access 50 MHz-3.8GHz
- Hybrid Edge computer composed of FPGA and GPU/CPU-based processing,
- Hub Board aggregates/distributes streams of radio samples



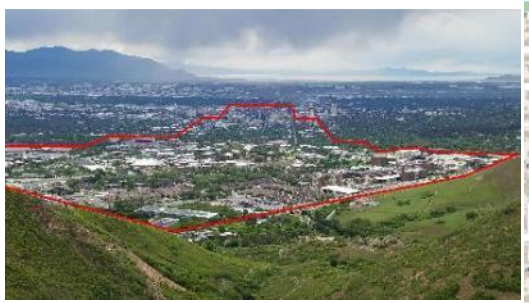
Architectural view of RENEW base station

IRIS software-defined radio modules

POWDER/RENEW: System Architecture

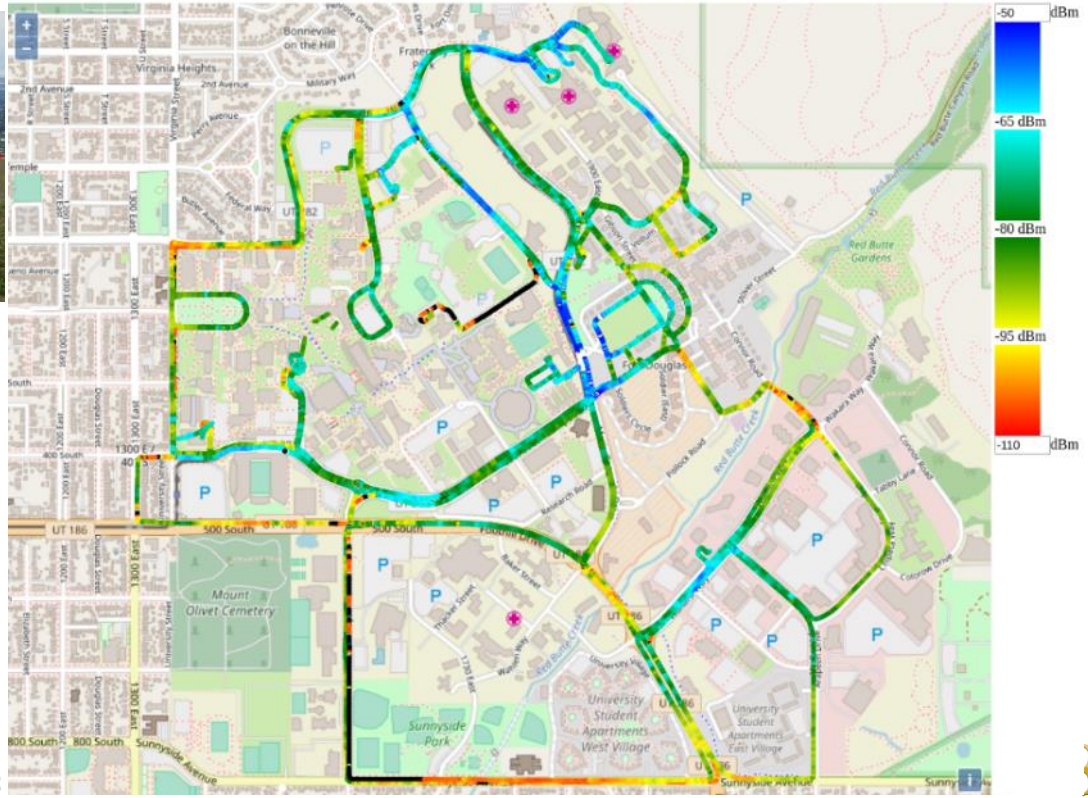


POWDER/RENEW: Truly City Scale



Base Station locations

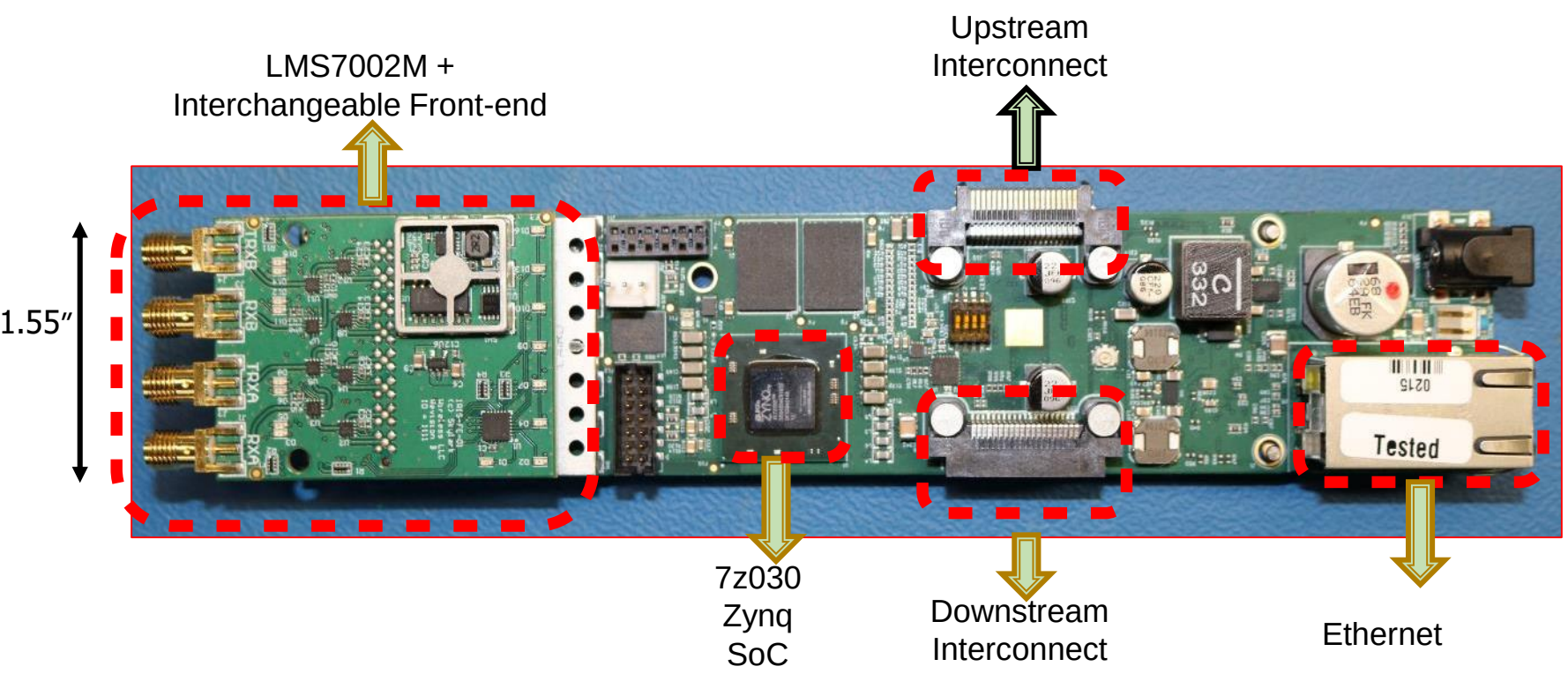
Campus Shuttle Routes



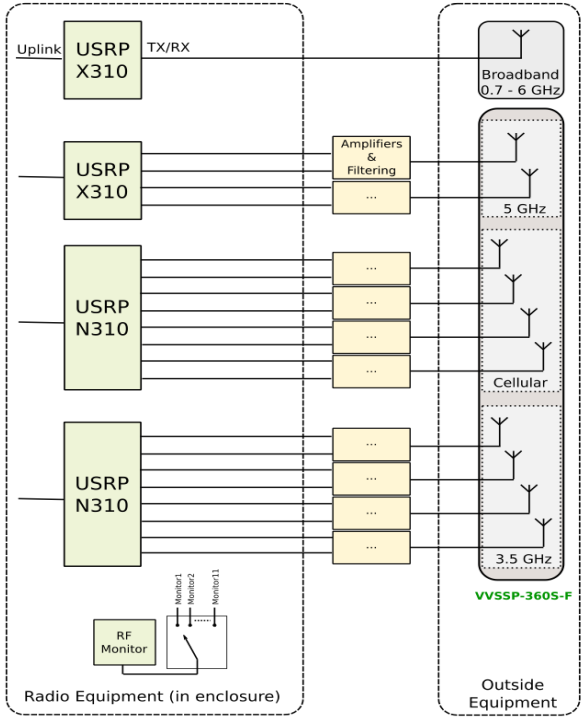
Renew: Massive MIMO Base Stations

- Iris SDR is the building block
- 64-128 antenna configs
  - Next gen design targets 256-antennas
- 40 Gbps Ethernet backhaul through fiber
  - Next gen design targets 100Gbps link
- HW Built-in Clock Sync
  - Support for SyncE/PTP underway
- Software initiated triggers for time synchronization

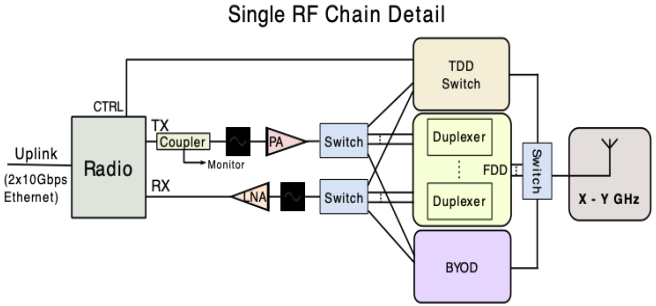
Renew Building Block: Skylark Iris Module



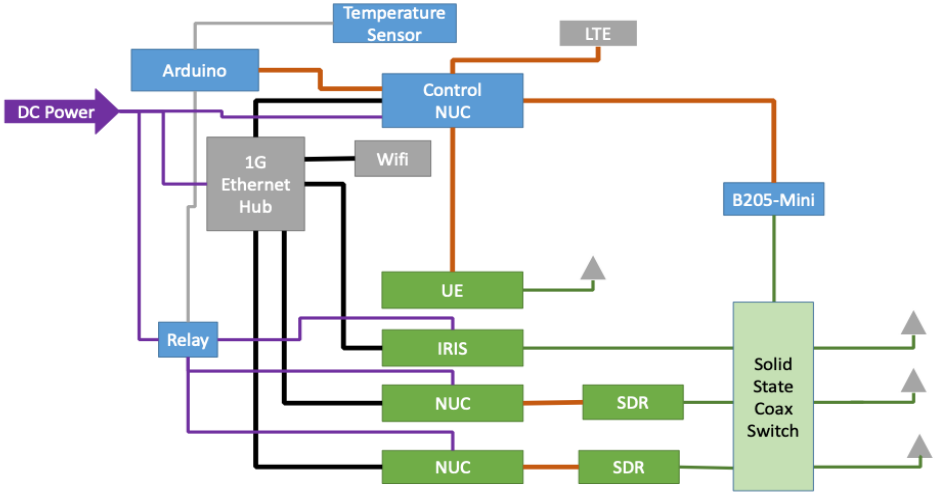
POWDER/RENEW: Rooftop Base Station



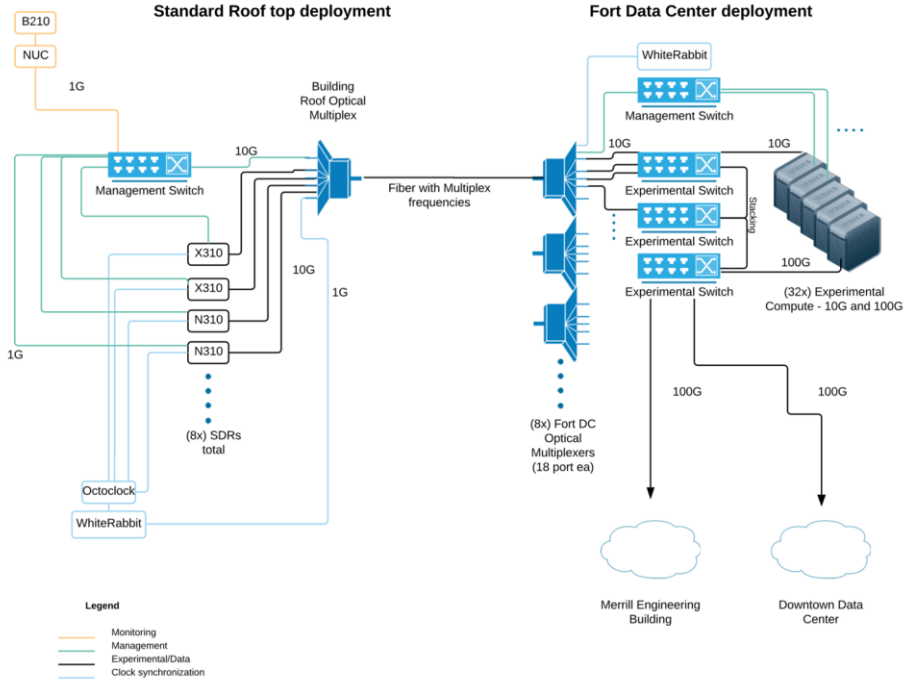
Powder Base Station RF Front-end

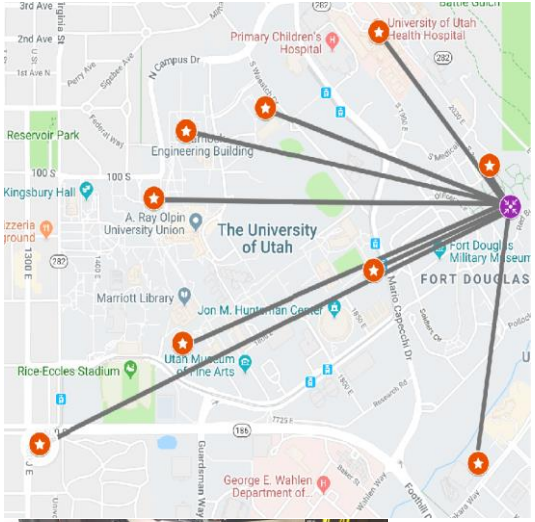


POWDER/RENEW: Fixed End Point



POWDER/RENEW: Edge Compute & Fiber





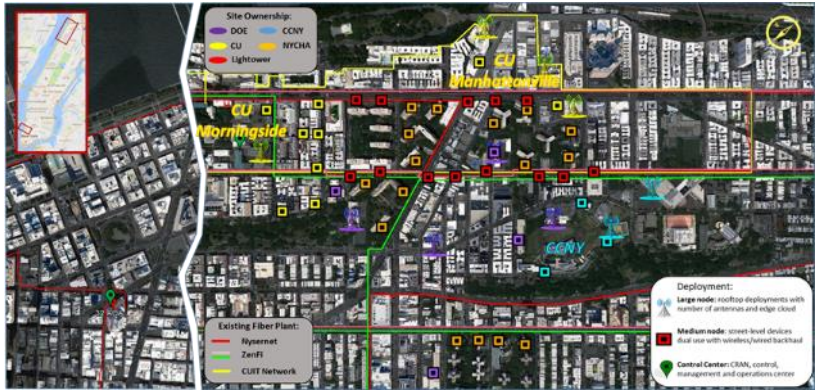
POWDER/RENEW: Pilot available today

8 Rooftop Base station and Fixed End Point sites

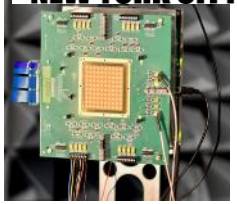
Software Profiles Available:
- Open Air Interface
- Worked with ONF to provide basic XRAN functionality in OAI
- Open Network Automation Platform (ONAP) [LF]
- Converged Multi-Access and Core (COMAC)/Open Mobile Evolved Core (OMEC) [ONF]
- Akraino Edge Stack, Radio Edge Control (REC)
- RAN Intelligent Controller (RIC)
- O-RAN [O-RAN Alliance]

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

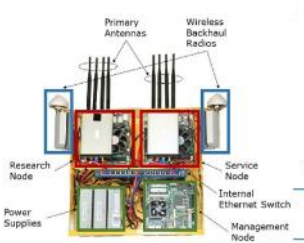
- A multi-layered computing system with an RF thin client; flexible signal processing; network function virtualization (NFV) between a local SDR (with FPGA assist) and a remote cloud radio access network (CRAN) with massive CPU/GPU and FPGA assist
- Deployed in New York City, one of the country's most populated urban centers
- Wideband radio signal processing (with bandwidths of ~500 MHz or more)
- Support for mmWave communication (28 and 60 GHz)
- Optical switching technology (~1µs) provides passive WDM switch fabrics and
- radio over fiber interfaces for ultra-low latency connections



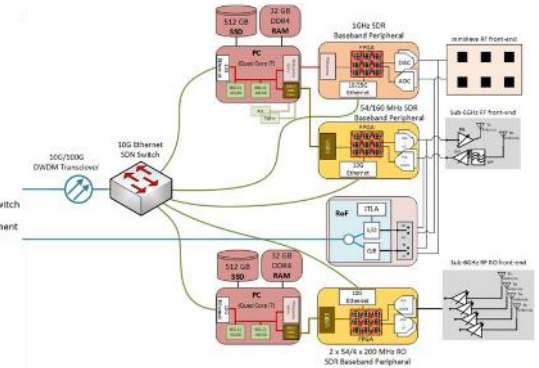
Deployment Area: West Manhattan/Harlem



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

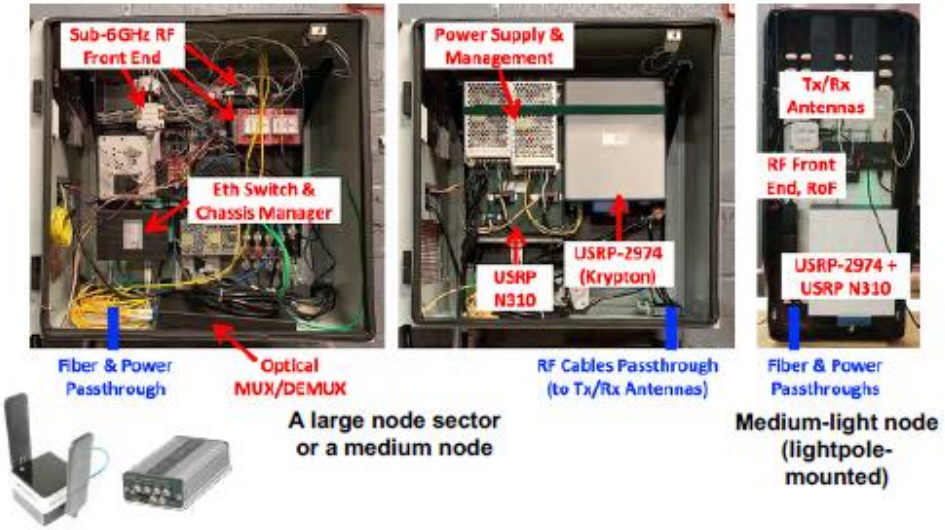


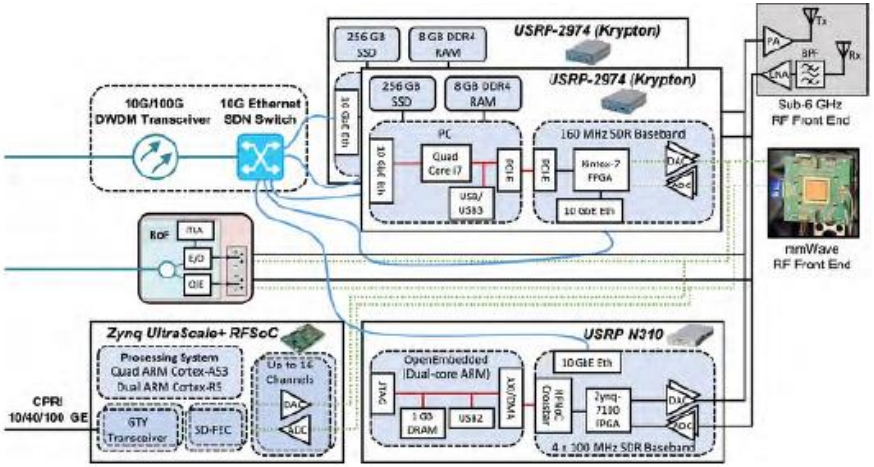
COSMOS Radio Site Design



All-Optical Network Design

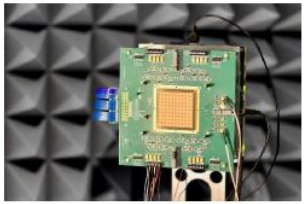
COSMOS: Large and Medium Nodes





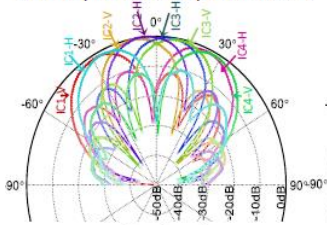
COSMOS: Node Specifications

- 64-dual polarized antennas and 4 ICs each with 32 TRX elements
- 128 TRX elements in total
- 8 independent 16-element beamformers, each supporting 1 polarization of 16 ant.
- RF true time delay based architecture
- 28GHz RF, 5GHz ext. LO, 3GHz input/output IF
- 54dBm saturated EIRP on each polarization

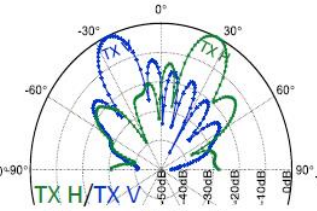


28GHz phased array eval. board

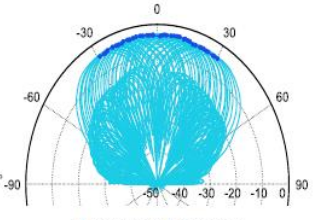
Example outdoor link experiment at IBM



Measured 8 simultaneous 16-element beams



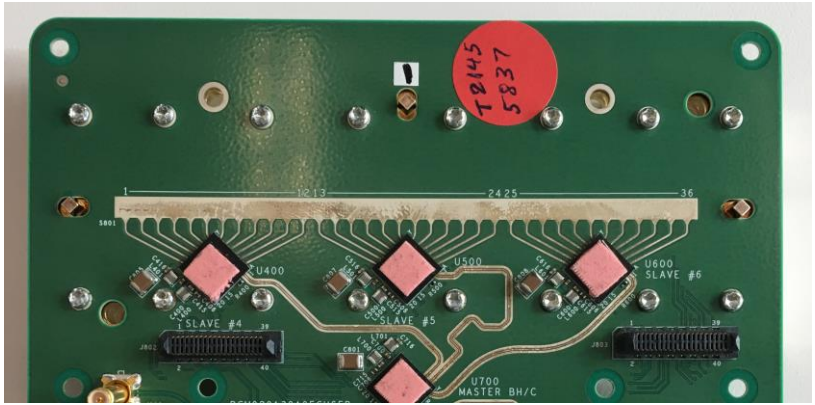
Measured 2 simultaneous 64-element beams



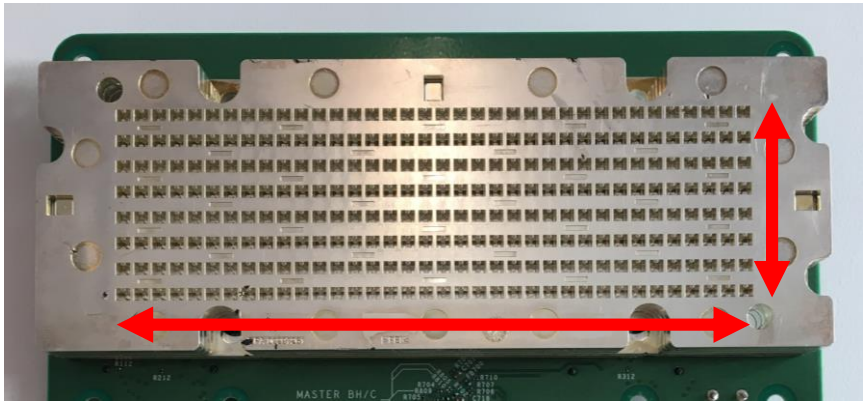
Measured Precise 1.4°/step beam steering

COSMOS: Facebook TerraGraph 60 GHz Antenna

Back: RFICs connecting to antenna feeds



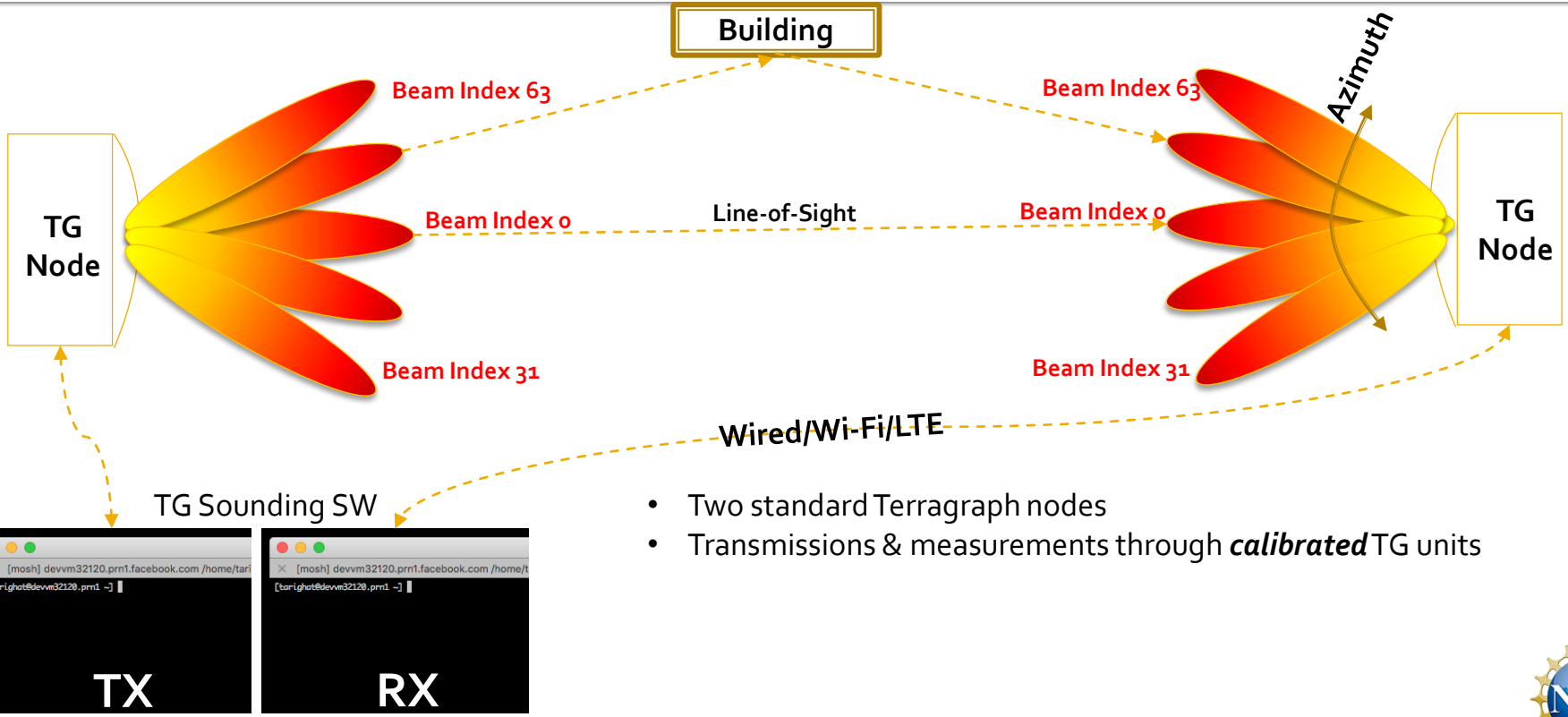
Front: Phased array antenna



8-Elements
(corporate feed)

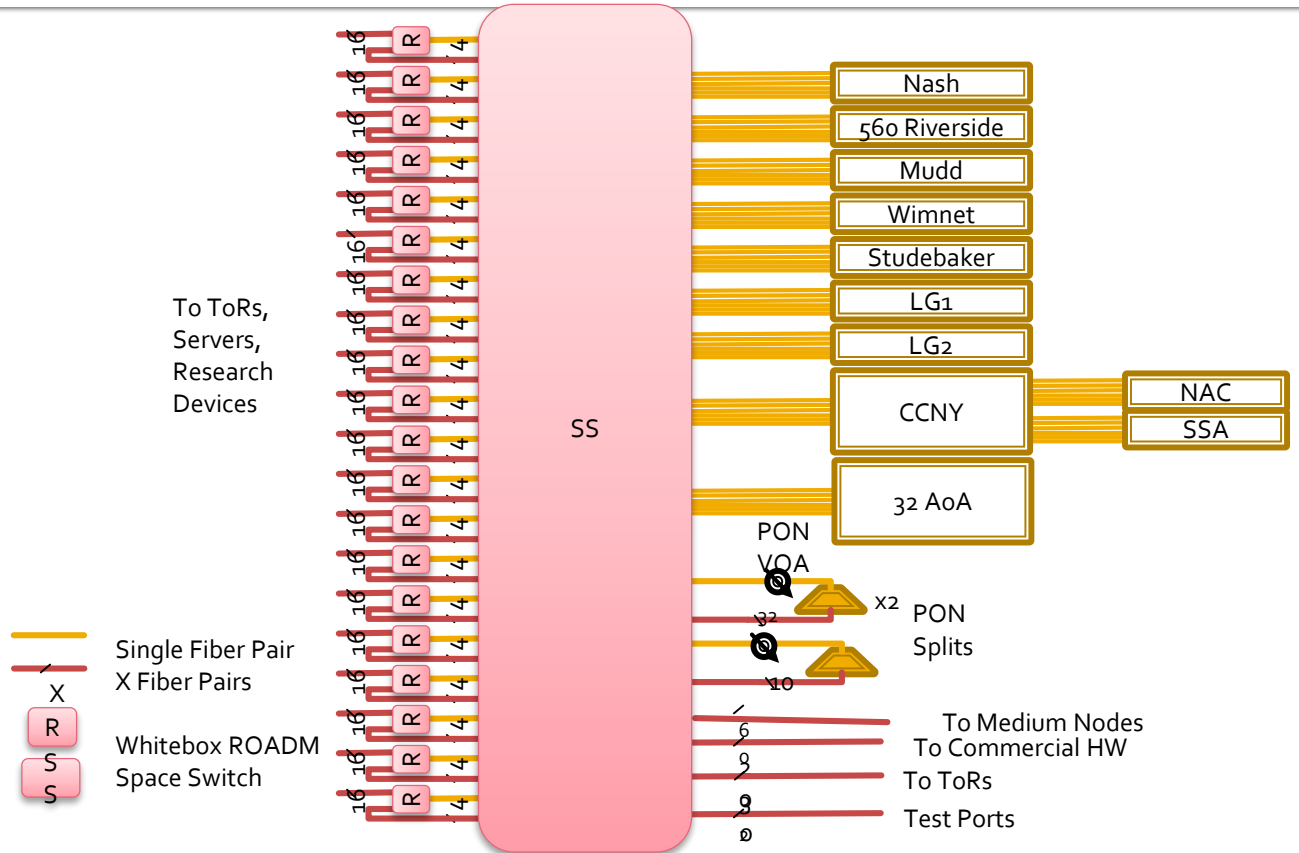
36 RF feeds
(independently controlled phase shifters)

COSMOS: Two TerraGraph Nodes



- Two standard Terragraph nodes
- Transmissions & measurements through ***calibrated*** TG units

COSMOS: Optical Backbone



COSMOS: Optical Facilities

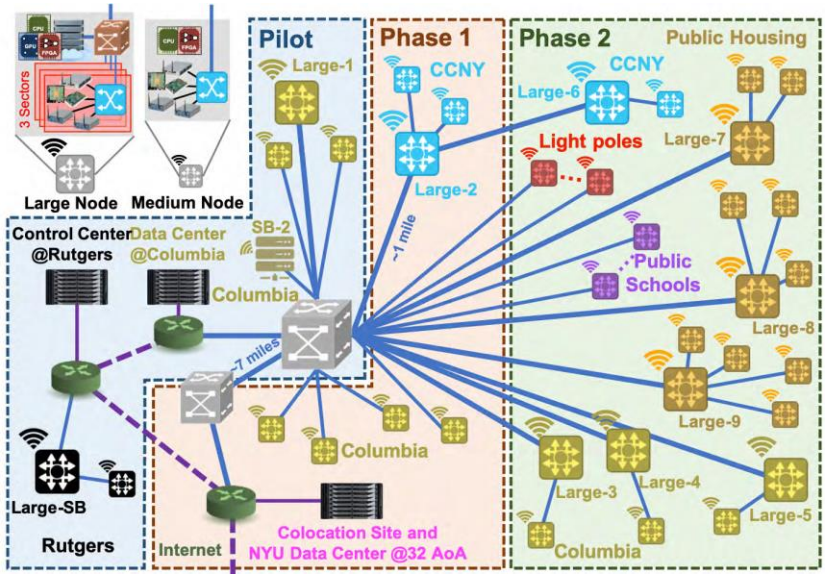
Base Configuration

- S320: 320 fiber pairs
  - 8 Large radio nodes: 48 fiber pairs
  - 32 AoA node: 6 fiber pairs
  - 20 ROADM line side ports
    - 320 wavelength filtered add/drop fiber pairs (16x20)
  - 80 ROADM filtered add/drop fiber pairs (4x20)
  - PON networks: 3x11=33 fiber pairs
    - 3 setups with 10 way splits, maybe reconfigured to 1 setup with a 32 port split
    - PON splits: 2 1x10 splits and 1 1x32 split
  - ToRs: 30 Fiber Pairs
  - Commercial Hardware: 20 fiber pairs
  - Medium node direct connections: 60 fiber pairs
  - Test Connections: 20 fiber pairs
  - Spares: 3 fiber pairs

COSMOS: Pilot Available Today

Base Configuration

- 2 Large and 3 Medium Nodes
- 16 port Space Switch
  - ROADMs: 1 fiber pair each, 2 total
  - Direct CRF connections: 6 fiber pairs
  - Eth Switch: 2 fiber pairs



AERPAW: Aerial Experimentation and Research Platform for Advanced Wireless

Goals

- Accelerate the integration of UAS into the national air-space
- Enable new advanced wireless features for UAS platforms, including flying base stations for hot spot wireless connectivity

Focus areas

- Advanced wireless communication technologies that enable beyond-VLOS and autonomous UAS operations and three-dimensional mobility for UAS
- New use cases for advanced wireless technologies that are emerging in the unmanned aerial systems (UAS) space

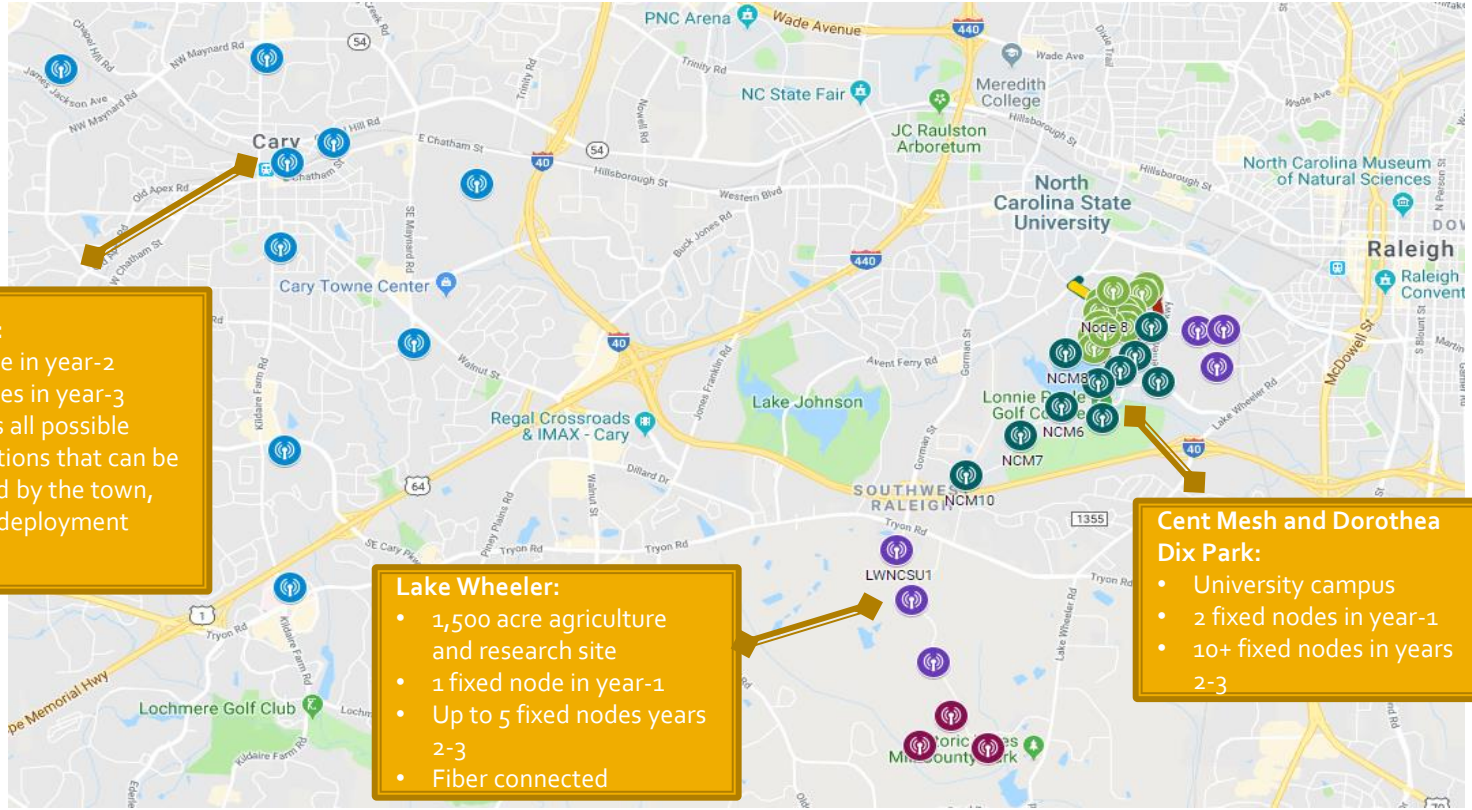
Tactics

- Create a one-of-a-kind aerial wireless experimentation platform and a proving ground and technological enabler for emerging innovations, including package delivery platforms and urban air mobility
- Accelerate development, verification, and testing of transformative advances and breakthroughs in telecommunications, transportation, infrastructure monitoring, agriculture, and public safety

AERPAW at a glance

- Led by North Carolina State University (NCSU) with three other universities
- Start date 9/01/2019
- NSF award of $**9,094,403** over 5 years
- Estimated Industry Consortium cash and in-kind match of up to **$10M**, including major contributions from:
  - National Instruments, Keysight, Ericsson, Commscope
  - Private spectrum licensees
- Approximately 20 fixed nodes at 3 main sites in the RDU Triangle area
- 20+ unmanned autonomous vehicles (drones) with advanced wireless tech through the coverage area

AERPAW: Deployment Plans



Town of Cary:

- 1 fixed node in year-2
- 3 fixed nodes in year-3
- Map shows all possible tower locations that can be contributed by the town, not actual deployment locations

Lake Wheeler:

- 1,500 acre agriculture and research site
- 1 fixed node in year-1
- Up to 5 fixed nodes years 2-3
- Fiber connected

Cent Mesh and Dorothea Dix Park:

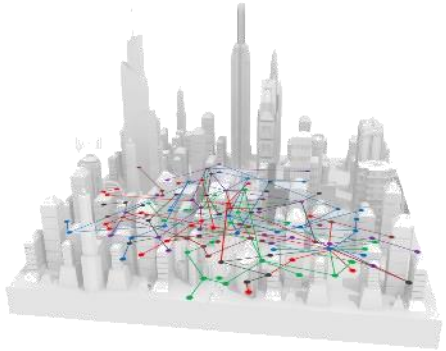
- University campus
- 2 fixed nodes in year-1
- 10+ fixed nodes in years 2-3

Colosseum

Colosseum is the **world's largest** wireless network emulator with granularity at the RF signal level

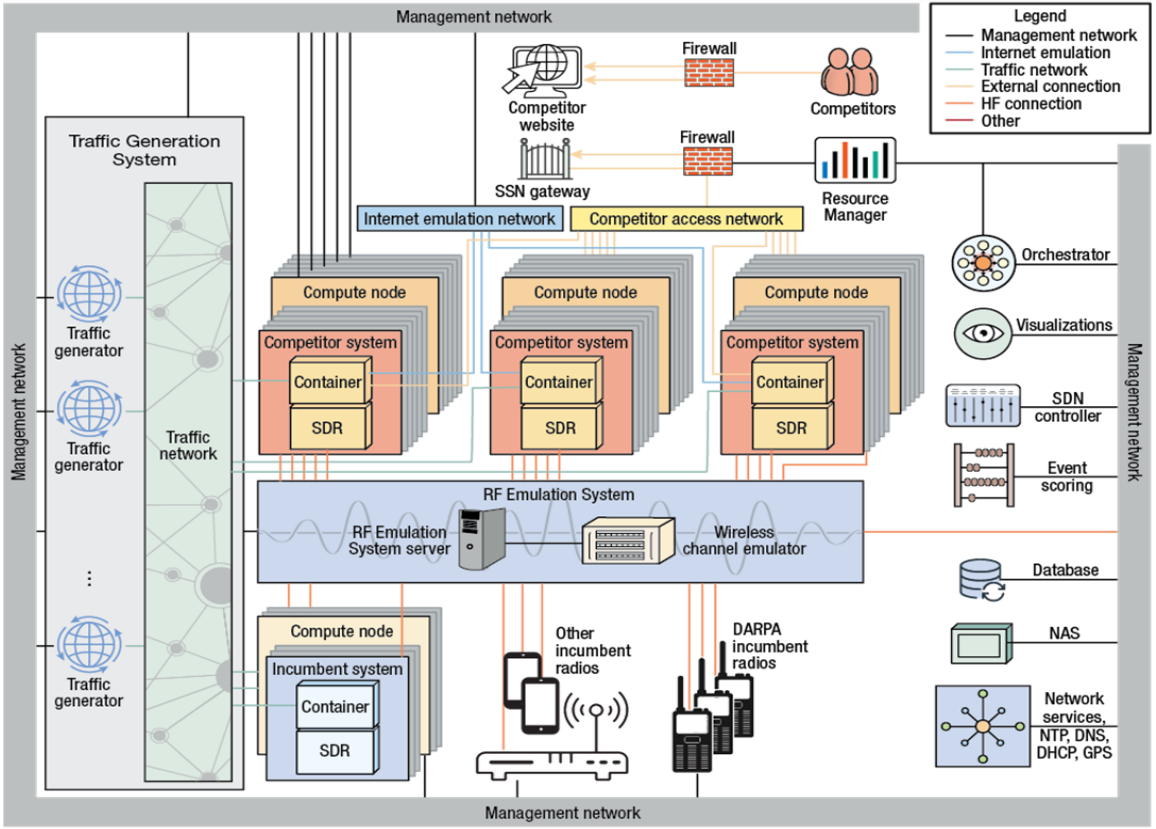
Northeastern University

- 256 x 256 100 MHz RF channel emulation
- 128 Programmable Radio Nodes
- Computing resources (CPU, GPU, FPGA)
- Access control and scheduling infrastructure
- Supports remote shared access
- Colosseum is a General Purpose Cooperative Radio Development and Testing Environment
- https://www.darpa.mil/program/spectrum-collaboration-challenge

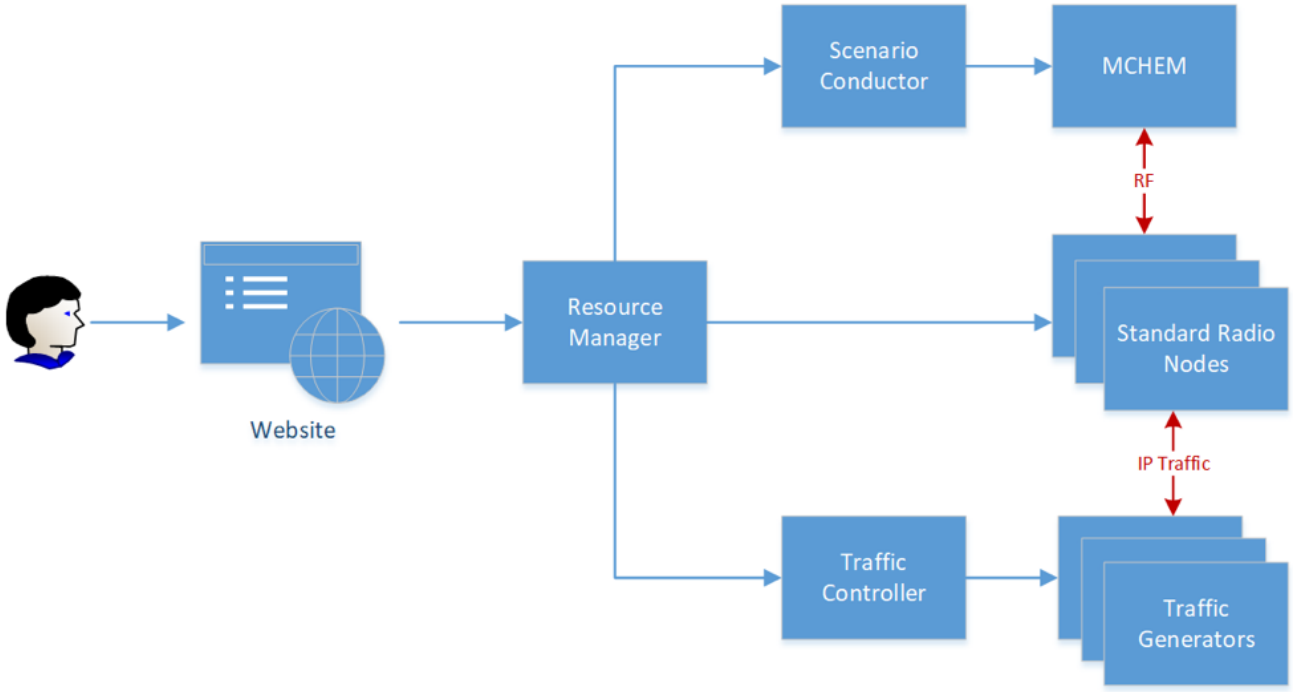


NSF

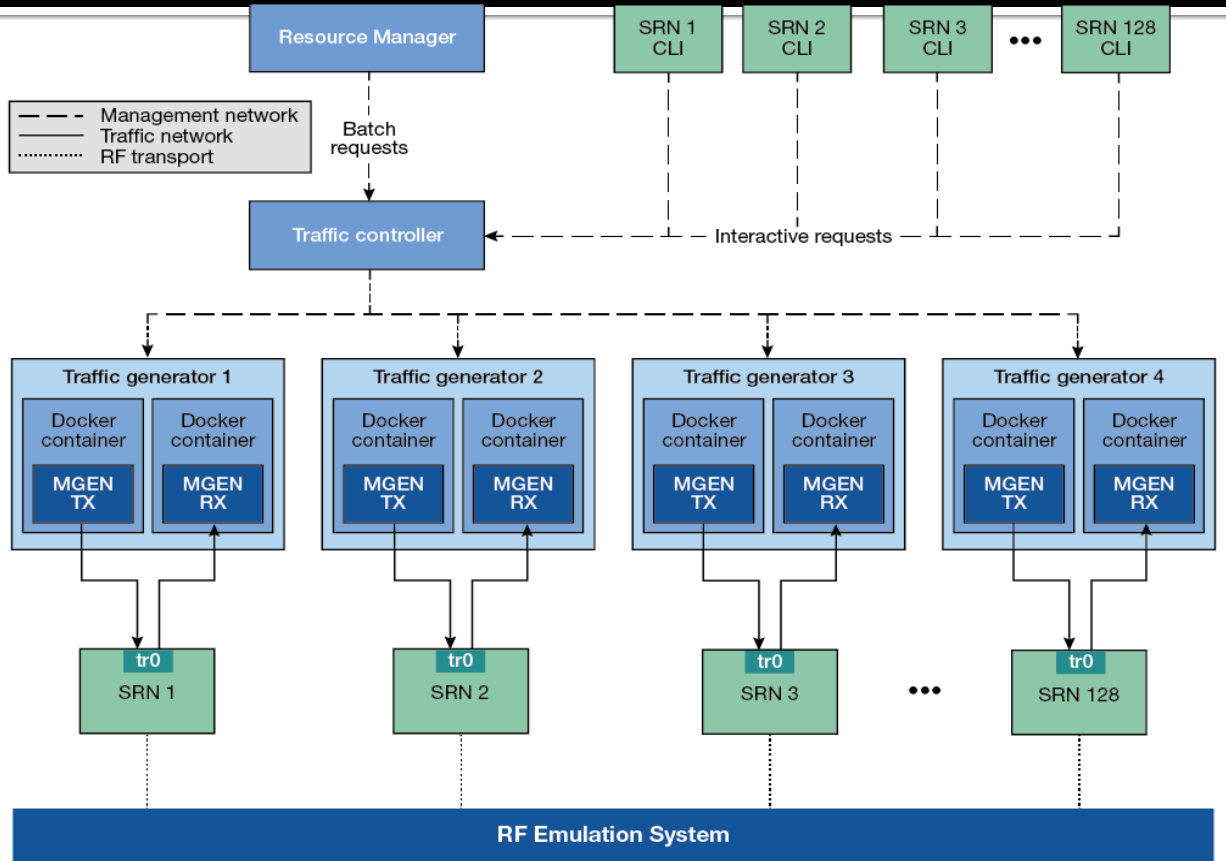
Colosseum architecture



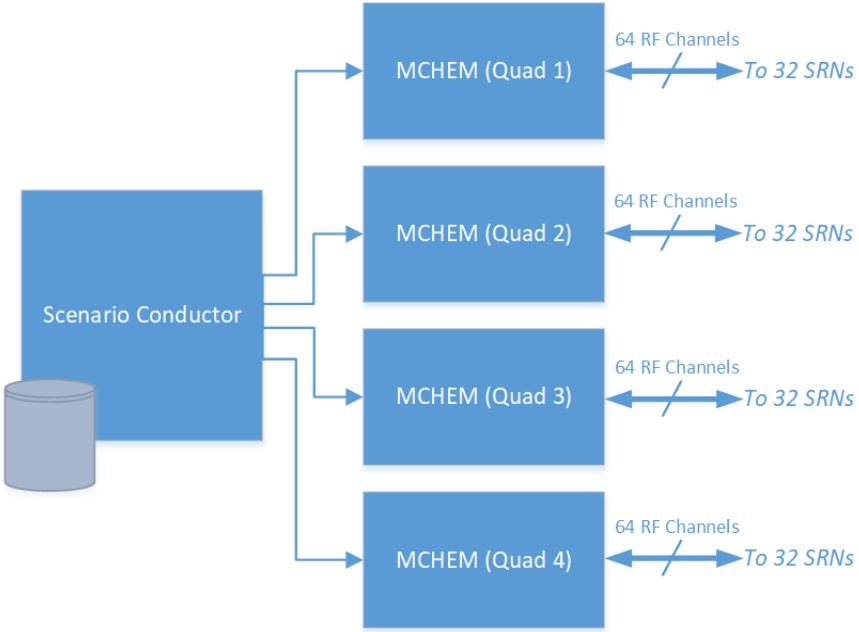
Colosseum Components

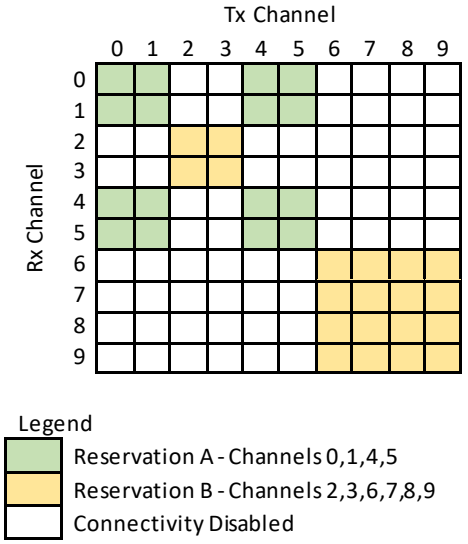


Colosseum: traffic system

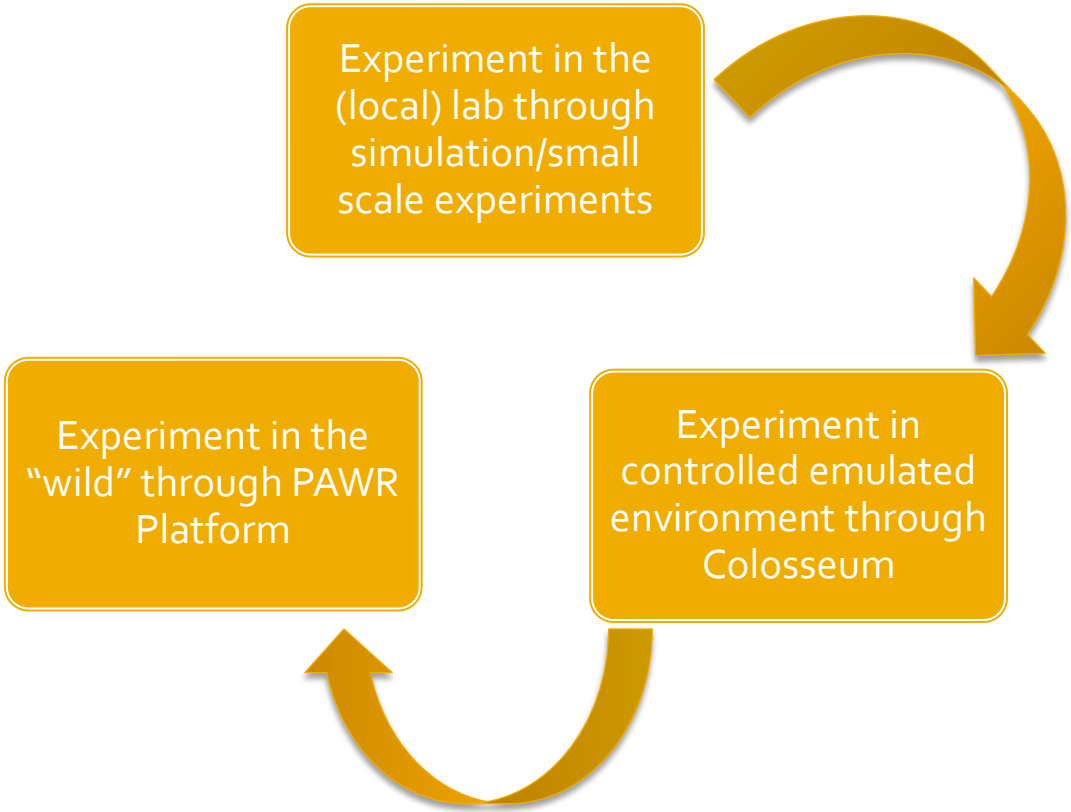


Colosseum: scenario conductor



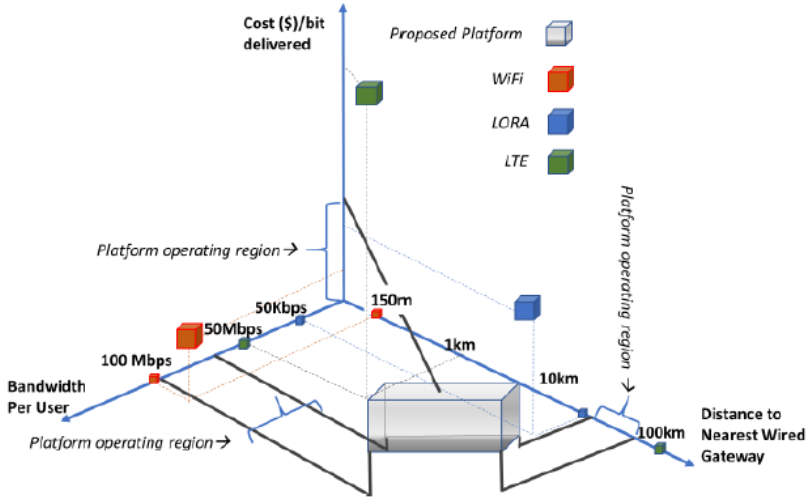


Envisioned Experiment Lifecycle For Future Wireless Research



Round III RFP: Rural Broadband.

- Open-ended for emerging and frontier ideas
- Focus on architectures – question assumptions and conventional wisdom
- Provide solutions and specifications as well as relevant trade-offs and implications;
- Looking for various possible solutions to particular challenges in rural broadband
  - LOI due: October 25, 2019
  - Full proposals due: December 13, 2019
  - Focus:
    - Rural broadband connectivity.
    - Reduce cost/bit using a mix of technologies: fiber, microwave, mmWave, satellite etc.



https://advancedwireless.org/wp-content/uploads/2019/10/PAWR_Project_Office_LOI_Round_III-FINAL.pdf

Find out more

- POWDER/RENEW:
  - http://powderwireless.net
  - http://renew.rice.edu
- COSMOS: http://cosmos-lab.org
- AERPAW: http://aerpaw.org
- Colosseum:
  - https://www.spectrumcollaborationchallenge.com/the-colosseum/
  - https://www.northeastern.edu/wiot/colosseum (not available yet)
- PAWR Project: http://advancedwireless.org