Institute for the Wireless Internet of Things
at Northeastern University

Shaping the Ubiquitous, Transparent, and Tactile Wireless Network of the Future

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AGENDA

- Overview of WIOT @ Northeastern University
- Portfolio of Research Infrastructure for 5G and Beyond
  - Platforms for Advanced Wireless Research (PAWR)
    - COSMOS
    - POWDER-RENEW
    - AERPAW
    - Rural Broadband Platform Vision
  - Blue-Sky Technology Area(s) Enabled
  - Colosseum- World's Largest RF Emulator

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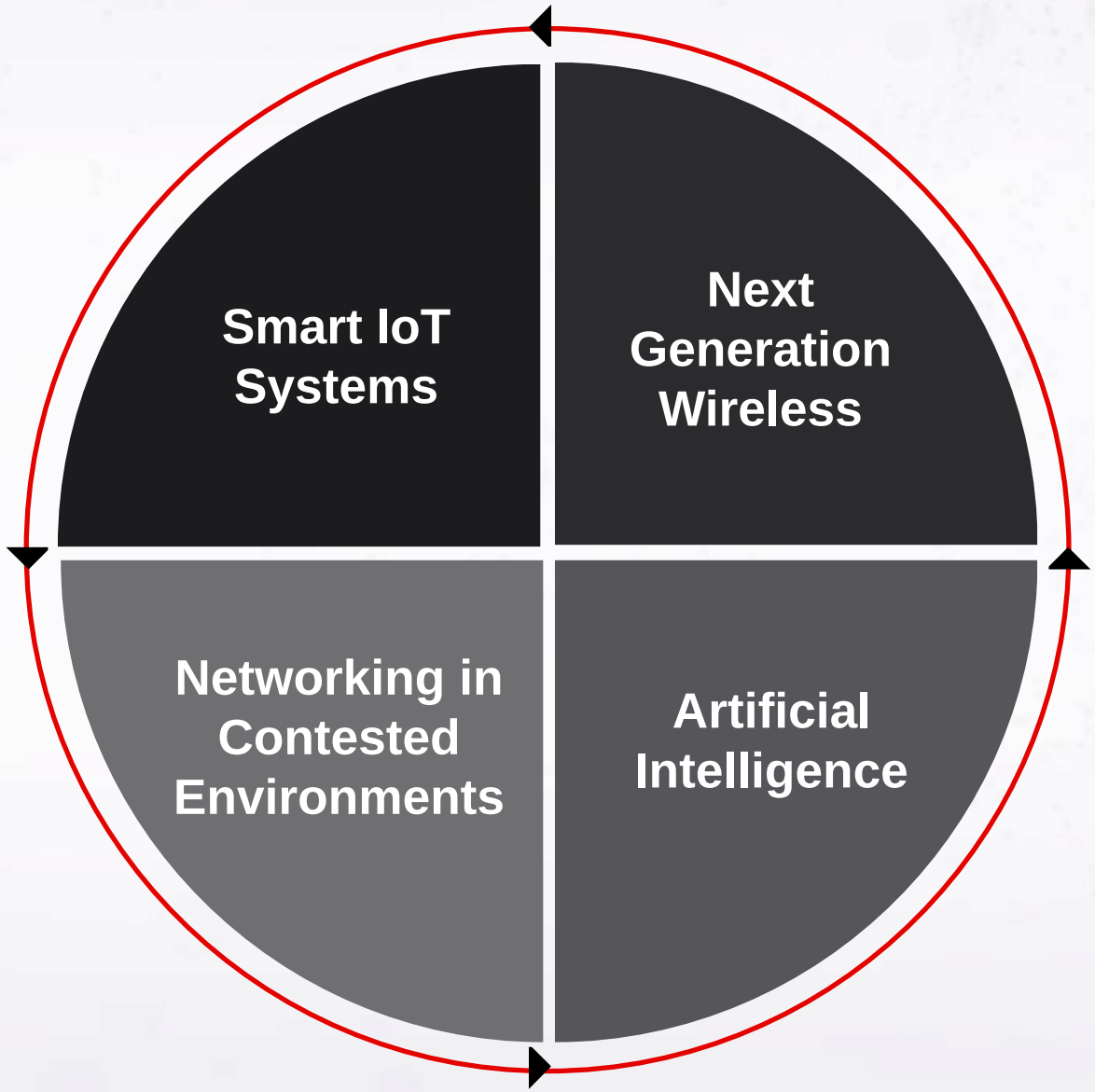
Institute for the Wireless Internet of Things

- Digital Health
- Industrial IoT
- Smart Agriculture
- Maritime IoT
- Blockchain



- 5G, 6G Wireless
- Spectrum Sharing
- Software-defined networks
- Underwater Networks

- Tactical Networks
- Secure Wireless Networking
- Resilient and elastic networking

- Cognitive Wireless Networks
- Connected Vehicles
- Deep Learning for IoT

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Institute for the Wireless Internet of Things

at Northeastern University

"An interdisciplinary engineering Institute to shape the untethered, ubiquitous, transparent, zero-power, and tactile **Internet of the future"**

Platforms for Advanced Wireless Research

Kick-Off April 2017

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

<$>
$50M

Level-Setting: 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

Charter Members

https://advancedwireless.org/partners

Mapping System Elements to a Changing Landscape

• Programmable Wireless (RF, Baseband) Substrate	Functional Disaggregation
• Wireless and/or Transport X-Haul	Move Processing closer to the edge
• Software configurable edge infrastructure	Softwarization + commodity hardware
• Modular Hardware; extensible; BYOD	Future Proof, Reduce CAPEX-OPEX
• White-Box and Black-Box User Equipment	DevOps + Closed Loop Network Automation

INITIAL BLUESKY TOPIC AREAS TO BE ENABLED BY RESEARCH PLATFORMS

mmWave/THz to enable 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 .

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.

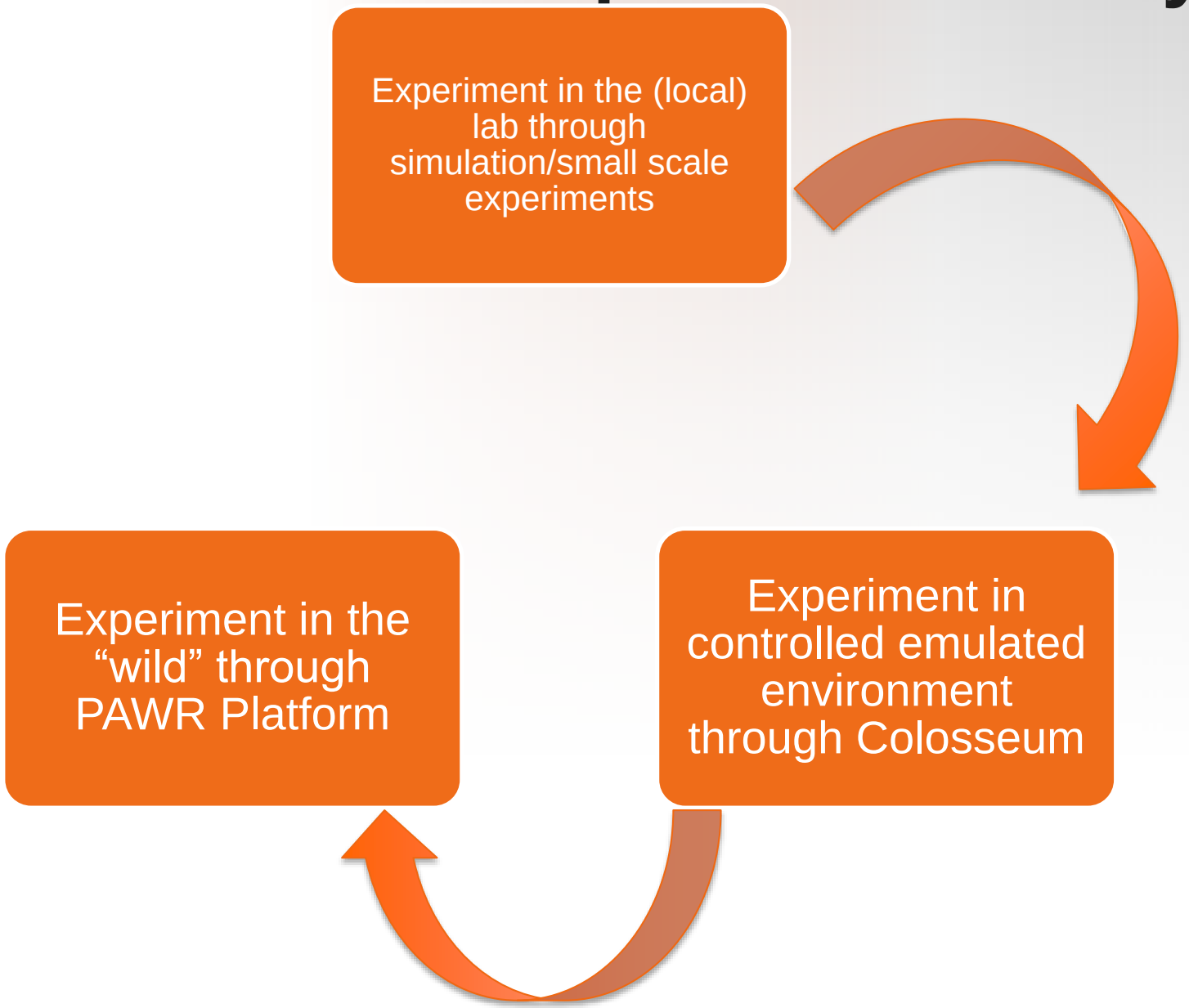
Microservices Architecture assembling, controlling, and composing services. We provide a service control plane that is layered on top of a diverse collection of back-end service implementations, including VM-hosted VNFs, container-based micro-services, and SDN-based control programs that embed functionality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

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.

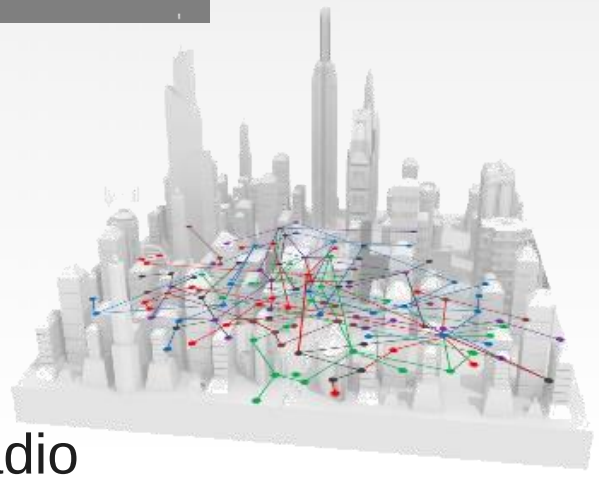
Applications/Services in later years – Platforms will serve as examples of Smart and Connected Community networks that demonstrate potential applications/services including Cyber-Physical Systems, Cyber-Security, Internet of Things, Robotics, Smart and Connected Health, and Big Data.

Envisioned Experiment LifeCycle



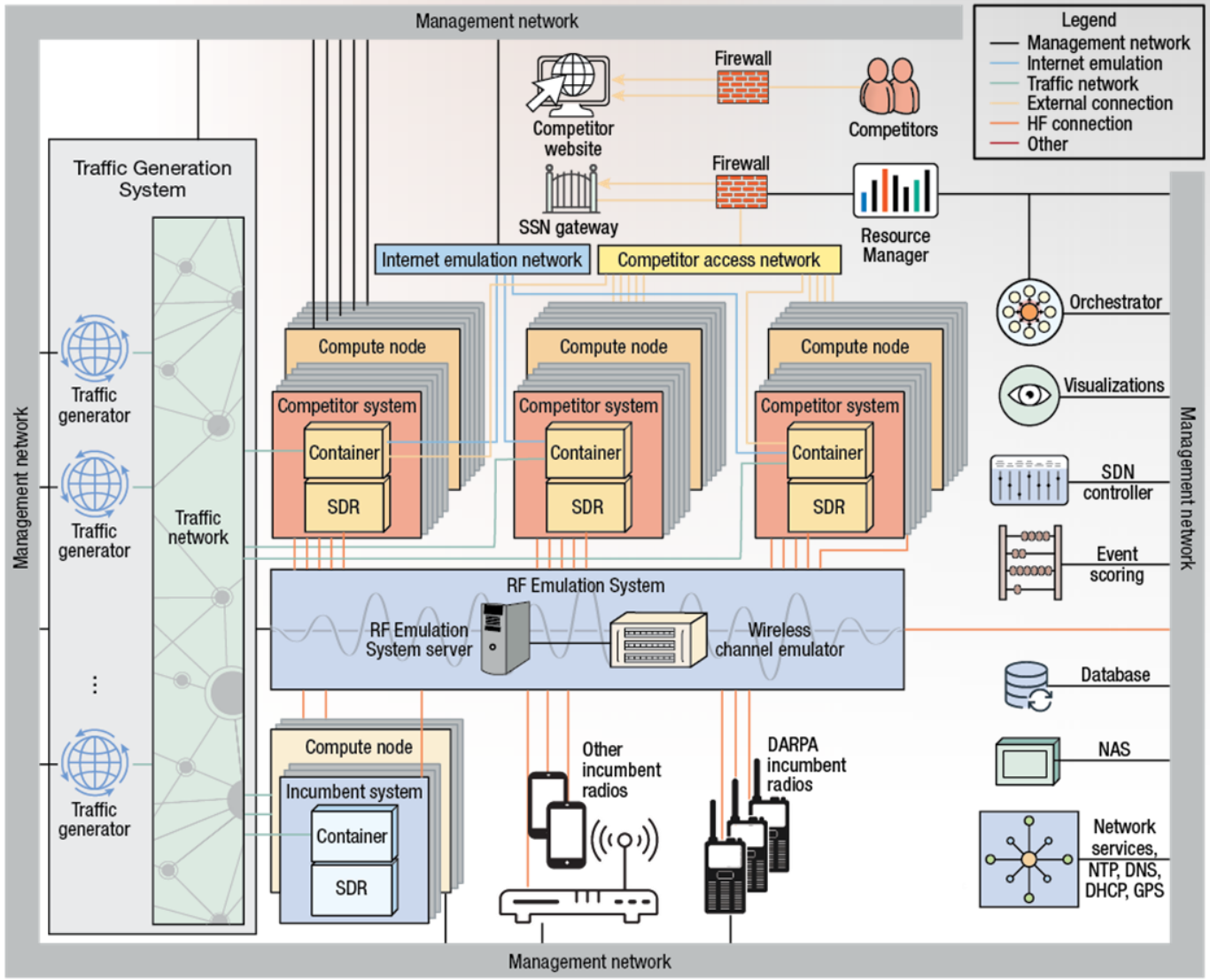
What is Colosseum?

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

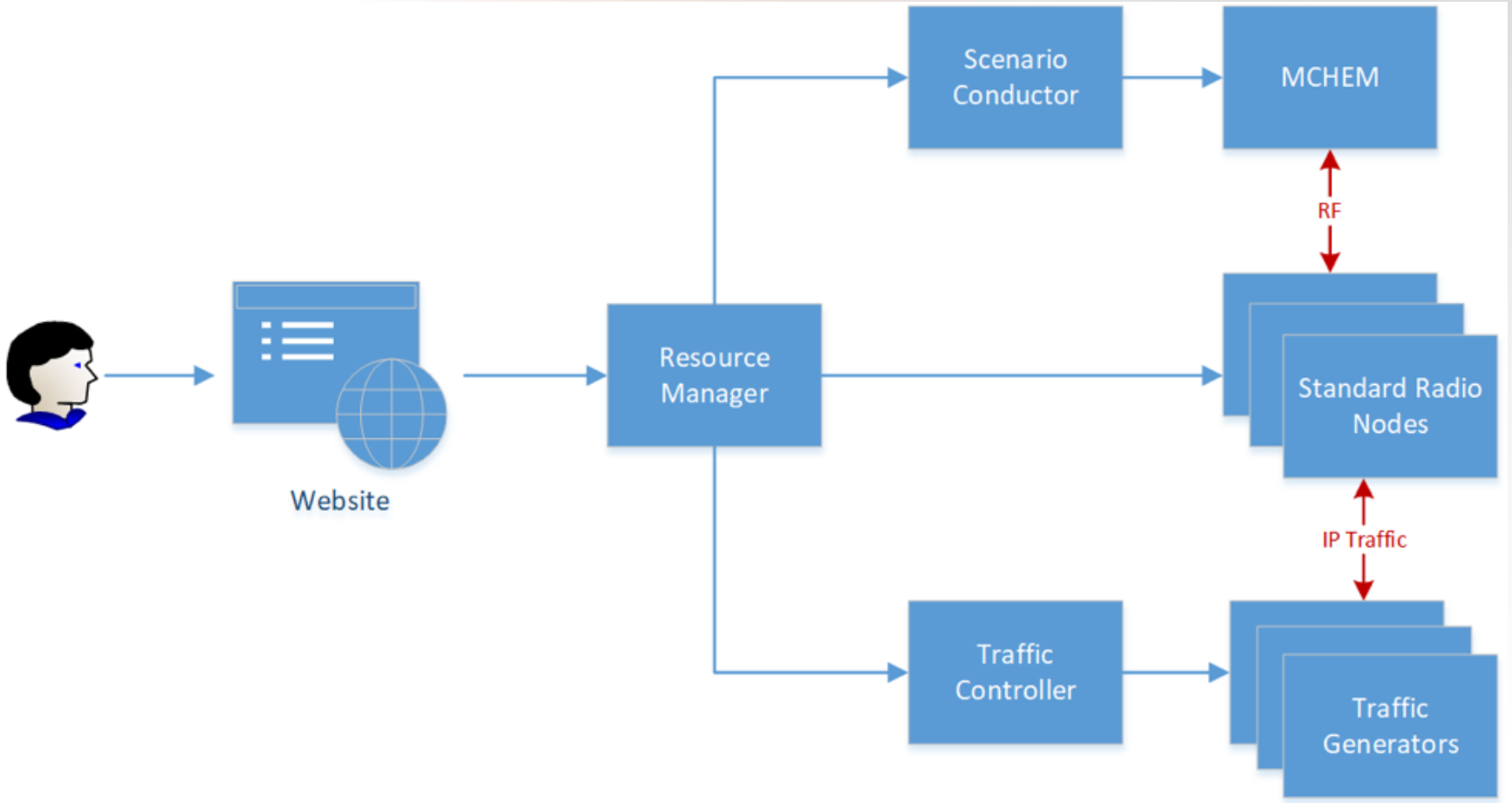


- 256 x 256 100 MHz RF channel emulation
- 128 Programmable Radio Nodes
- Computing resources (CPU, GPU, FPGA)
- Access control and scheduling infrastructure
- Supports remote shared access
- Colosseum is a General Purpose Cooperative Radio Development and Testing Environment
- https://www.darpa.mil/program/spectrum-collaboration-challenge

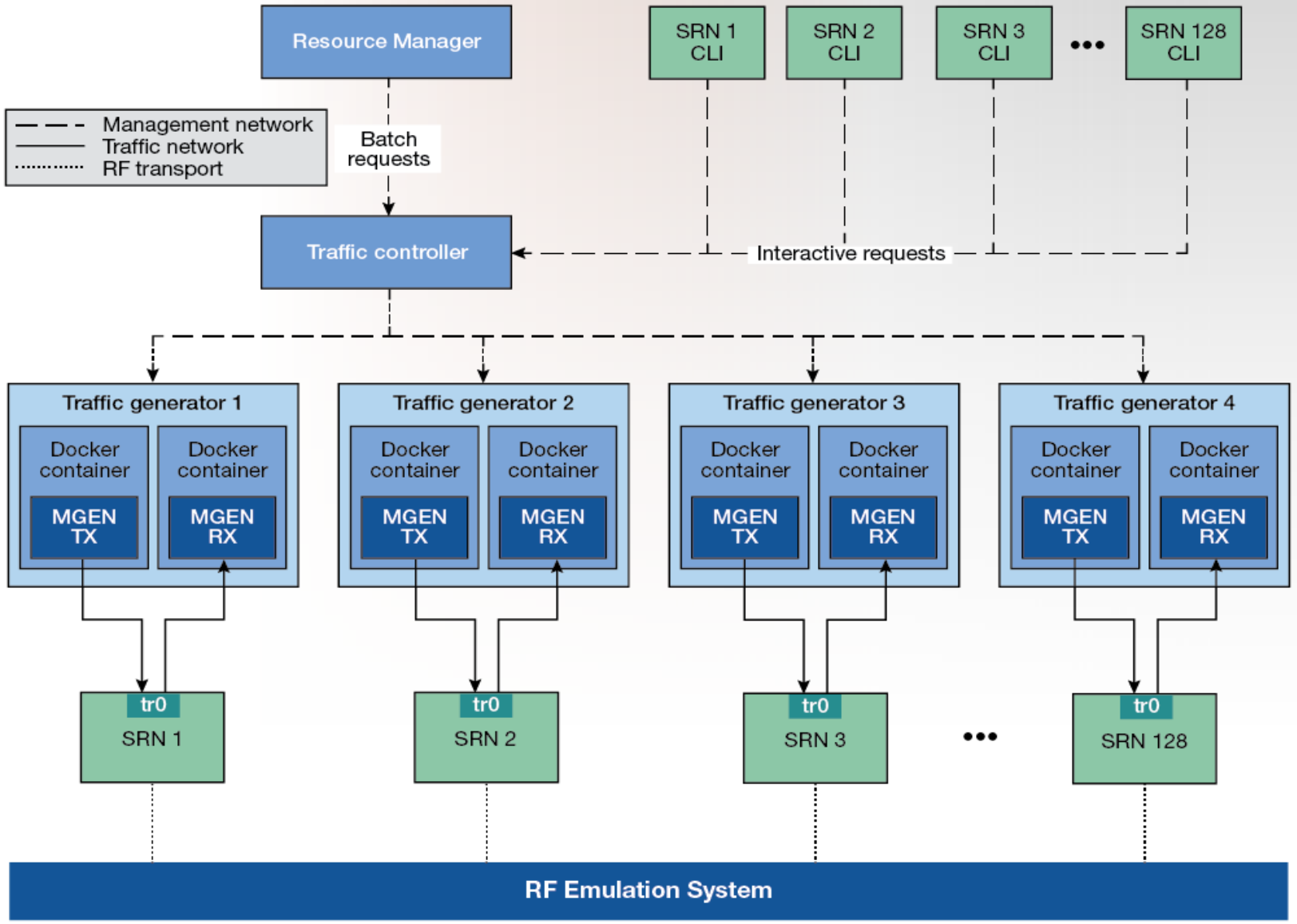
Colosseum Architecture



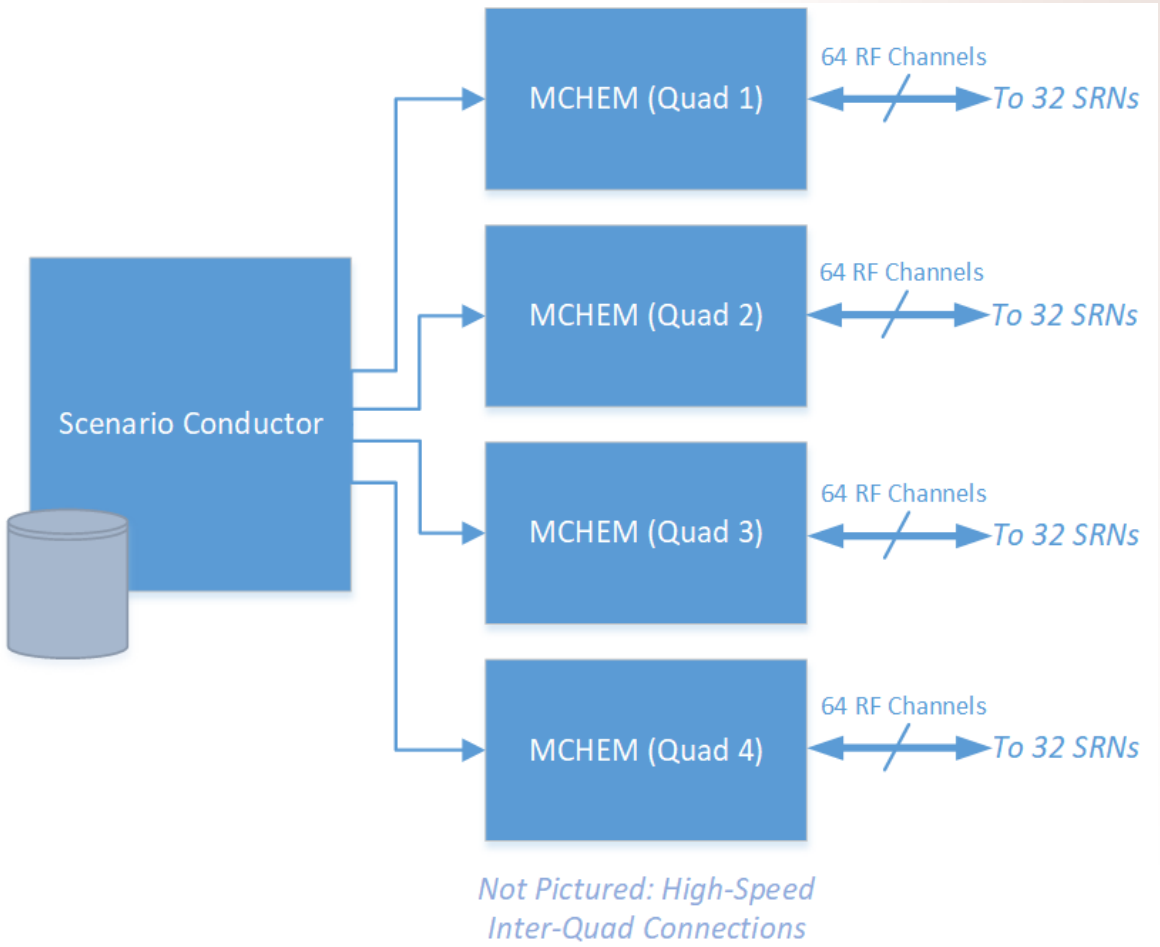
Components

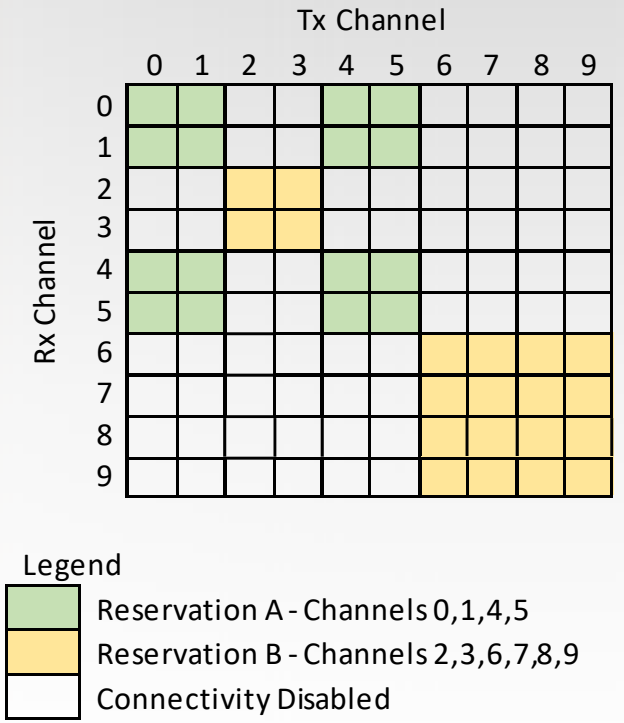

Scenario Conductor
MCHEM
RF
Website
Resource Manager
Standard Radio Nodes
IP Traffic
Traffic Controller
Traffic Generators

Traffic System



Scenario Conductor





PAWR Awardees

Announced April 9 2018

Round I Platforms

Salt Lake City

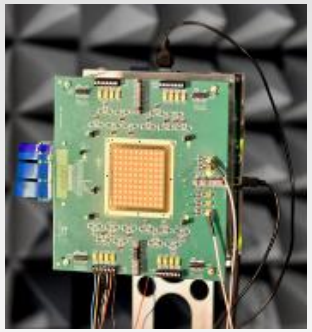
New York City

http://powderwireless.net

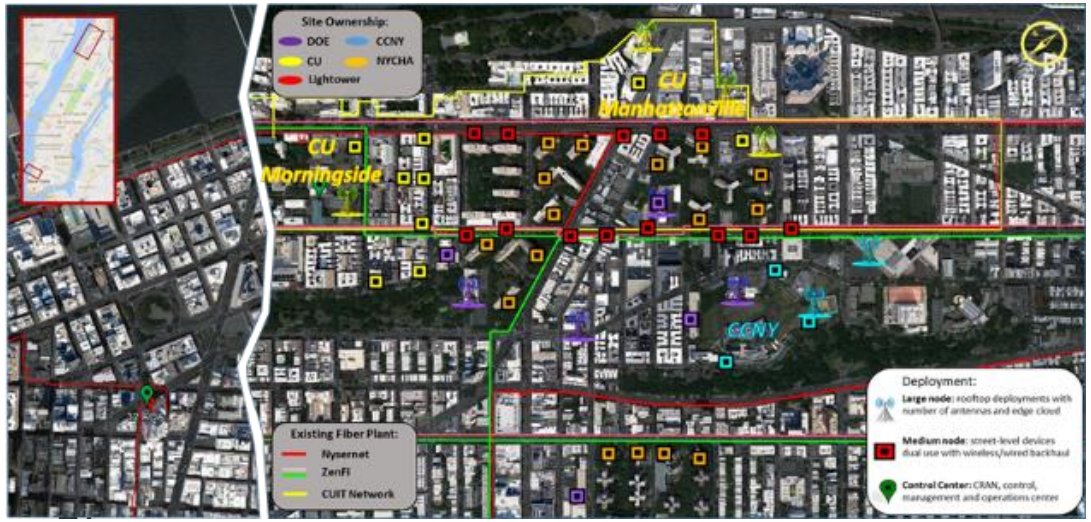
http://cosmos-lab.org

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

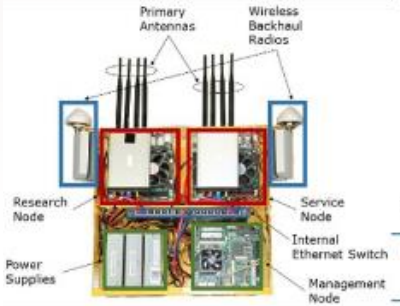
- A multi-layered computing system with an RF thin client; flexible signal processing; network function virtualization (NFV) between a local SDR (with FPGA assist) and a remote cloud radio access network (CRAN) with massive CPU/GPU and FPGA assist
- Deployed in New York City, one of the country's most 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



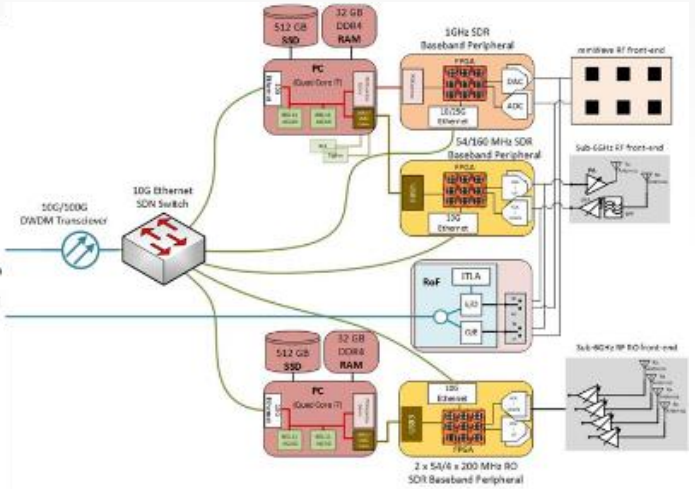
28GHz phased-array ICs and phased-array antenna modules (PAAM)



Deployment Area: West Manhattan/Harlem

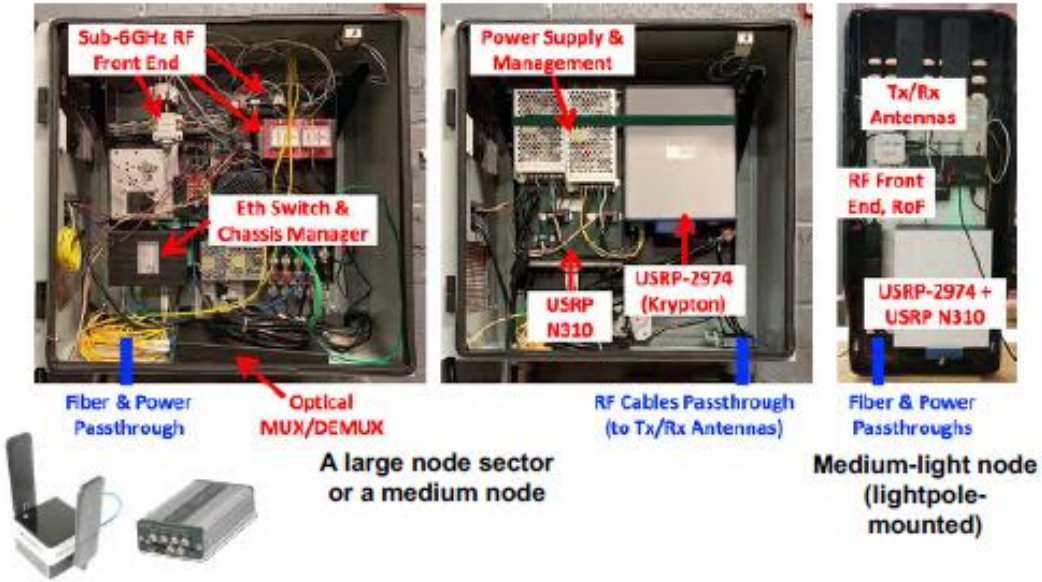


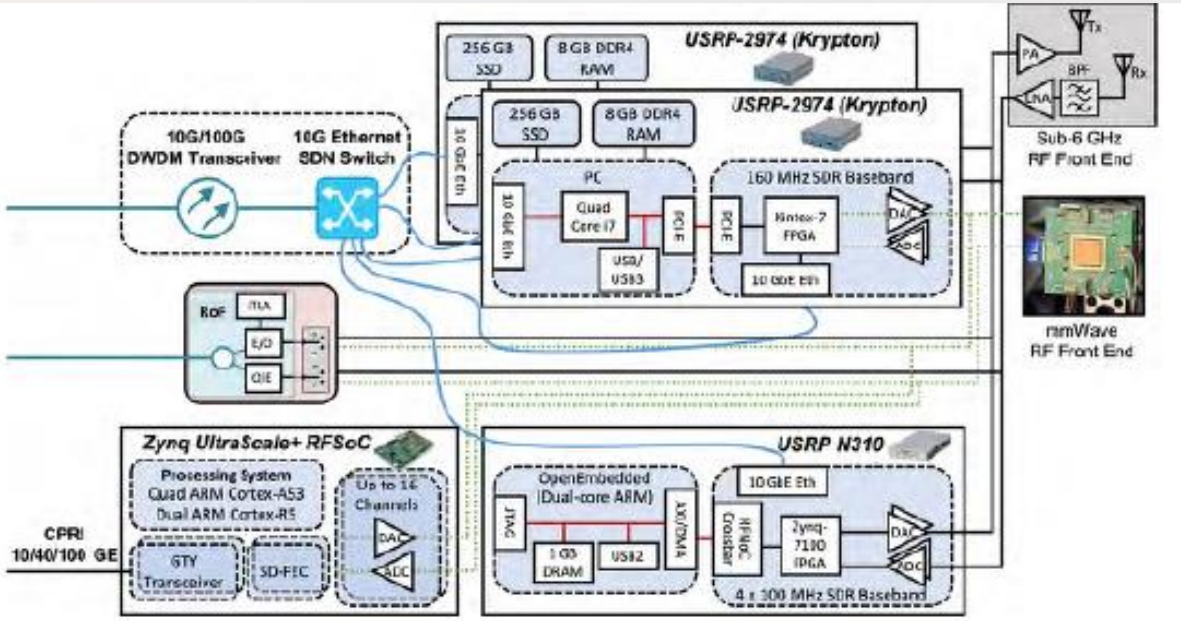
COSMOS Radio Site Design



All-Optical Network Design

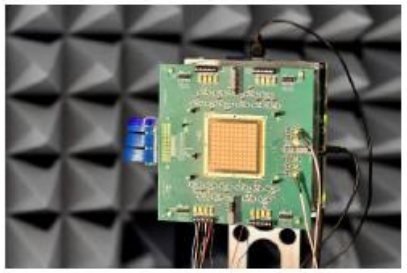
COSMOS Large and Medium Nodes





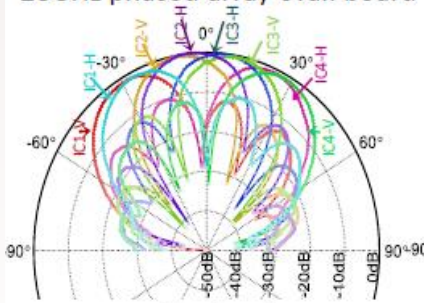
COSMOS mmWave Node Specifications

- 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

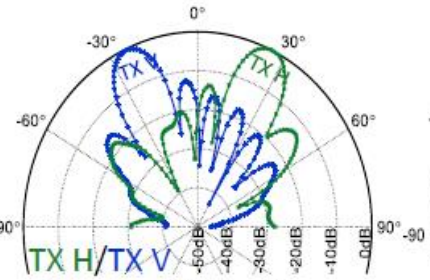


28GHz phased array eval. board

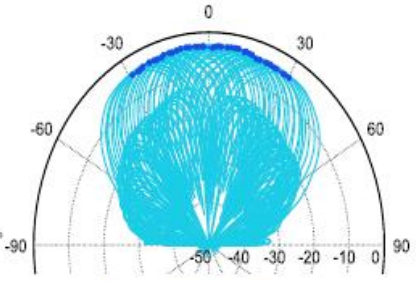
Example outdoor link experiment at IBM



Measured 8 simultaneous 16-element beams



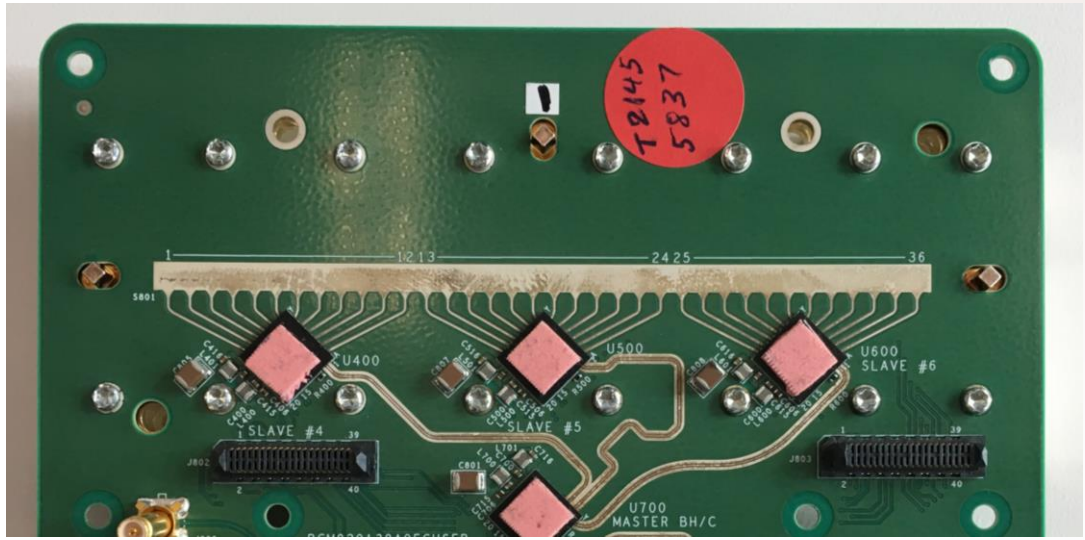
Measured 2 simultaneous 64-element beams



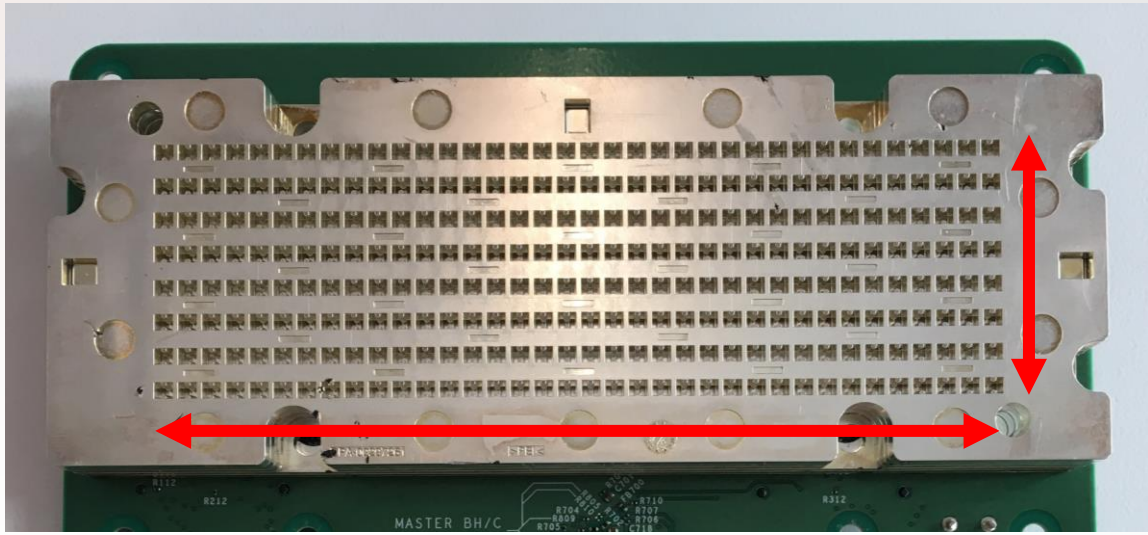
Measured Precise 1.4°/step beam steering

FaceBook TerraGraph 60GHz-Antenna Panel

Back: RFICs connecting to antenna feeds



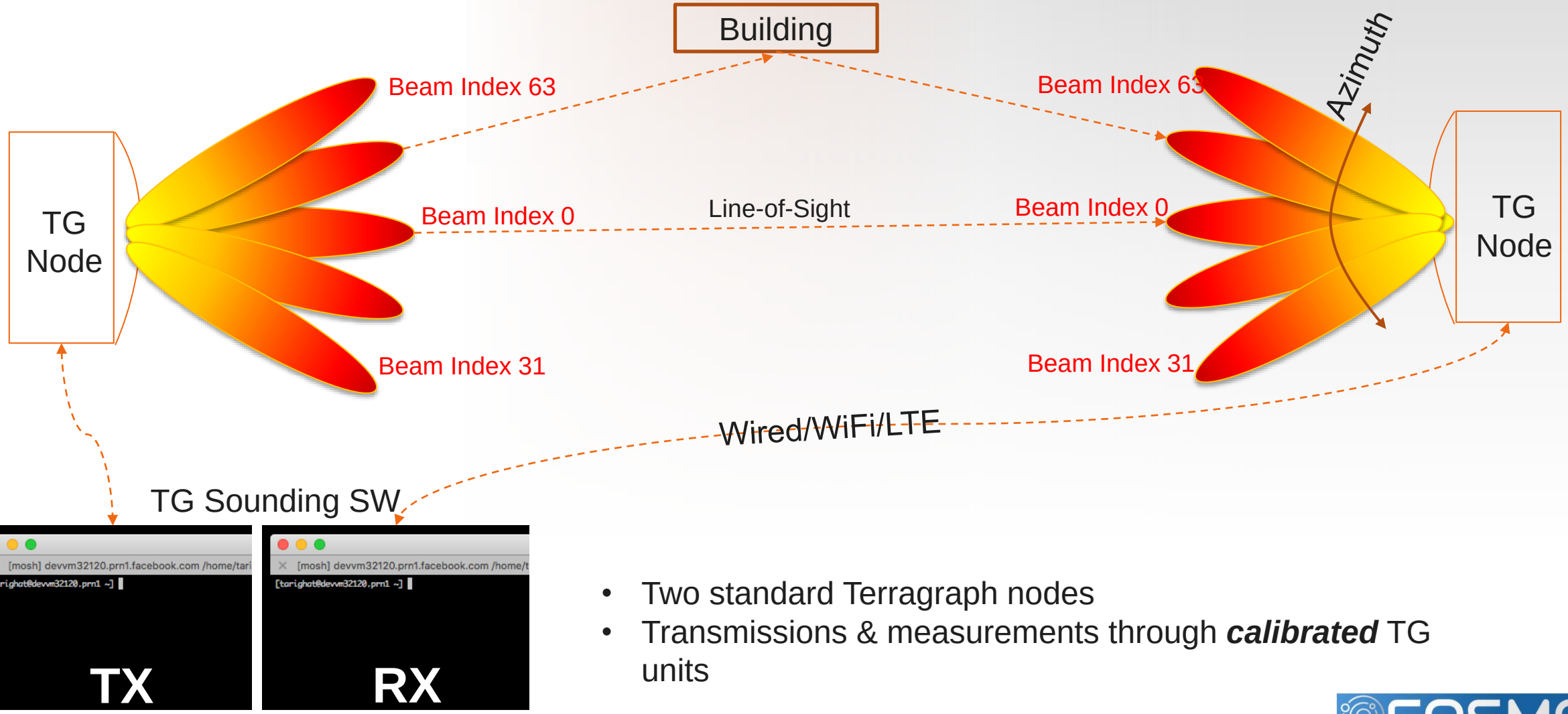
Front: Phased array antenna



8-Elements
(corporate feed)

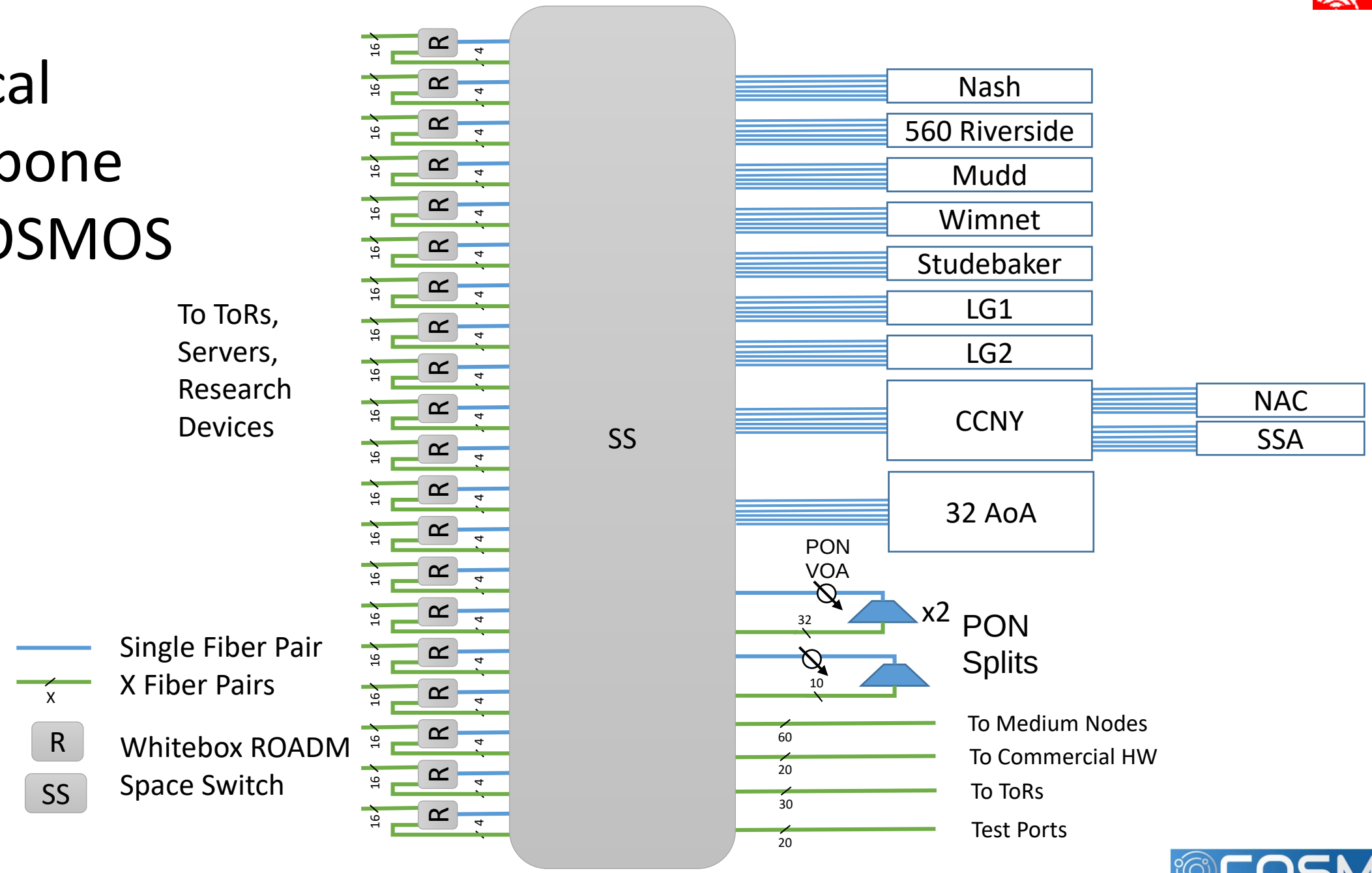
36 RF feeds
(independently controlled phase shifters)

Two Terragraph (TG) Nodes



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

Optical Backbone @ COSMOS



Central Facilities Space Switch Ports

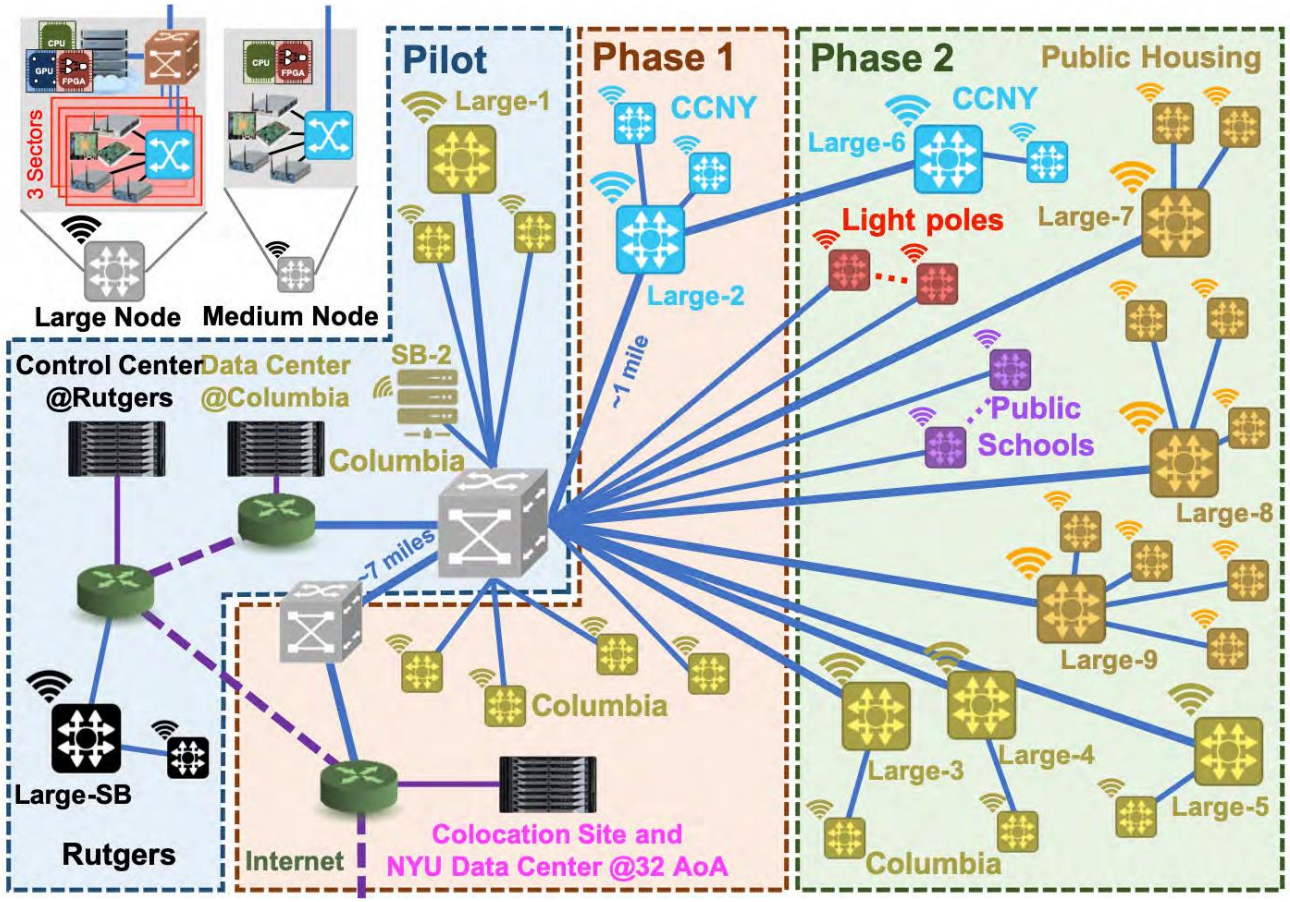
Base Configuration

- 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

Pilot COSMOS Network (Available Today)

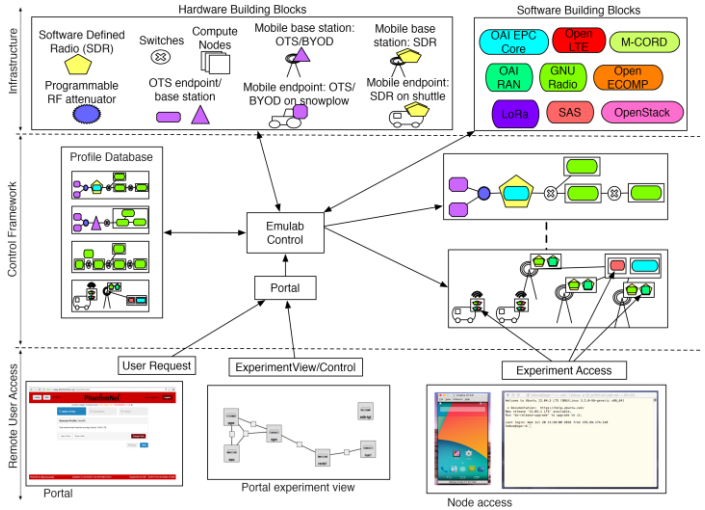
Base Configuration

- 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



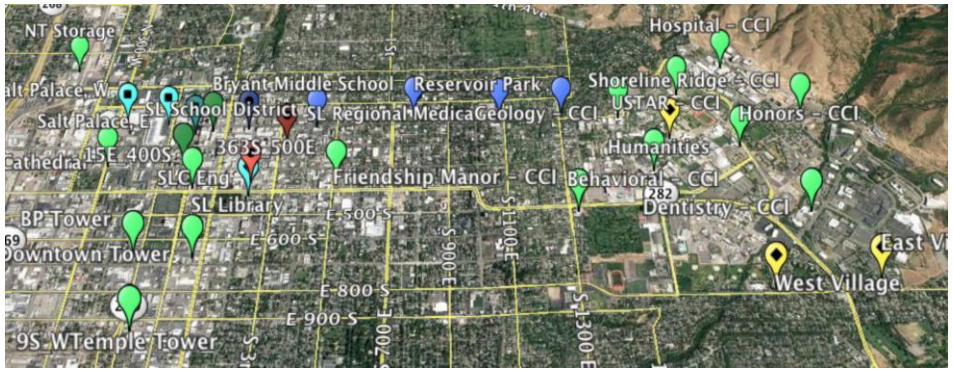
POWDER: Platform for Open Wireless Data-driven Experimental Research

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



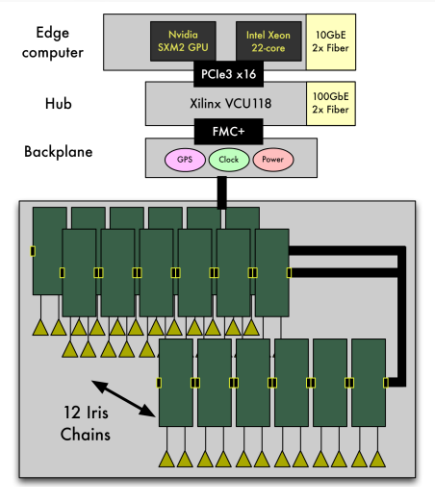
Control Framework with Hardware + Software Building Blocks

Deployment Area: UofU Campus +Downtown SLC + Connected Corridor



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

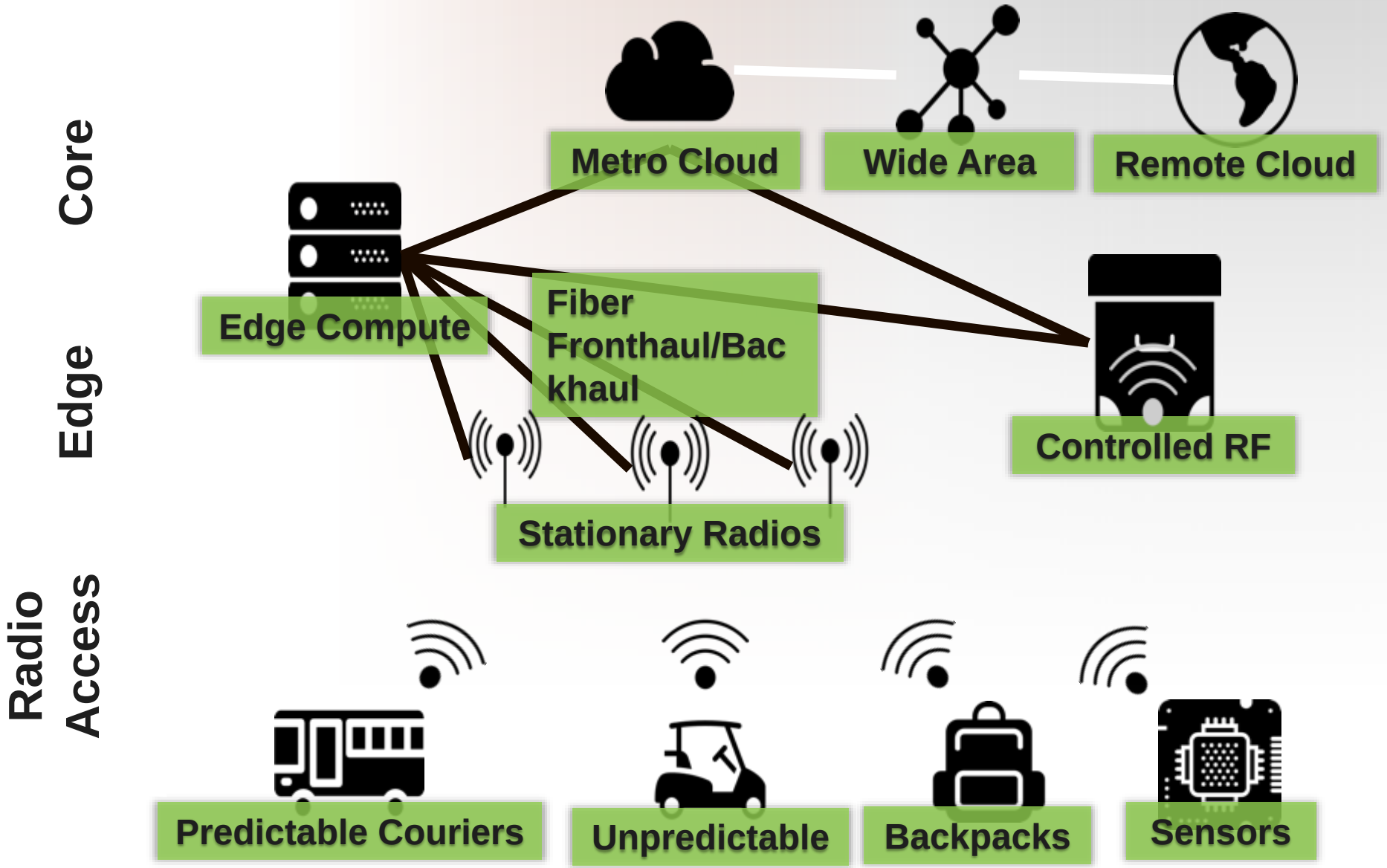
- RENEW Massive MIMO base station
- End-to-End Programmable
- Diverse Spectrum Access 50 MHz-3.8GHz
- Hybrid Edge computer composed of FPGA and GPU/CPU-based processing,
- Hub Board aggregates/distributes streams of radio samples



Architectural view of RENEW base station

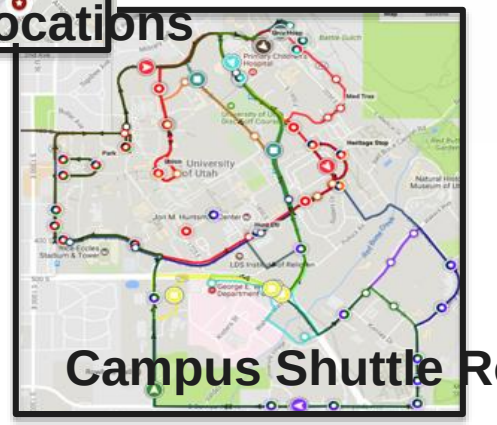
IRIS software-defined radio modules

System Architecture

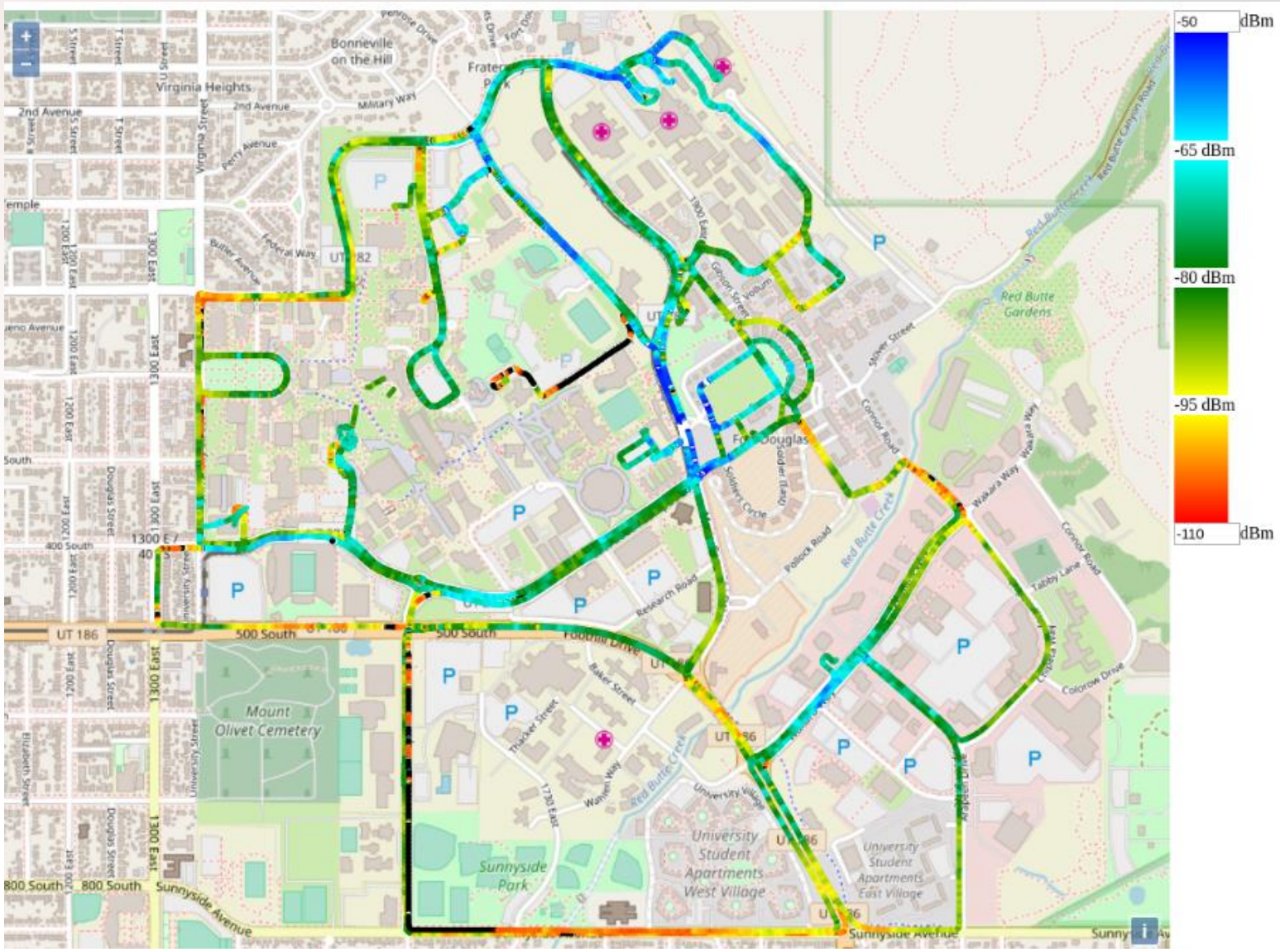


Truly City scale…

Basestation locations



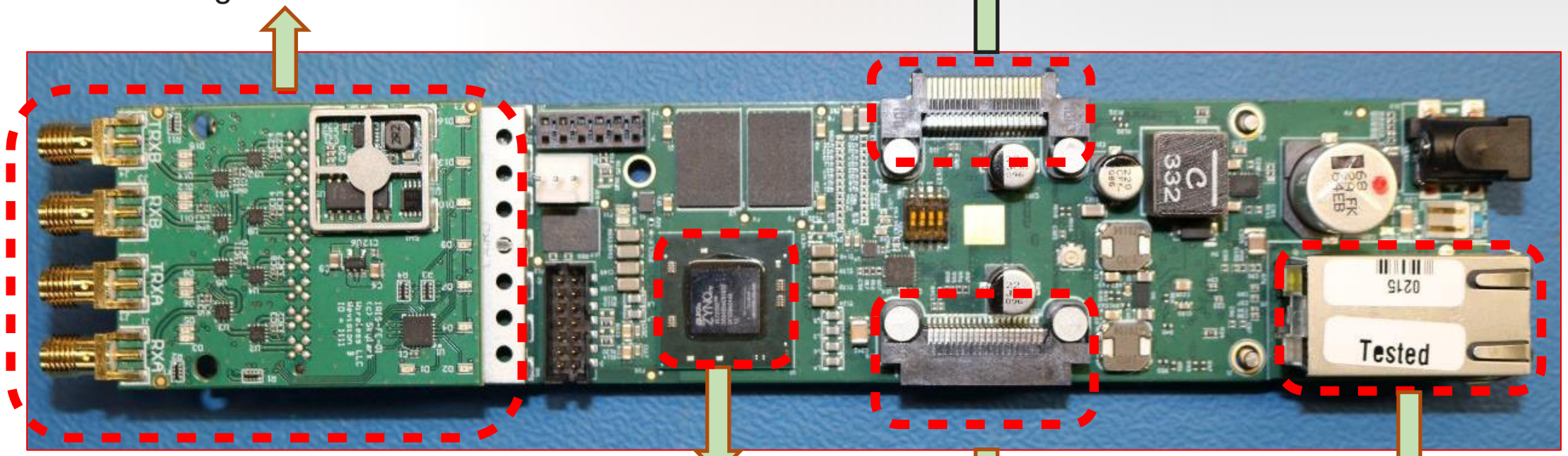
Campus Shuttle Routes



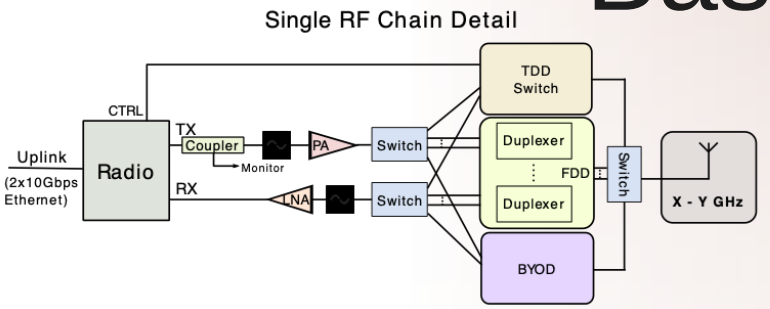
RENEW Massive-MIMO Base Stations

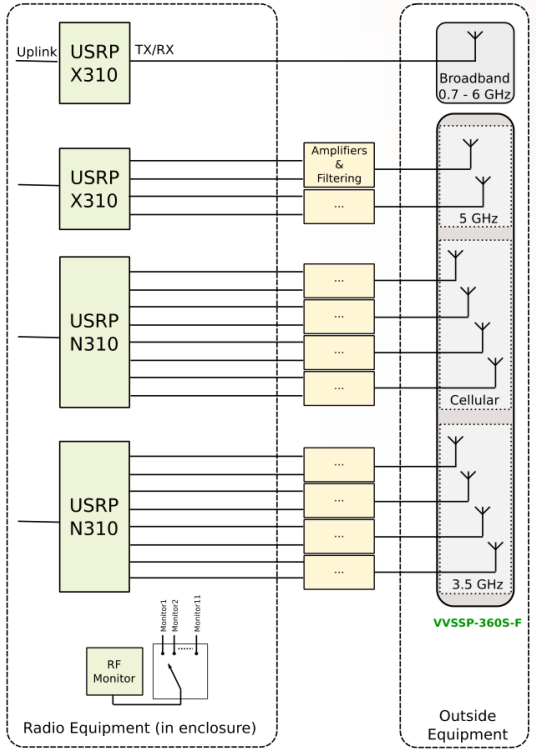
- Iris SDR is the building block
- 64-128 antenna configs
  - Next gen design targets 256-antennas
- 40 Gbps Ethernet backhaul through fiber
  - Next gen design targets 100Gbps link
- HW Built-in Clock Sync
  - Support for SyncE/PTP underway
- Software initiated triggers for time synchronization

Building Block: Skylark Iris Module



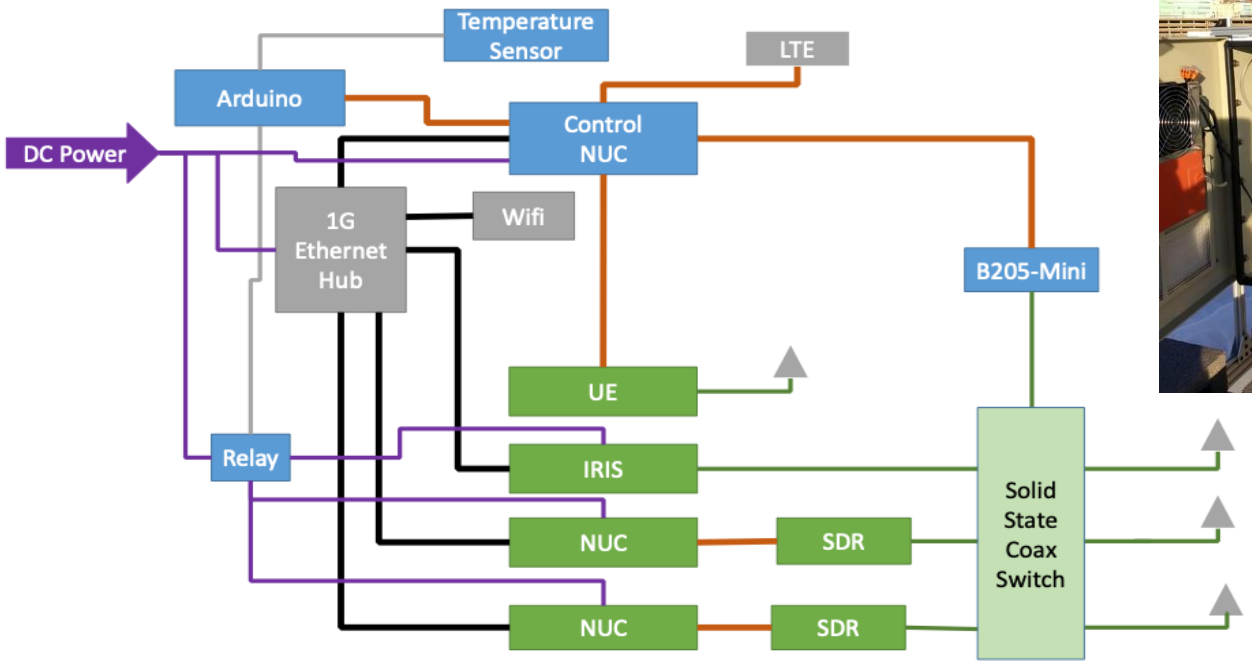
Stationary Radio (Rooftop Basestation)

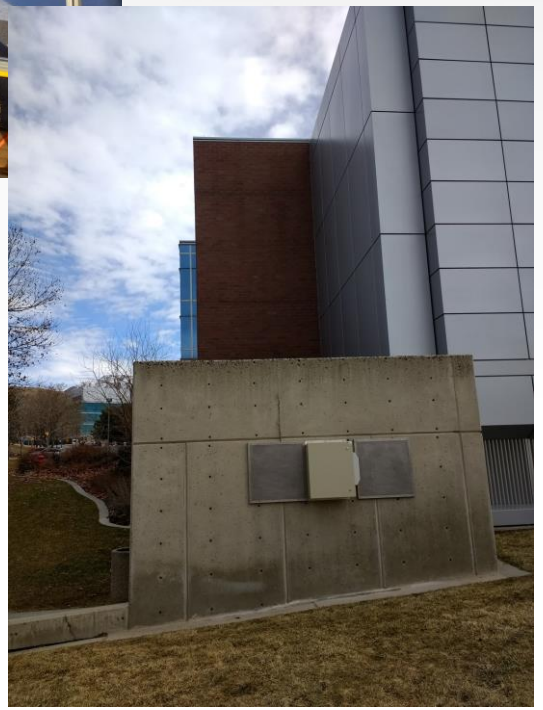




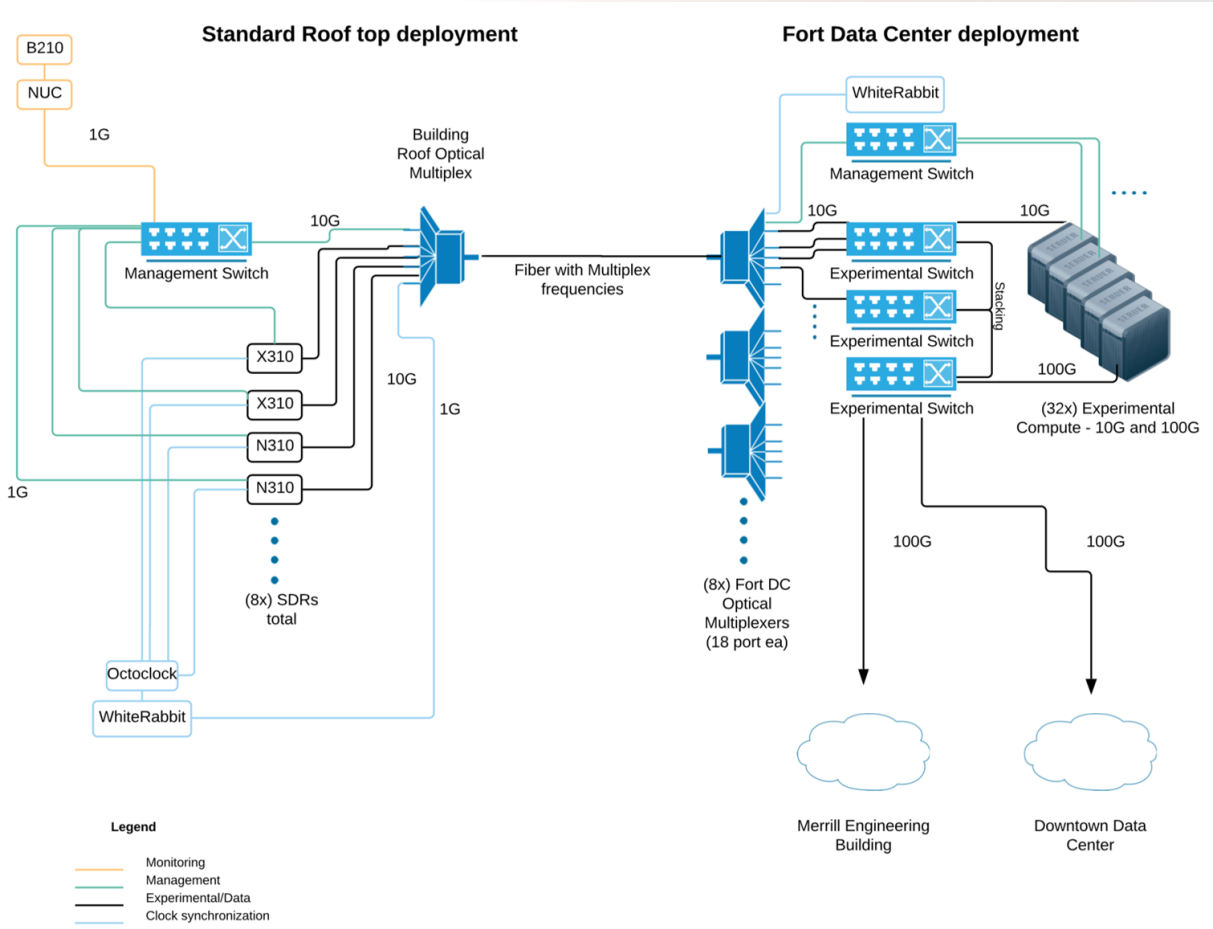
Powder Base Station RF Front-end

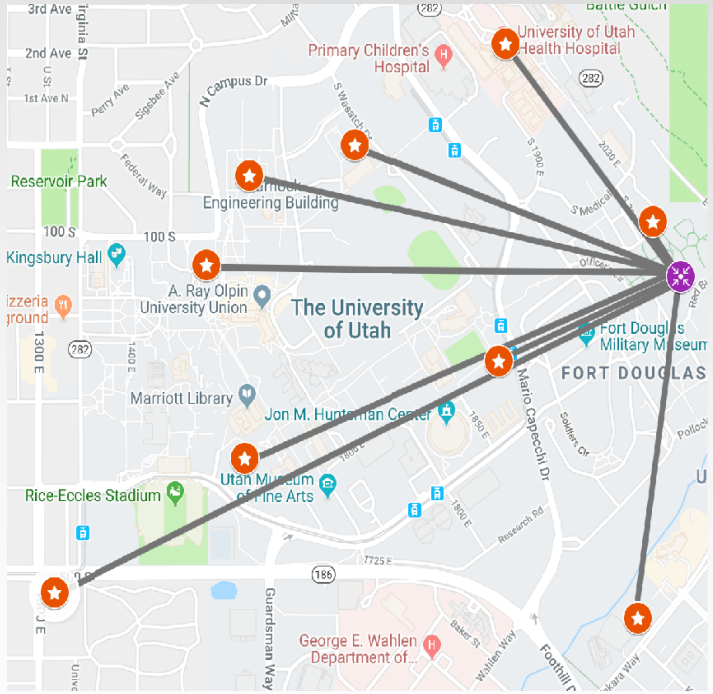
Fixed-endpoint





Edge compute, fiber fronthaul/backhaul

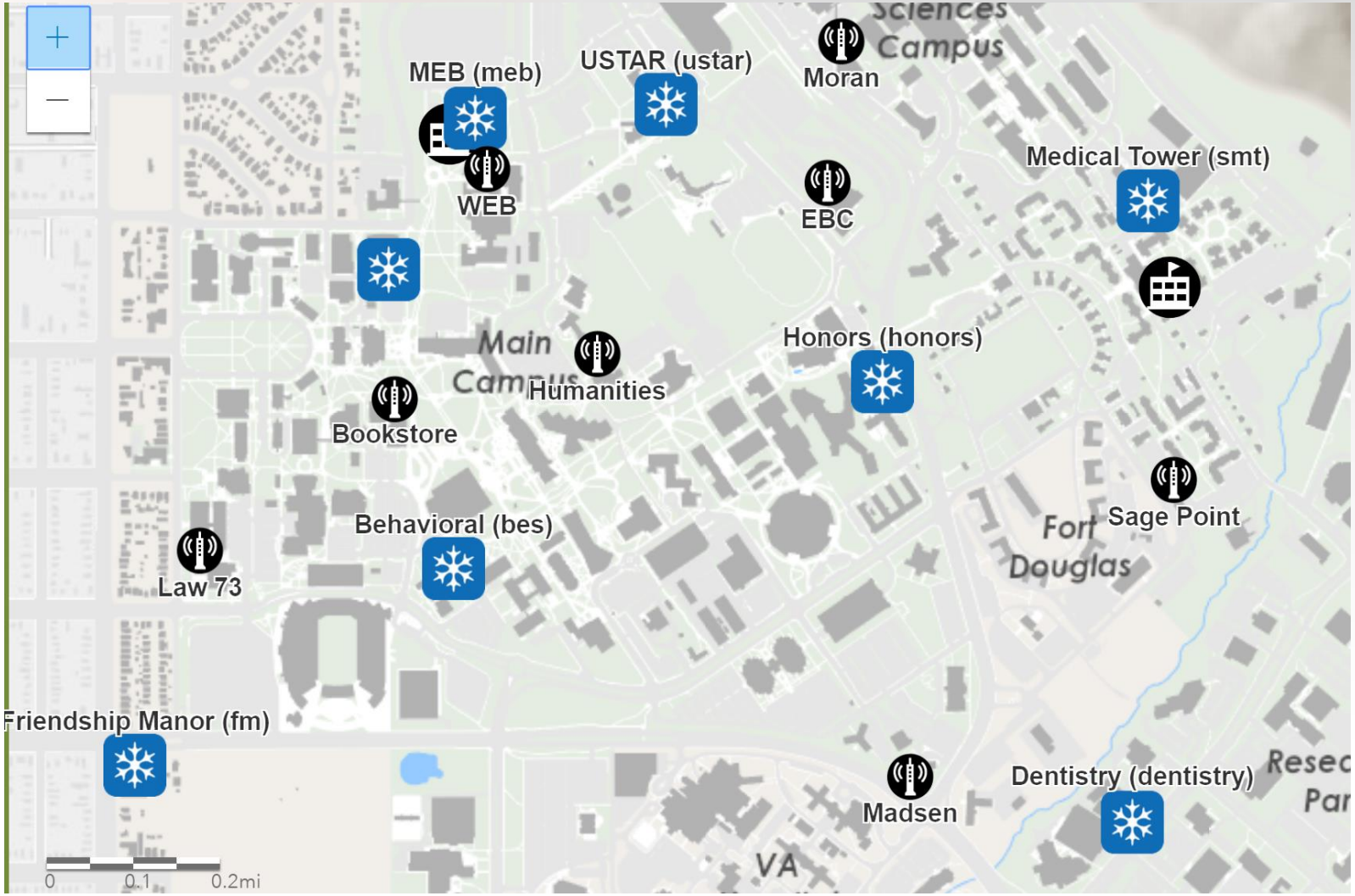




Pilot POWDER Network (Available Today)

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]



Looking Ahead: Shift in Focus

Applications drive Technical Requirements

- Open-ended for emerging and frontier ideas; focus on what is new and cutting-edge;
- Partner with Industry Vertical Experts to explore state of the what and the how;
- Provide solutions and specifications as well as relevant trade-offs and implications;
- Looking for various possible solutions to particular challenges

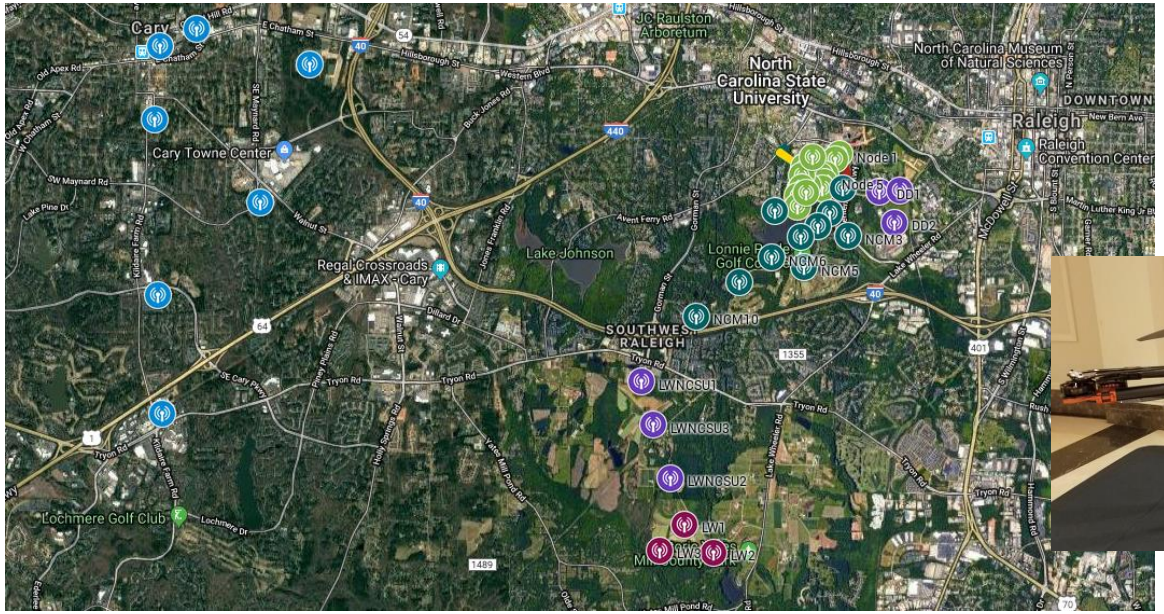
PAWR Round II Awardee

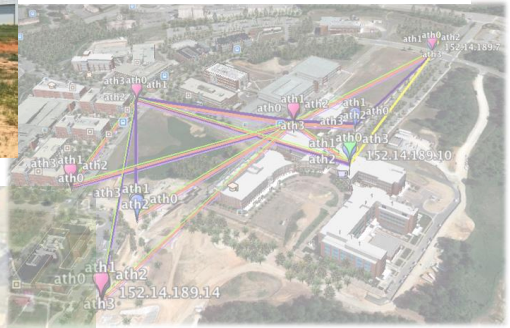
Announced Sept 18 2019

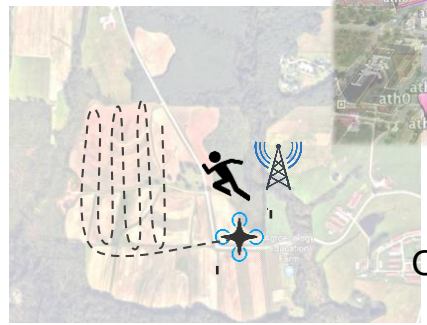
http://aerpaw.org

AERPAW: Aerial Experimentation and Research Platform for Advanced Wireless

- **Mobility** – Programmable autonomous UAVs & ground vehicles with AERPAW radio nodes
- **Software-defined radios** supporting existing (LTE) and emerging (5G) wireless at 1-6 GHz and then 28 GHz / 39 GHz
- **Rural to urban wireless environments** – Centennial, Lake Wheeler Field Lab, Cary, Dorothea Dix, eventually Raleigh…
- **Diverse drone experiments & use cases** – 4G/5G RAN experiments, propagation measurements, waveform design, localization/tracking, autonomous navigation, UTM, IoT for smart agriculture/city…
- **Reliable, supported, user-programmable, and remotely-accessible research infrastructure**








Operator

Town of Cary

NC STATE UNIVERSITY

wireless research center

MISSISSIPPI STATE UNIVERSITY

renci

PURDUE UNIVERSITY

UNIVERSITY OF SOUTH CAROLINA

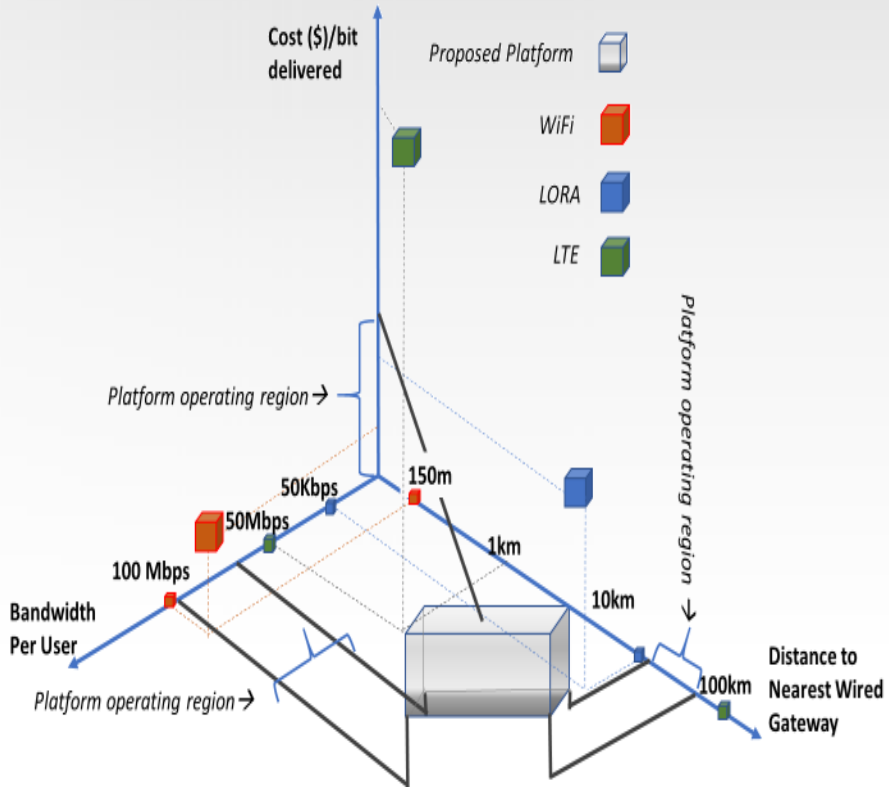
Raleigh

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

What Next ?

Round III RFP – Rural Broadband Focus

- ***Rural Focus:*** This third-round RFP seeks to focus on applying advanced wireless technologies to transform the deployment and operations of fast, low-latency, and reliable broadband networks in **rural and other low-density geographic areas** in an efficient and affordable way
- ***Innovative Technology****:* Proposers should create a testbed for experimenting with advanced wireless technologies and network architectures – combined with existing technologies – that may transform the existing rural broadband deployment cost curve through innovations in technologies and engineering processes



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