From 5G Trials to 6G Triumphs: Understanding Testing Complexity Issues

Open Research Infrastructures and Toolkits for 5G/6G R&D (OpenRIT 6G)
March 19, 2023

Ivan Seskar
WINLAB, Rutgers University
seskar@winlab.rutgers.edu

RUTGERS

WINLAB

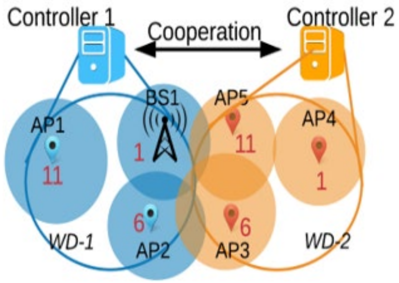
Rutgers, The State University of New Jersey / WINLAB

WINLAB 25,000 sq.ft. Tech Center Facility

WINLAB founded in 1989 as a collaborative industry-university research center with specialized focus on wireless networking

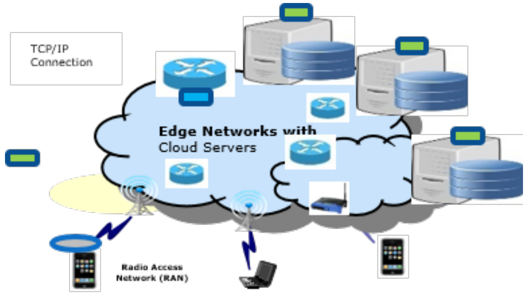
~25 faculty/staff, most from the ECE and CS departments at Rutgers
~40-50 grad students (80% PhD, 20% MS)

Center's research portfolio spans information theory, radio technology, wireless systems, mobile networks and computing

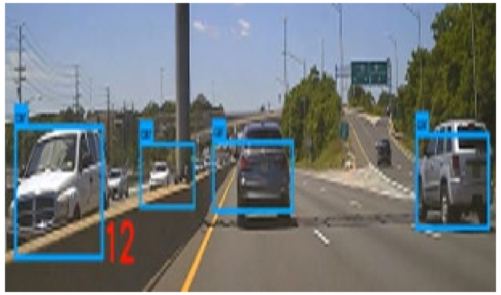


Dynamic Spectrum

Future Internet Arch.



Edge Cloud

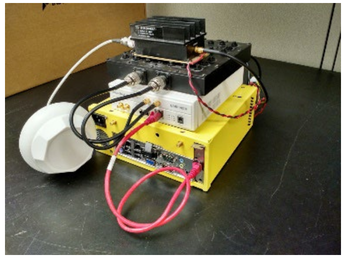


Connected Vehicle

Extensive experimental research infrastructure including COSMOS, ORBIT & GENI testbeds

Low Power IoT Device

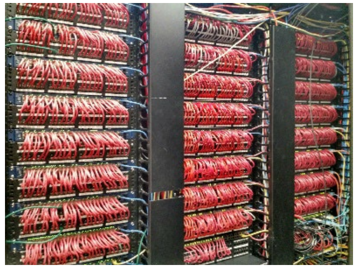
Massive MIMO



SDR

ORBIT Radio Grid Testbed

Computing Infrastructure



SDN

RUTGERS

WINLAB

Platforms for Advanced Wireless Research (PAWR)

- NSF public/private program ($50M + $50M)
- Managed by PAWR Project Office (NEU/US-Ignite)
- Build four “city scale” platforms in US
- Enable core wireless and mobile research
- Enable research related to services/applications that rely on wireless and mobile

POWDER
Salt Lake City

COSMOS
New York City

AERPAW
Research Triangle

ARA
Central Iowa

First round completed in early 2018:

- POWDER-RENEW (University of Utah, Rice University)
- COSMOS (Rutgers University, Columbia University, New York University)

Second round winner early 2020:

- AERPAW (North Carolina State University, Mississippi State University, RENCI)

Third round winner July 2021:

- ARA (Iowa State University)

Additional facilities and resources:

- Colosseum - The world's most powerful wireless network emulator
- OpenAirX-Labs (OAX) - An end-to-end open source 5G software lab

NSF

Platforms for Advanced Wireless Research

Objective : Take it Outside

COSMOS | RUTGERS | COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK | NYU | NYC | <sh> | The City College of New York | THE UNIVERSITY OF ARIZONA | IBM

COSMOS: Deployment Area

D. Raychaudhuri, I. Seskar, G. Zussman, T. Korakis, D. Kilper, T. Chen, J. Kolodziejski, M. Sherman, Z. Kostic, X. Gu, H. Krishnaswamy, S. Maheshwari, P. Skrimponis, and C. Gutterman, "Challenge: COSMOS: A city-scale programmable testbed for experimentation with advanced wireless," in *Proc. ACM MobiCom'20,* 2020.

COSMOS: Envisioned Deployment

- West Harlem with an area of ~1 sq. mile
  - ~15 city blocks and ~5 city avenues

- **Large** sites
  - Rooftop base stations
- **Medium** sites
  - Building side- or lightpole-mounted
- **Small** nodes
  - Including vehicular and hand-held

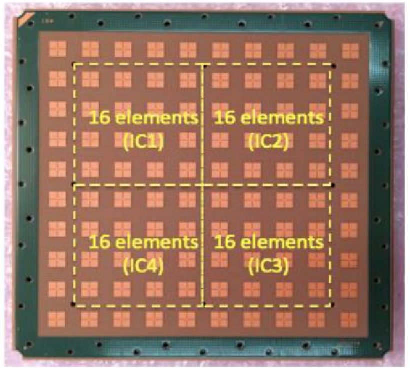
COSMOS Key Technologies

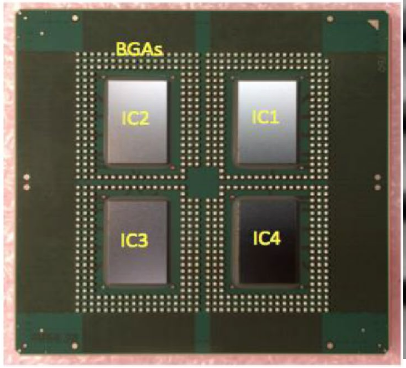
SDR

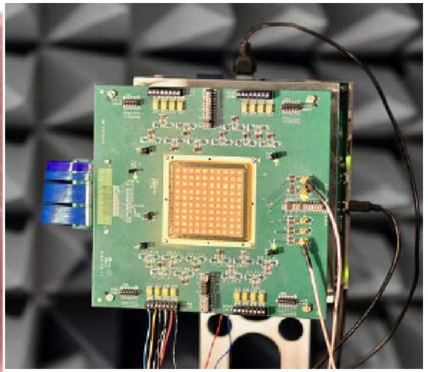
Design goal: 70 Mhz – 6 Ghz + 28 Ghz and 60 Ghz bands, ~500 Mhz BW, Gbps

mmWave

IBM 28 GHz mmWave phased arrays (64 antennas with 1 or 8 beams)

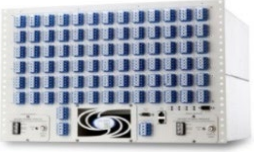




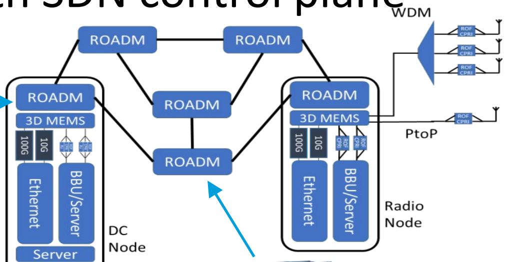


Optical Networking

Fast and low latency optical x-haul network using 3D MEMS switch and WDM ROADM - wide range of topologies with SDN control plane



MEMS Switch



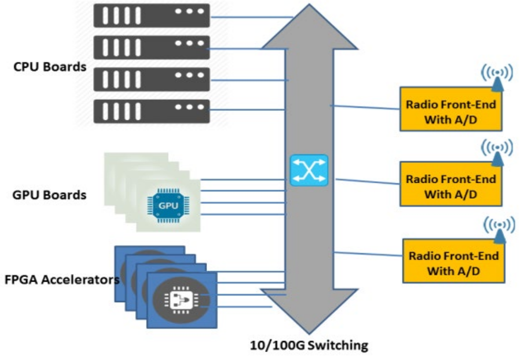
fast front-haul/mid-haul/back-haul connectivity between radio nodes and edge cloud

ROADM (whitebox)

SDN and (distributed) Cloud

Compute clusters with choice of CPU, GPU and FPGA proc.

SDN control plane used to control x-haul and (near) cloud server connectivity



Access to regular (far) cloud racks over L3

COSMOS

RUTGERS

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

NYU

NYC

<sh>

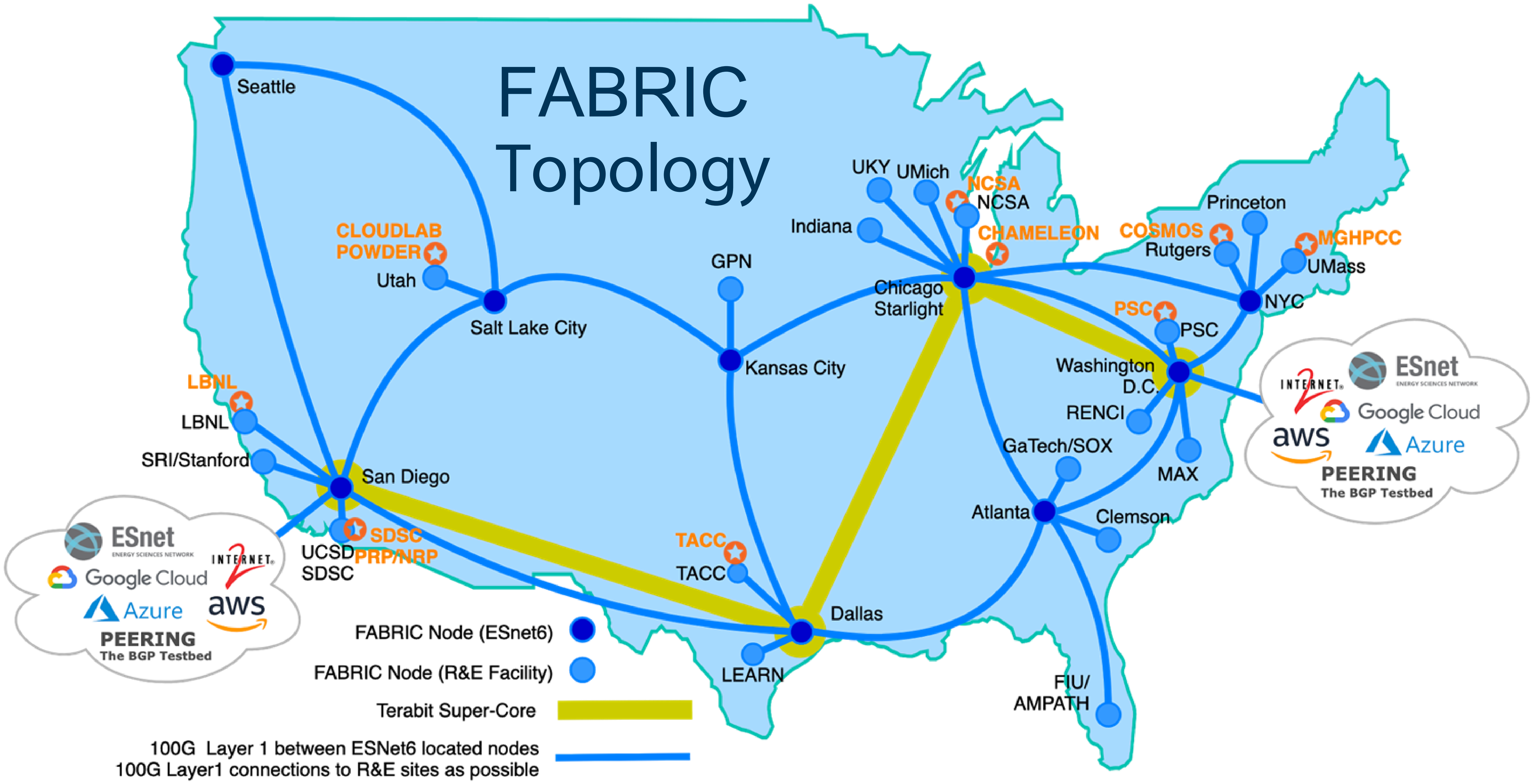
The City College of New York

THE UNIVERSITY OF ARIZONA

IBM

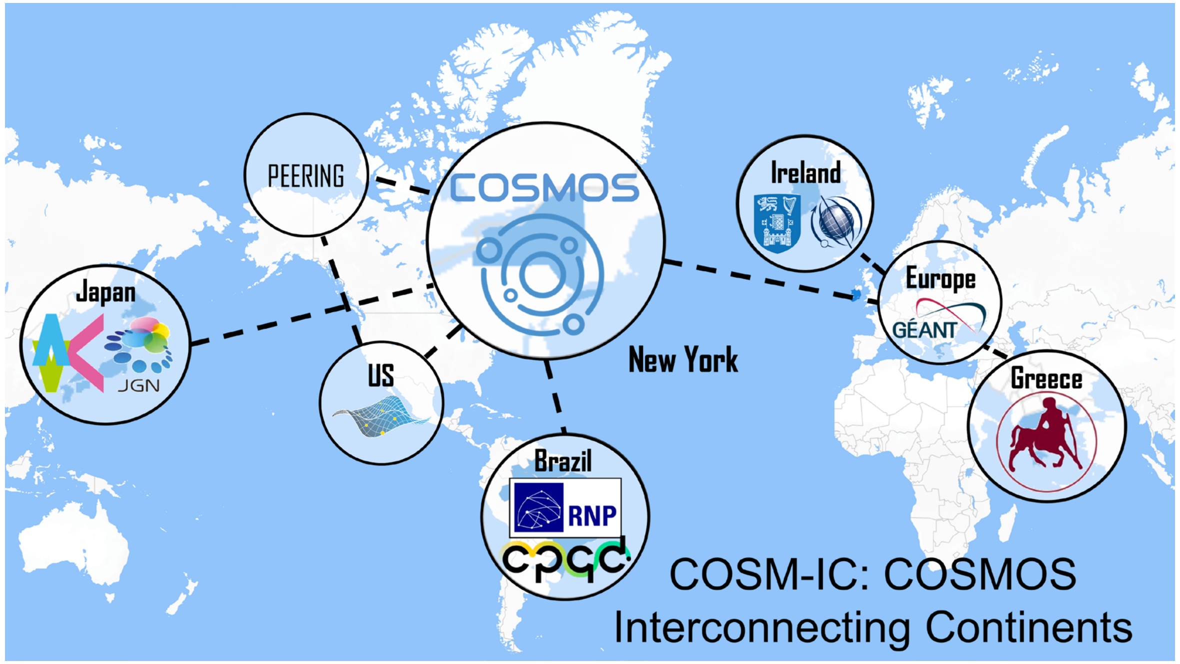
FCC Innovation Zone

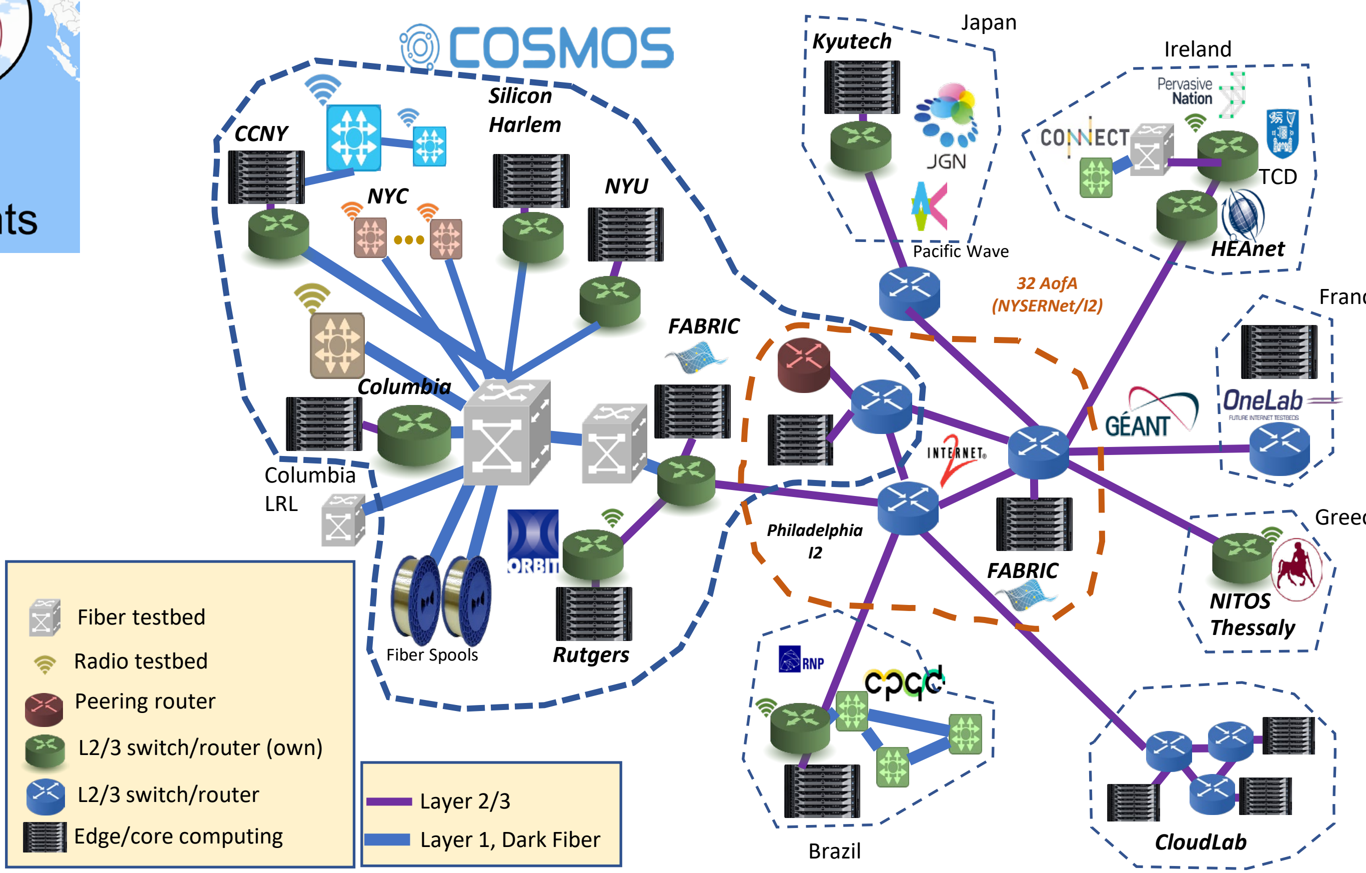
Frequency band	Type of operation	Allocation	Maximum EIRP (dBm)
2500-2690 MHz	Fixed	Non-federal	20
3700-4200 MHz	Mobile	Non-federal	20
5850-5925 MHz	Mobile	Shared	20
5925-7125 MHz	Fixed & Mobile	Non-federal	20
27.5-28.35 GHz	Fixed	Non-federal	40
38.6-40.0 GHz	Fixed	Non-federal	40



FABRIC Testbed

Implementation of connectivity between several wireless/optical/IoT testbeds to support global experimentation



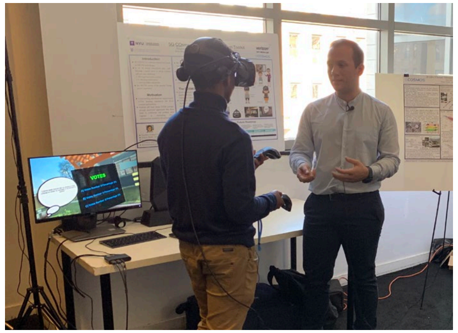


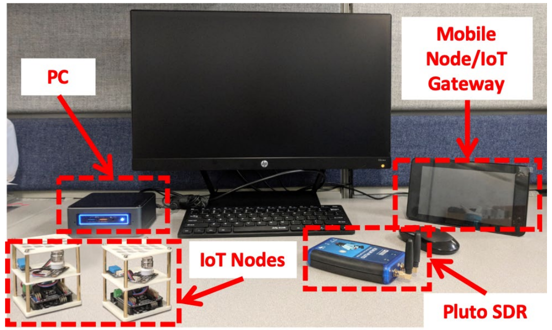
Research Plan:

- Cross Layer SDX Experimentation
- Mininet Optical with Data-Driven Platform Models
- Federating with and via PEERING
- EIR (Edge Aware Interdomain Routing) Experimentation
- Education and Outreach

COSMOS/EFRI Research Experience and Mentoring for Teachers (RET/REM)

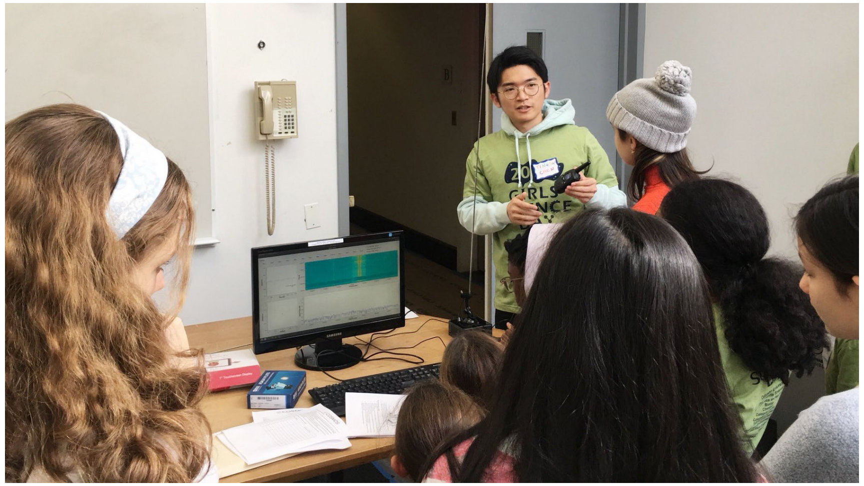
- Building on Summers 2018–2022 programs for teachers
- the COSMOS education toolkit - A small pre-configured COSMOS node offering 100+ K–12 educational labs in Math/Science/CS using SDRs
- Toolkit is remote/virtual since 2022


5G COVET



COSMOS education toolkit


COSMOS Research Experiences for Teachers (RET) program


Columbia Girls' Science Day

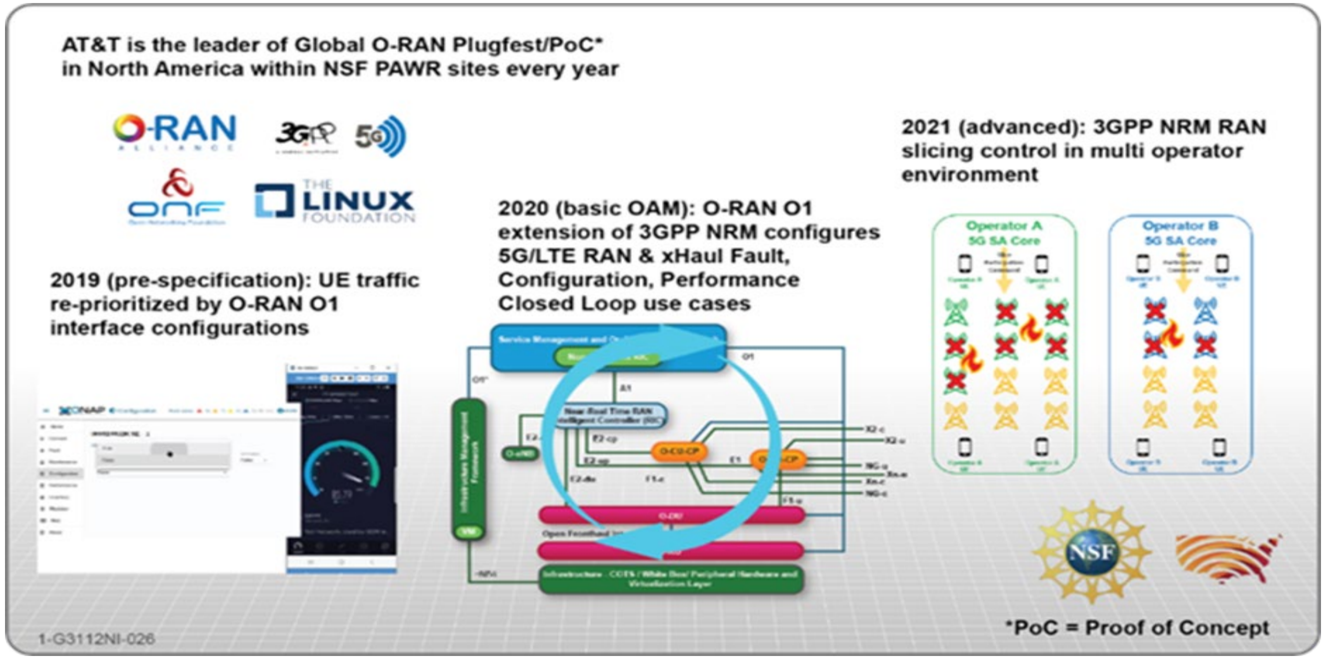

Students in Frederick Douglass Academy using the COSMOS toolkit

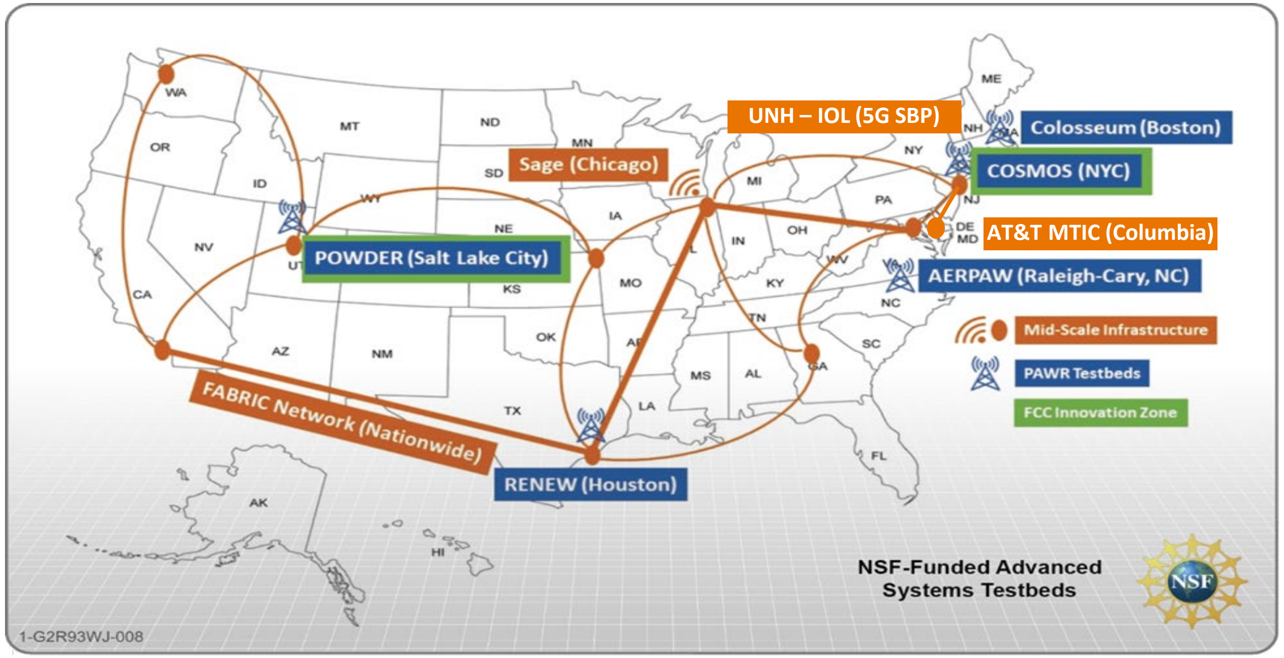
- P. Skrimponis, N. Makris, K. Cheng, J. Ostrometzky, Z. Kostic, G. Zussman, T. Korakis, and S. Borges Rajguru, "Evaluation: A teacher professional development program using wireless communications and NGSS to enhance STEM teaching & learning," in *Proc. ASEE Annual Conference*, 2020.
- P. Skrimponis, N. Makris, S. Borges Rajguru, K. Cheng, J. Ostrometzky, E. Ford, Z. Kostic, G. Zussman, and T. Korakis, "COSMOS educational toolkit: Using experimental wireless networking to enhance middle/high school STEM education," *ACM SIGCOMM Computer Communication Review*, vol. 50, no. 4, pp. 58–65, 2020.

LaaS - Lab as a Service

The Platform for Advanced Wireless Research program is enabling experimental exploration of new wireless devices, communication techniques, networks, systems, and services that will revolutionize the nation's wireless ecosystem while sustaining US leadership and economic competitiveness for decades to come. PAWR is funded by NSF and a wireless Industry Consortium of 30 companies and associations.

AT&T established the Open Wireless Lab (OWL) within Rutgers/WINLAB (now NSF PAWR COSMOS) in 2016. (https://wiki.onap.org/display/DW/Open+Wireless+Lab)





O-RAN Proofs of Concept & Plugfests "PoC-fests"

O-RAN PoC-fests support the ecosystem players in testing and integration of their solutions, ensuring the openness and interoperability of O-RAN solutions from different providers.

AT&T has been a co-leader of the O-RAN/LFN/ONF joint PoC-fests within NSF PAWR sites every year since the inception of O-RAN

7th global O-RAN PoC/Plugfest – 4Q 2023
6th global O-RAN PoC/Plugfest – 2Q 2023
5th global O-RAN PoC/Plugfest – 4Q 2022
4th global O-RAN PoC/Plugfest – 2Q 2022
3rd global O-RAN PoC/Plugfest – 4Q 2021
2nd global O-RAN PoC/Plugfest – 3Q 2020
1st global O-RAN PoC/Plugfest – 4Q 2019

New Jersey Indoor Facility

25,000 sq.ft. indoor facility with large open (7,000 sq.ft.) lab space

Permanent setup for ONAP/ORAN experimentation:

- 6 control nodes
- 30 compute nodes
- Number of other (vendor) components

Three permanent agile dev. configurations (OpenStack/ONAP/ORAN):

- Stable
- Development
- Experimental

Additional (on-demand) resources:

- Main outdoor COSMOS testbed (West Harlem, NYC, NY)
- Indoor testbed (North Brunswick, NJ):
- Indoor grid (400 nodes)
    - 2 larger sandboxes (8 nodes)
    - 8 smaller sandboxes (2 nodes)

WINLAB 25,000 sq.ft. Tech Center Facility

O-RAN Key Deployment Scenarios & Use Cases

O-RAN adopter radios/basebands in dominant vendor RAN

- O-RAN adopter indoor and small cell systems overlay on dominant vendor macro network
- O-RAN adopter radios integrated with dominant vendor VRAN baseband stack
- Dominant vendor macro radios integrated with O-RAN adopter VRAN baseband stack
- Performance parity testing in a mixed RAN environment

O-RAN adopter baseband hardware in dominant vendor RAN

- VRAN deployment of dominant vendor RAN DUs on commodity IT silicon in Hybrid Multi-Cloud environments
- Performance parity testing in a mixed RAN environment

O-RAN adopter resource management/automation in a dominant vendor environment (multi-subnet, Core / Transport / Access)

- O-RAN adopter (3rd party) rApps and SMO in dominant vendor RAN
- O-RAN adopter (3rd party) xApps and nRT-RIC in dominant vendor RAN

O-RAN MVP "Intelligent Package" of AI/ML-enabled use cases

- Traffic Steering
- QoS and QoE Optimization
- RAN Slicing and SLA Assurance
- SMO (Service Management and Orchestration)
- Energy Saving/ Energy Efficiency
- Massive MIMO Optimization
- Multi-vendor Slices
- O-RAN Dynamic Spectrum Sharing
- RAN Slice Resource Allocation Optimization
- Local Indoor Positioning in RAN
- Massive MIMO SU/MU-MIMO Grouping Optimization
- O-RAN Signaling Storm Protection
- Congestion Prediction and Management
- Industrial IoT Optimization
- O-DU Pooling to Achieve RAN Elasticity

Updates (November 2023)

O-RAN PlugFest

- Hosting 7th consecutive O-RAN PlugFest: 2 teams with 6 vendors and operator co-hosts: AT&T, DISH, Verizon.

Added/Upgraded Lab Capabilities

- Increased (O-RAN dedicated) cloud capacity
- Anritsu test instrumentation; Fujitsu indoor and outdoor deployment; Nokia outdoor deployment

Certification and Badging updates

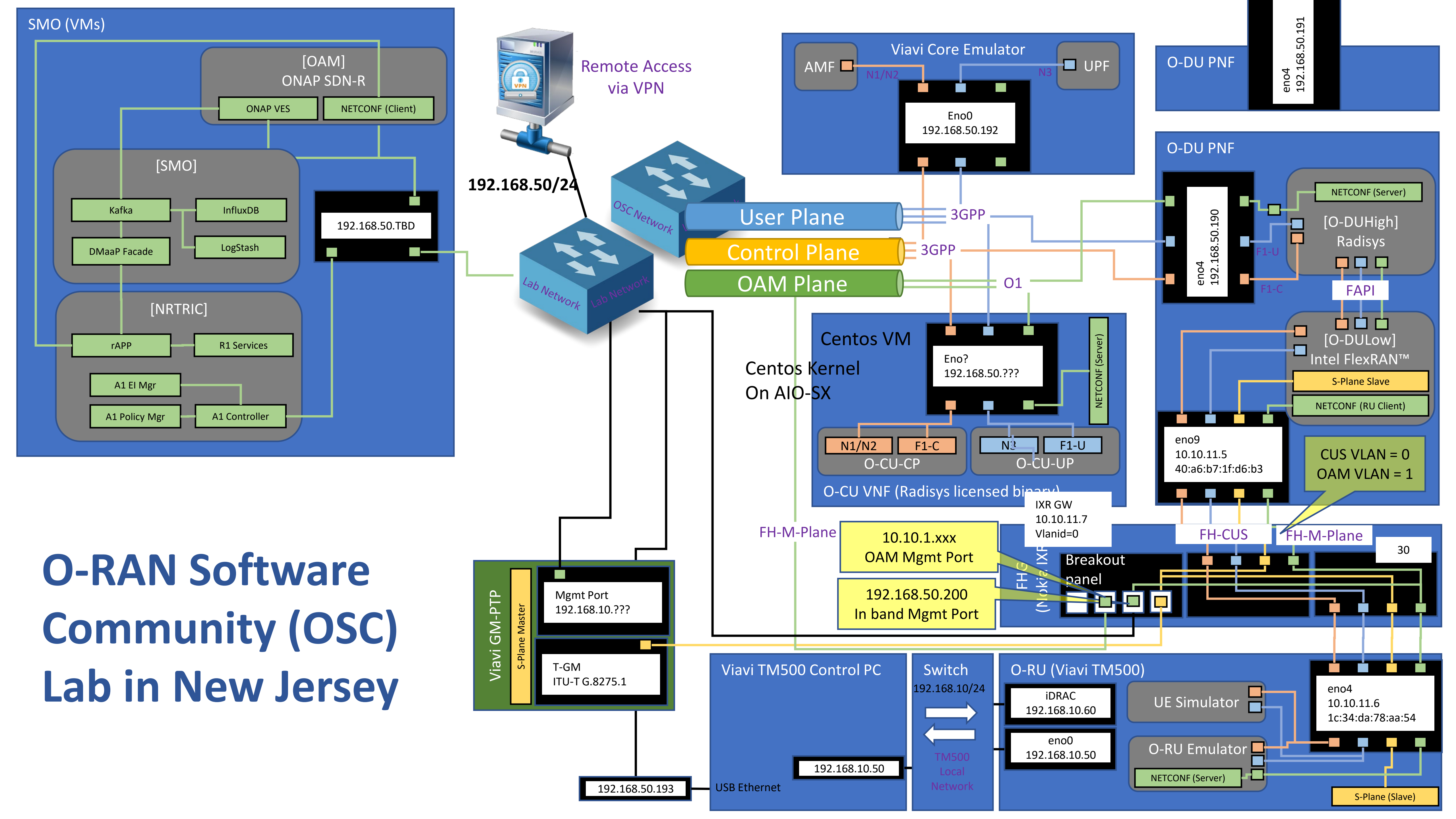
- Still no certification or badging request by vendors

Other O-RAN relevant activities

- Served as dev & test environment for open-source O-RU controller selected for inclusion within NTIA 2023 5G Challenge https://5gchallenge.ntia.gov/ and winner of Best in Show and Wraparound Emulation prizes
- Participation in 1st OTIC summit
- Continuous integration of AI-enabled multi-operator orchestration prototype
- Deployment of open-source (and SDR) based end-to-end (OAI, srsRAN, and Amarisoft)
- Undergraduate/graduate summer internship with introductory O-RAN curriculum: https://www.orbit-lab.org/wiki/Other/Summer/2023/OH2023
- Numerous national and international visitors
- Serving as dev & test environment for NTIA 2024 RIC Forum

Copyright © by the O-RAN ALLIANCE e.V.

O-RAN Software Community (OSC) Lab in New Jersey



PoC: AI Planner, rApps, Multi-operator SMO

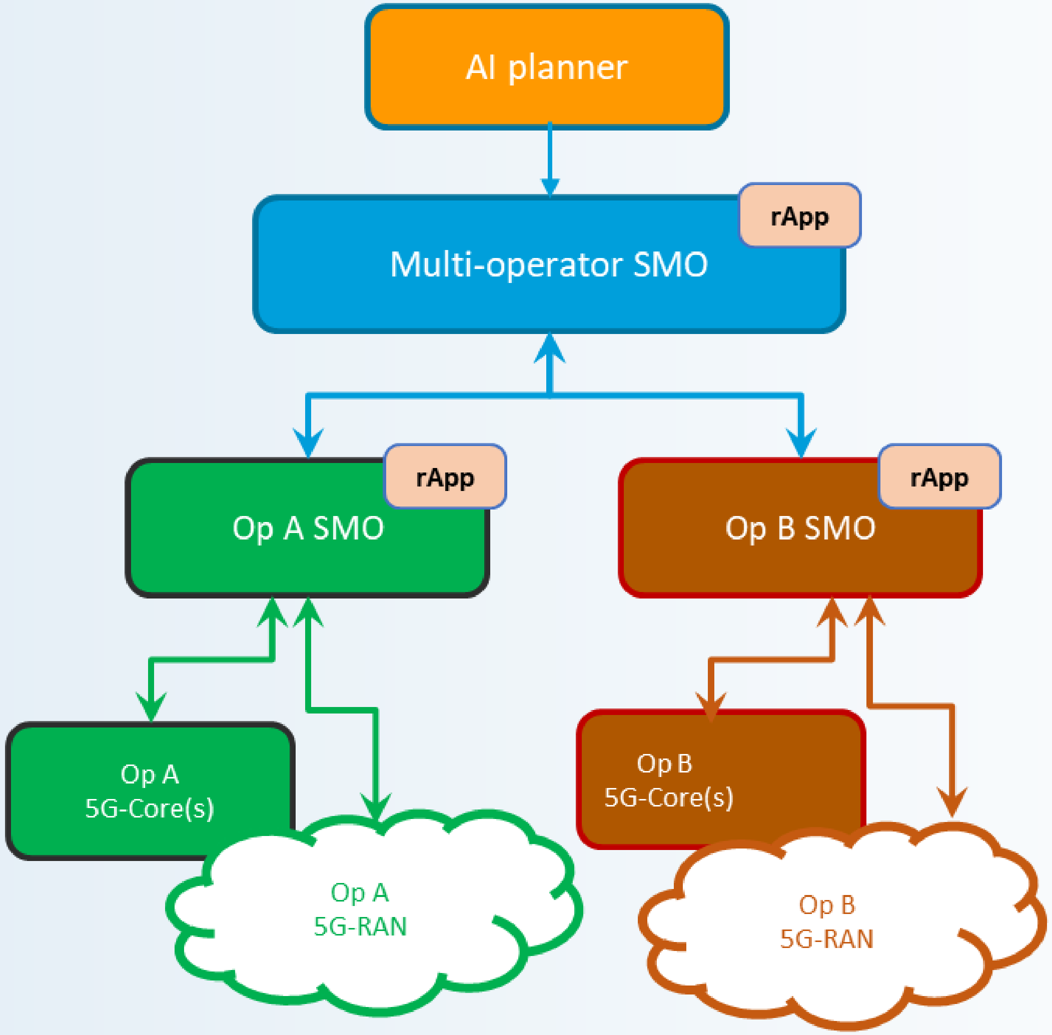
AI planner, along with a Multi-operator SMO (Service **Management & Orchestration), utilizes multiple networks & technologies,** and accelerates decision-making to manage resources within ~seconds.

AI Planner:

- Incorporates knowledge and strategies/tactics of human experts
- Constructs plans to achieve the goals, including resilience, security, and QoE objectives
- Conveys commands to the multi-operator SMO
- Creates hierarchical plans through iterative refinement, easily understandable by humans
- Explainability: unlike deep learning systems, planner is a “white box” (Human-Centered AI)

rApps:

- Open RAN-enabled intelligent apps
- Map mission/user objectives to network objectives
- Monitor network status and communicate with SMOs



Observations

- We need performance parity in parallel with conformance testing
- Lack of "true" interoperability testing
- Identified need for increase emphasis on security
- Insistence on testing with particular T&M equipment vendors (normalizing data?)
- End-to-end is still very elusive
- No willingness to share measured KPIs with public
- Smaller and new innovative vendor don't have the bandwidth for multiple time consuming and cost intensive certification processes.
- Need E2E baseline performance tests (and calibration) and benchmarks (and publishing E2E performance results)

Copyright © by the O-RAN ALLIANCE e.V.

Observations (2)

- Diverse vendor ecosystem creates problems for potential interoperability issues and whether SW components can effectively interact with diverse HW elements.
- Disaggregated Architecture necessitates robust testing to ensure the AI/ML models in the RIC can effectively manage and coordinate these disaggregated elements
- Increased attack surface due to open architecture of O-RAN (includes assessing the AI/ML models' susceptibility to adversarial attacks)
- Current tests (and certification procedures) are not adequate for evaluation of AI/ML based solutions
- Energy consumption problem (extra "0")!

Copyright © by the O-RAN ALLIANCE e.V.

Escalating Challenges Towards 6G

1. The Complexity of Testing (AI/ML Components)
   - Challenges in testing AI/ML-driven RICs
   - The need for simulations and real-world testing environments
2. Ensuring Repeatability in Testing
   - The significance of repeatability in AI/ML component testing
   - The challenge of requiring massive data sets for effective training
3. Diverse Data for Robust Model Verification
   - The necessity for diverse and complex data
   - How varied data ensures model performance across scenarios

6G Testing Challenges

- **Replicating Real-World Conditions:** Creating test environments that accurately reflect the dynamic and ever-changing nature of 6G networks (sensing, terahertz spectrum, etc.)
- **Balancing Efficiency and Comprehensiveness:** Striking a balance between efficient testing methodologies and ensuring comprehensive evaluation of AI/ML models (performance, security, robustness, etc.).
- **Evolving Standards and Protocols:** 6G is still under development; testing frameworks need to be adaptable.
- **Standardization of Testing Methods:** The lack of standardized testing methodologies for AI/ML in 5G networks adds to the complexity; establishing robust and standardized testing procedures will be vital for 6G.
- **Scalability and Resource Management:** Testing AI/ML models for 6G will require significant computational resources. Developing efficient algorithms and scalable testing infrastructure will be critical.

Relevant Links

Related links:

- WINLAB: https://www.winlab.rutgers.edu
- ORBIT: https://www.orbit-lab.org/
- PAWR: https://advancedwireless.org/
- COSMOS: https://www.cosmos-lab.org/ Twitter: **#pawrcosmos**
- CS3: https://cs3-erc.org/
- Open Wireless Lab: https://wiki.onap.org/display/DW/Open+Wireless+Lab
- OSC: https://wiki.o-ran-sc.org/