COSMOS: An Open, Programmable, City-Scale Wireless and Optical Testbed

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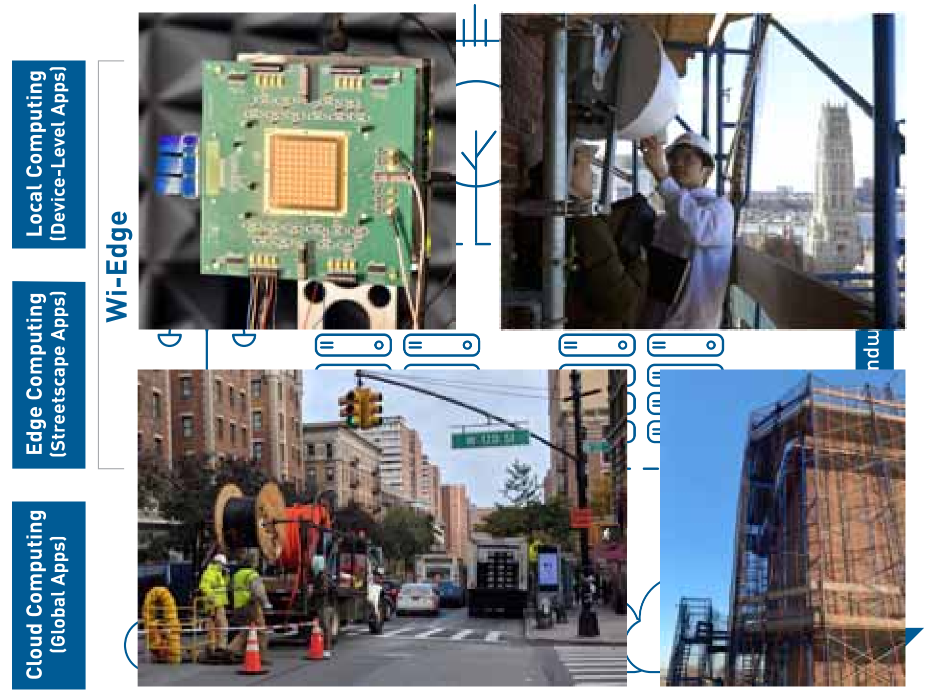
COSMOS: Project Vision

- Latency and compute power are two important dimensions and metrics
- Edge computing can enable real-time applications
- Objective: Real-world investigation or urban environments with
  - Ultra-high bandwidth (~Gbps)
  - Low latency (<5 ms)
  - Bandwidth densities (~10 Tbps/km^2)
- Enablers:
  - 10s of 64-element millimeter-wave arrays
  - 10s of miles of Manhattan dark fiber
  - B5G edge cloud base stations
  - Programmability



Ultra-high bandwidth, low latency, and powerful edge computing will enable new classes of real-time applications. Domains including AR/VR, connected cars, smart city (with high-bandwidth sensing), and industrial control

COSMOS: Envisioned Deployment

- West Harlem with an area of ~1 sq. mile
  - ~15 city blocks and ~5 city avenues
- ~9 Large sites
  - Rooftop base stations
- ~40 Medium sites
  - Building side- or lightpole-mounted
- ~200 Small nodes
  - Including vehicular and hand-held

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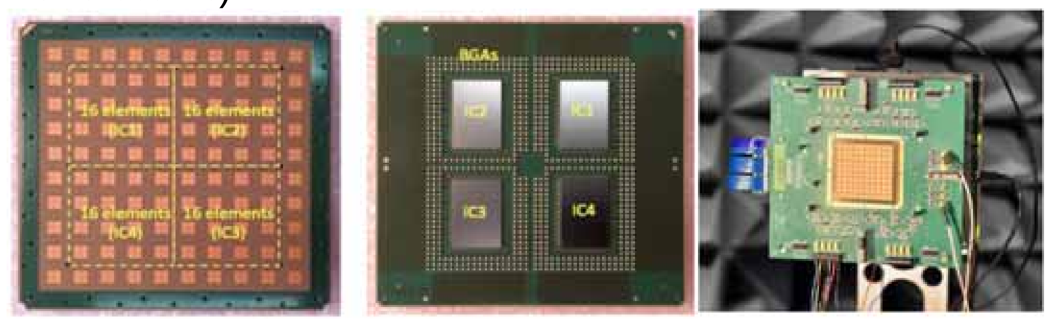
COSMOS Key Technologies

SDR

Design goal: 400 Mhz – 6 Ghz + 28 Ghz and 60 Ghz bands, ~500 Mhz BW, Gbps

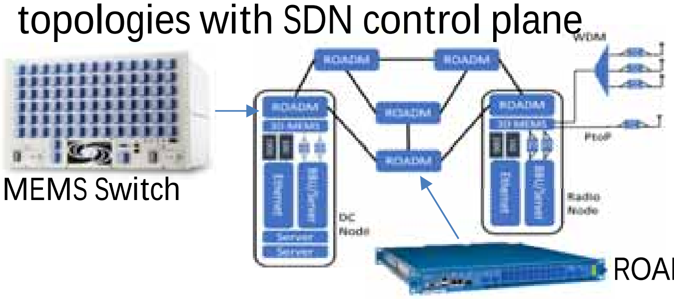
mmWave

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

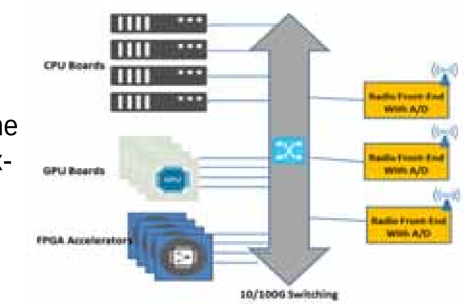
ROADM (whitebox)

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

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

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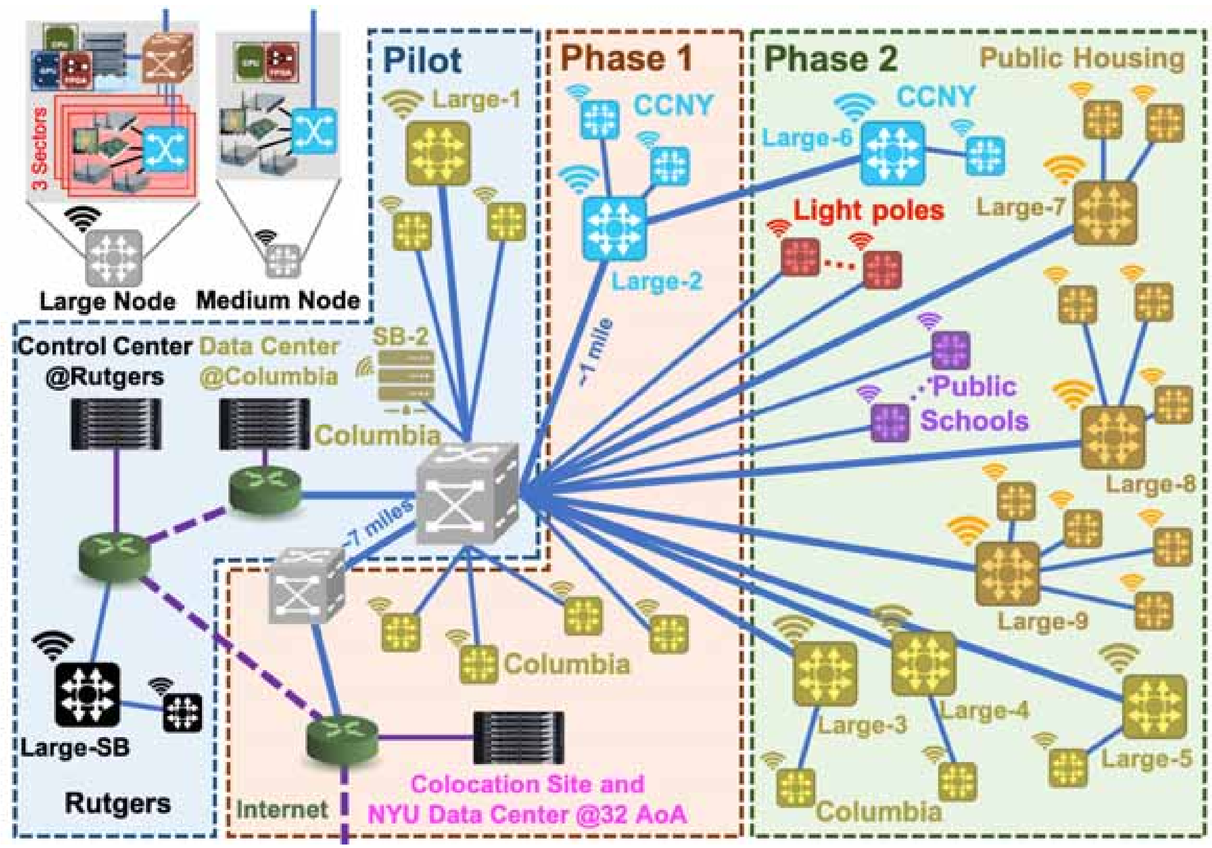
COSMOS: Phased Deployment

- A phased approach:
  - May 2019: Pilot completion
  - Sept. 2019: FCC Innovation Zone
  - June 2020: General Available
  - During 2021*****: Phase 1 completion

  *Deployments affected by the COVID-19 pandemic

- Fiber connection to CCNY sites
- Fiber connection to Rutgers, NYU Data Center (at 32 Ave. of Americas), GENI, and Internet2, etc.
- Connections to international partners (COSM-IC Project)



COSMOS Experimental Licenses

FCC Innovation Zone: "The New York City Innovation Zone encompasses area bounded by W 120th Street on the south, Amsterdam Avenue to the east, W 136th Street to the north and Hudson River on the west"

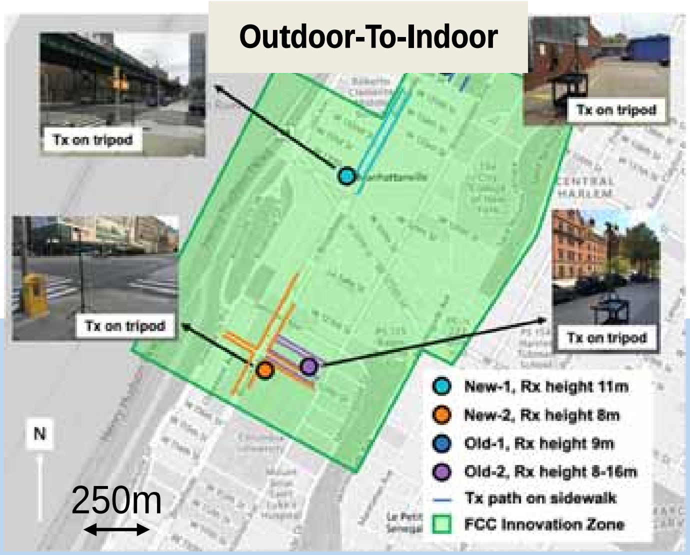
Frequency Band	Type of operation	Allocation	Maximum EIRP (dBm)
2500-2690 MHz	Fixed	Non-federal	20*
3700-4200 MHz	Mobile	Non-federal	20*
5850-5925 MHz	Mobile	Shared	20*
5925-7125 MHz	Fixed & Mobile	Non-federal	20*
27.5-28.35 GHz	Fixed	Non-federal	40*
38.6-40.0 GHz	Fixed	Non-federal	40*

(Additional) Program Experimental License: at Rutgers, Columbia and CCNY campuses

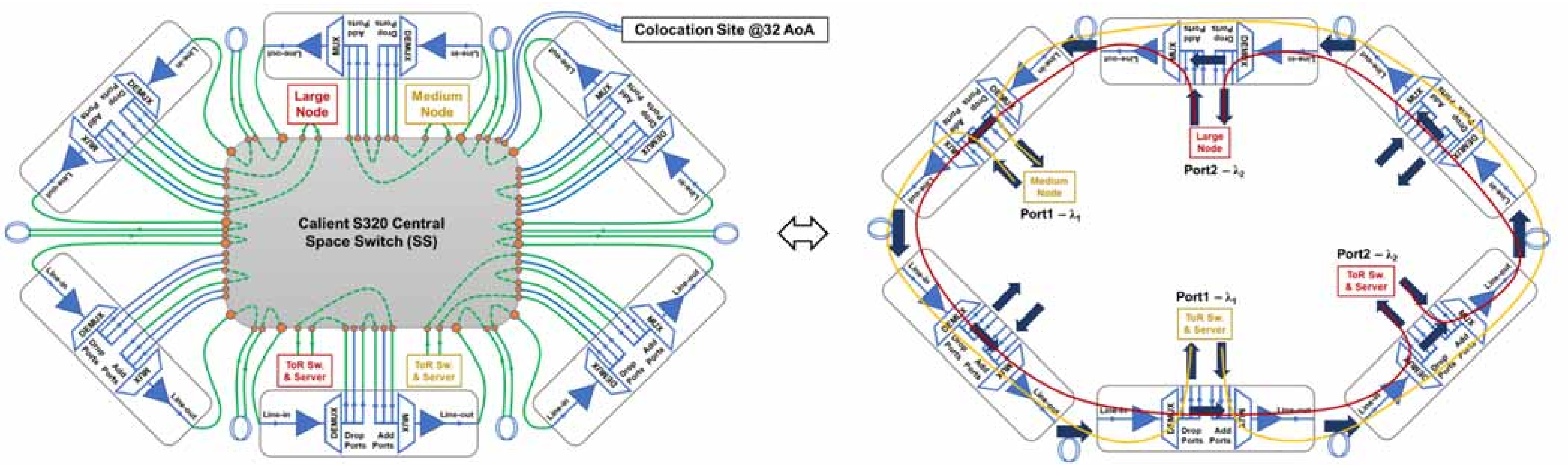
Nokia Bell Labs’ 28 GHz Measurement Campaign

(in collaboration with WiMNet Lab at Columbia)
Spring 2019-Spring 2022

- The COSMOS testbed deployment area and the FCC Innovation Zone are representative of a ***dense urban street canyon*** environment
- Representative (potential) deployment sites of mmWave BSs (building rooftops, street light poles, etc.)
- Extensive **outdoor** measurements on various ***long sidewalks*** (e.g., up to 1.1 km) with ***fine-grained link step size*** (e.g., 1.5/3 m)
  - Over **41 million** power measurements were collected from over **2,600 links** on **22 sidewalks** in **4 different sites** and in different settings
- (ongoing) Extensive outdoor-to-indoor measurements within buildings with ***fine-grained link step size*** (e.g., 1.5/3 m)
  - Over **45 million** power measurements were collected from over **2,837 links** in **9 different sites**



- D. Chizhik, J. Du, R. Valenzuela, “Universal path gain laws for common wireless communication environments”, to appear in IEEE Transactions on Antennas and Propagation, 2021
- J. Du, D. Chizhik, R. Valenzuela, R. Feick, M. Rodríguez, G. Castro, T. Chen, M. Kohli, and G. Zussman, “Directional measurements in urban street canyons from macro rooftop sites at 28GHz for 90% outdoor coverage,” *IEEE Transactions on Antenna and Propagation*, vol. 69, no. 6, pp. 3459–3469, June 2021.
- T. Chen, M. Kohli, T. Dai, A. D. Estigarribia, D. Chizhik, J. Du, R. Feick, R. Valenzuela, and G. Zussman, “28GHz channel measurements in the COSMOS testbed deployment area,” in *Proc. ACM MobiCom’19 Workshop on Millimeter-Wave Networks and Sensing Systems (mmNets)*, 2019.



Composable X-Haul Networks

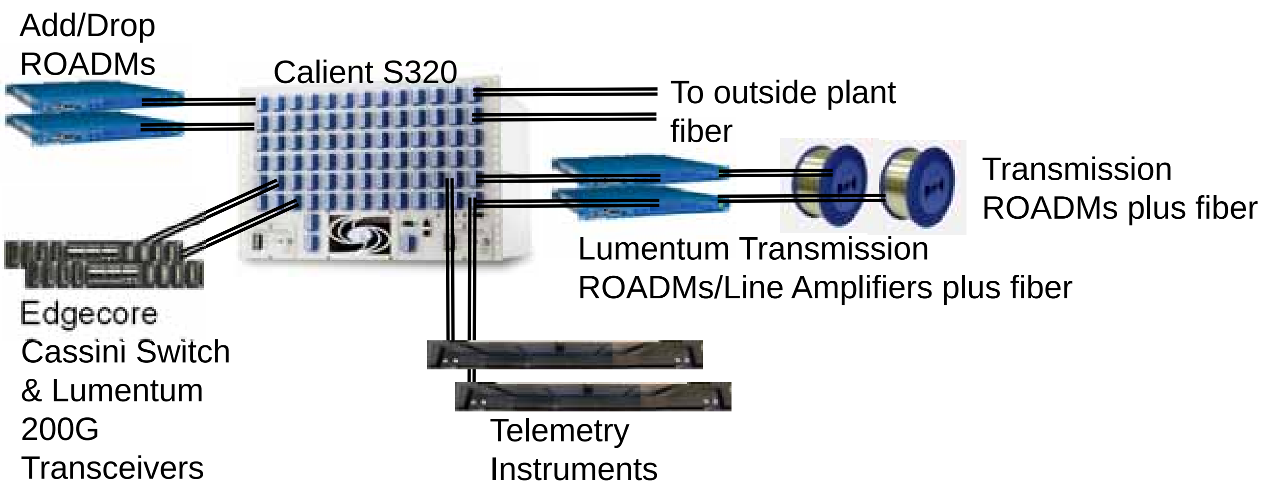
Use Calient switch to configure different network topologies, different add-drop configurations

Pilot: In lab + 32 AoA link

Full Deployment: Lab + Any large node

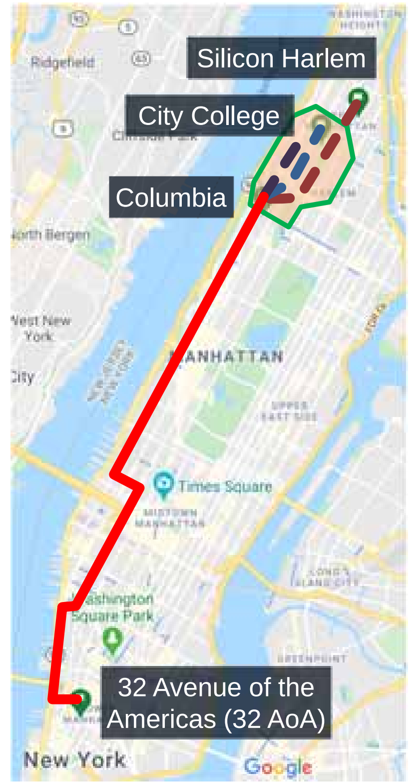
Optical Telemetry & Control Testing

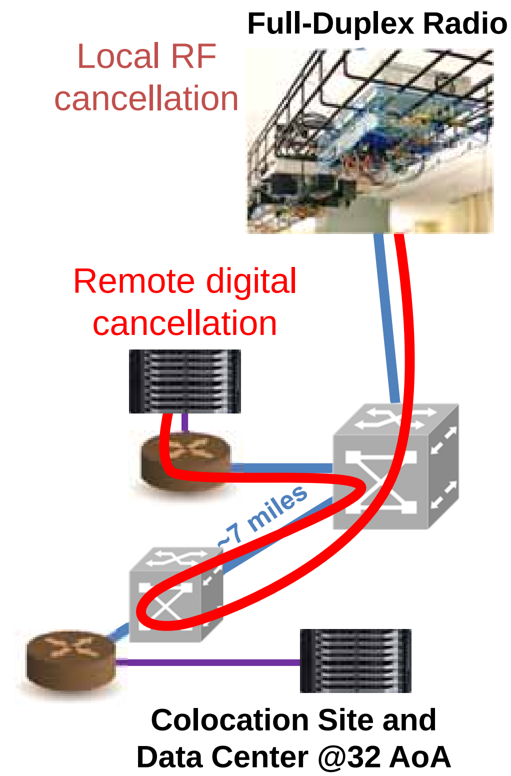
- Disaggregated optical systems pose many challenges due to the lack of end-to-end system testing
- New telemetry methods combined with AI-based controls have potential to overcome these challenges
- Team of industry and university partners conducted experiments on optical telemetry and data collection for AI



Pilot Experiment: Remote-Processing

- Full-duplex radio integrated with COSMOS' dark fiber-based optical x-haul network
- Local RF self-interference cancellation at the full-duplex radio
- Remote digital self-interference cancellation at the server (~14 miles away from the radio)





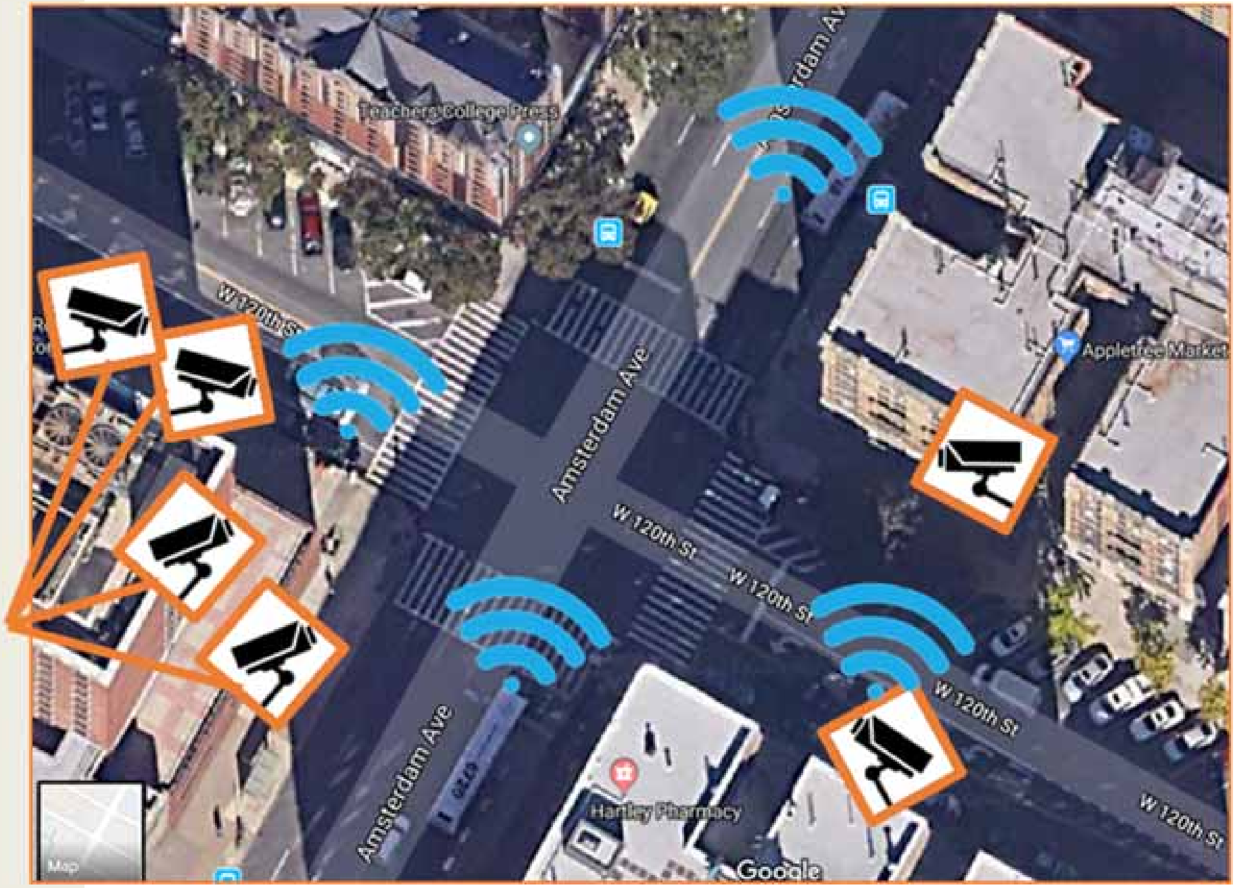
COSMOS dark fiber deployment and the supported Cloud-RAN applications

- J. Yu, T. Chen, C. Gutterman, S. Zhu, G. Zussman, I. Seskar, and D. Kilper, "COSMOS: Optical architecture and prototyping," in *Proc. OSA OFC'19, M3G.3 (invited)*, 2019.

Smart City Applications

Amsterdam Avenue and 120th St.
Northeast corner of Mudd Engineering building.

Smart Intersection:
Radios, cameras, edge cloud computing node, GPUs and FPGAs. AI/ML algorithms.



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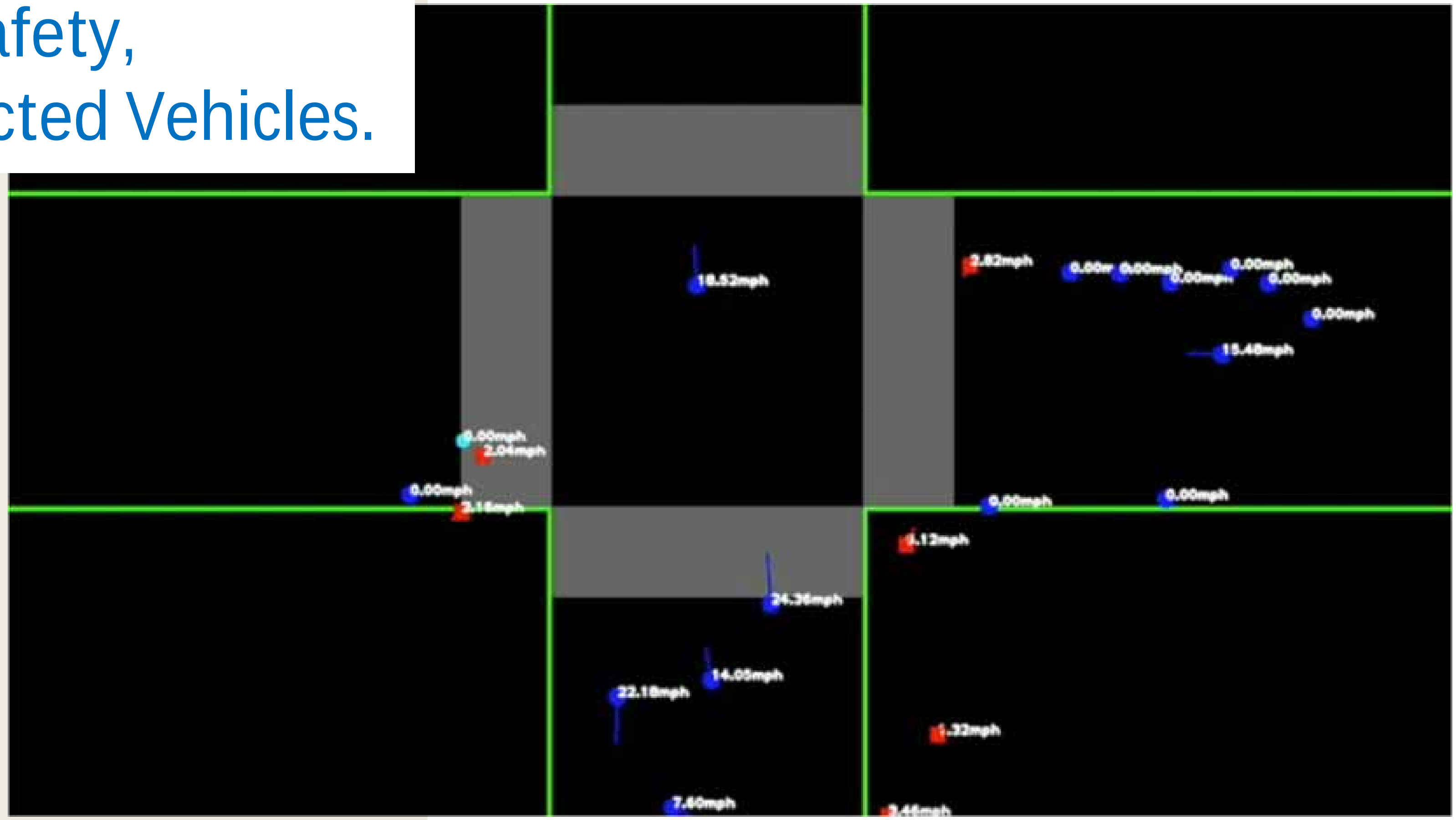
Real-Time Radar Map: Pedestrian Safety, Cloud Connected Vehicles.

Detect and track objects.
Broadcast to all: from inference node to vehicles and pedestrians,
...in real time.
Target closed loop latency: 10ms.
Video link.



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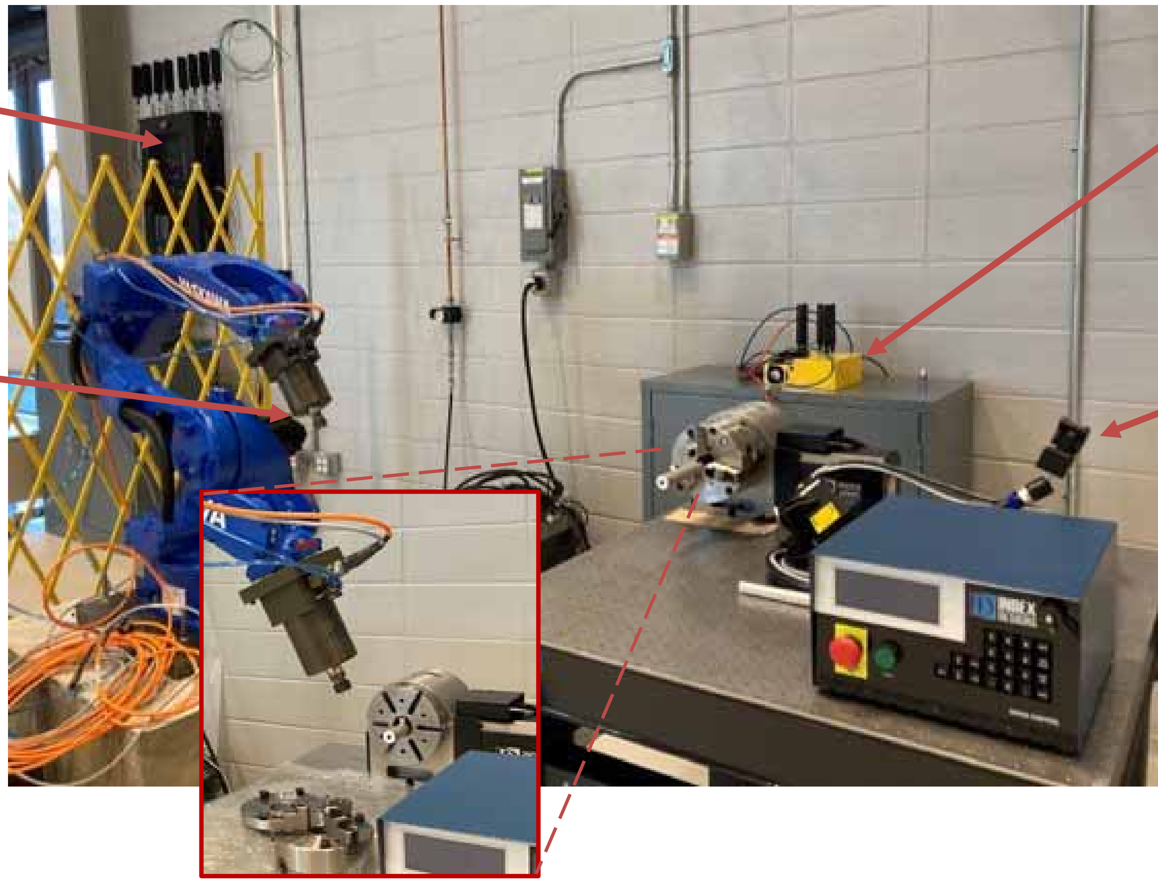
COSMOS: Industrial Lab Extension (Weeks Hall)

COSMOS Large node

Robot Manufacturing Setup

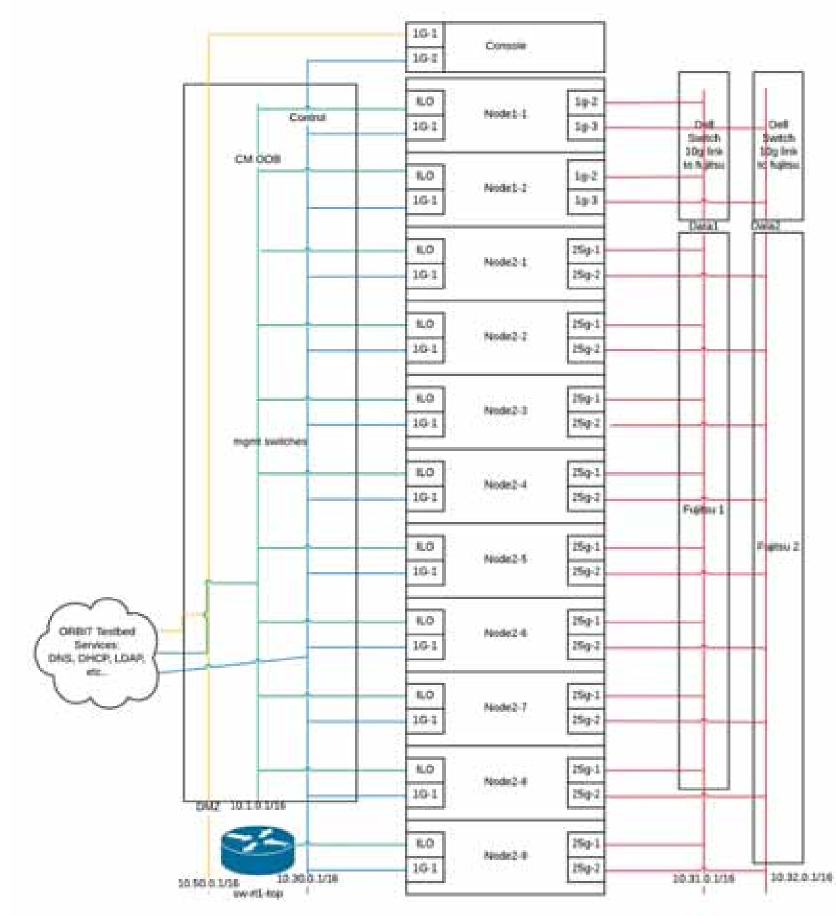


COSMOS Small Node

Surface Inspection Camera

O-RAN/ONAP (Candidate) OTIC

- Used for ONAP PoCs since 2017
- Environment
  - Entry point at console located at console.sb10.orbit-lab.org
  - 16 Ubuntu servers, all managed by OpenStack
  - Control Node and Compute Nodes
- Access Methods
  - Organizations can gain access by requesting an account – details at: https://wiki.onap.org/pages/viewpage.action?pageId=45298557
  - Tunnels to other testing and integration labs around the world



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O-RAN Plugfest and Proof-of-concept (#3)

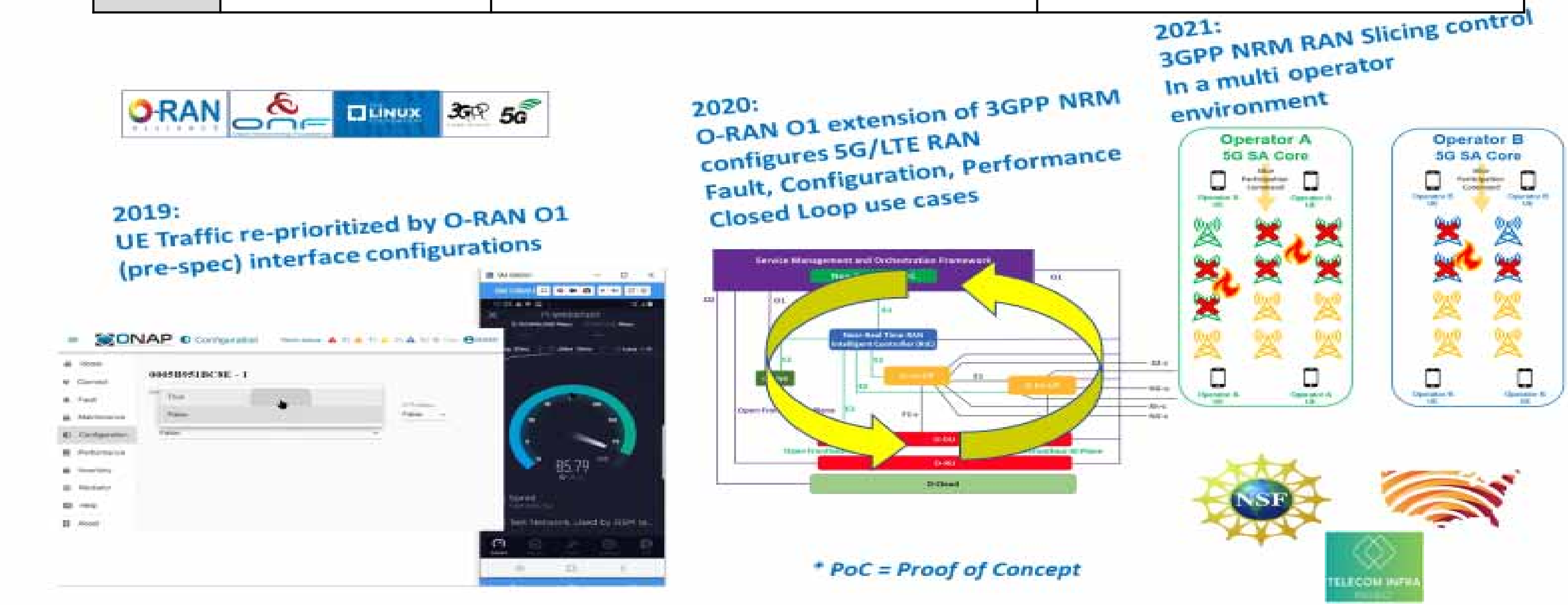
North America

PlugFest	PoC	PlugFest & PoC
TELECOM INFRA PROJECT	THE UNIVERSITY OF UTAH	RUTGERS
TIP Community Lab @ Meta Menlo Park, CA	POWDER Lab, Salt Lake City, UT NSF PAWR SITE FCC Innov Zone	COSMOS Lab, NJ/NYC metro NSF PAWR SITE FCC Innov Zone

Plugfest Participation

Comparison 2019, 2020, 2021

	Number of labs	Number of participating companies	Number of scenarios/setups
2019	1	9	7
2020	2	21	11
2021	3	33	27



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2021 JOINT

O-RAN ALLIANCE

LINUX FOUNDATION

THE UNIVERSITY OF UTAH

PLUGFEST AND PROOF OF CONCEPT

Sponsored by:

AT&T

Platforms for Advanced Wireless Research

TELECOM INFRA PROJECT

verizon

PARTICIPANTS

ANALOG DEVICES

FOXCONN

NEC

Capgemini

KEYSIGHT TECHNOLOGIES

highstreet technologies Network solutions

casa systems

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Calnex

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VVDN TECHNOLOGIES

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ROHDE&SCHWARZ

The City College of New York

North America: Joint O-RAN, TIP, Linux Foundation PlugFest & PoC

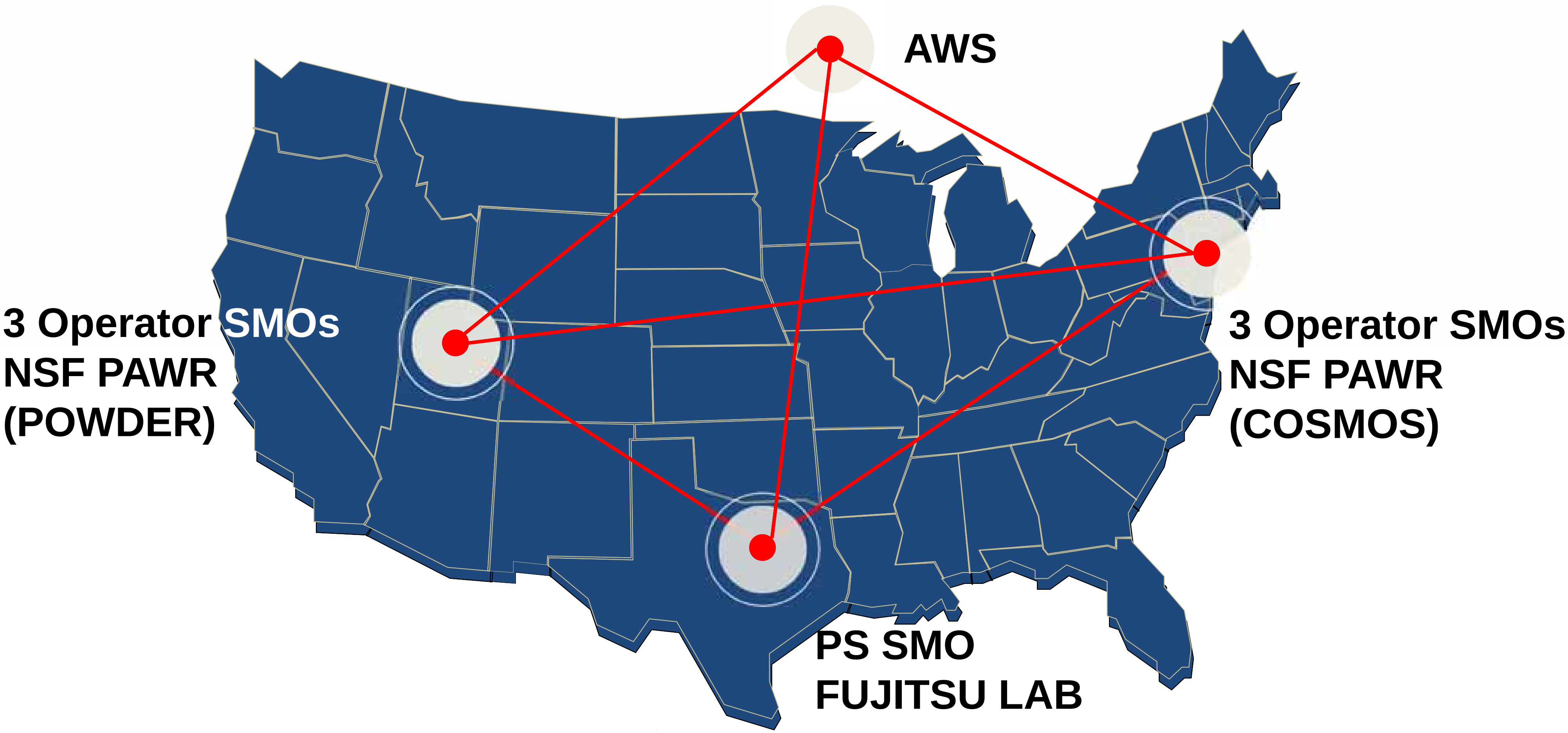
PlugFest:

- Activities focused on conformance testing and multi-vendor interoperability – 16 unique test combinations across 2 labs.

Proofs of Concept (PoC):

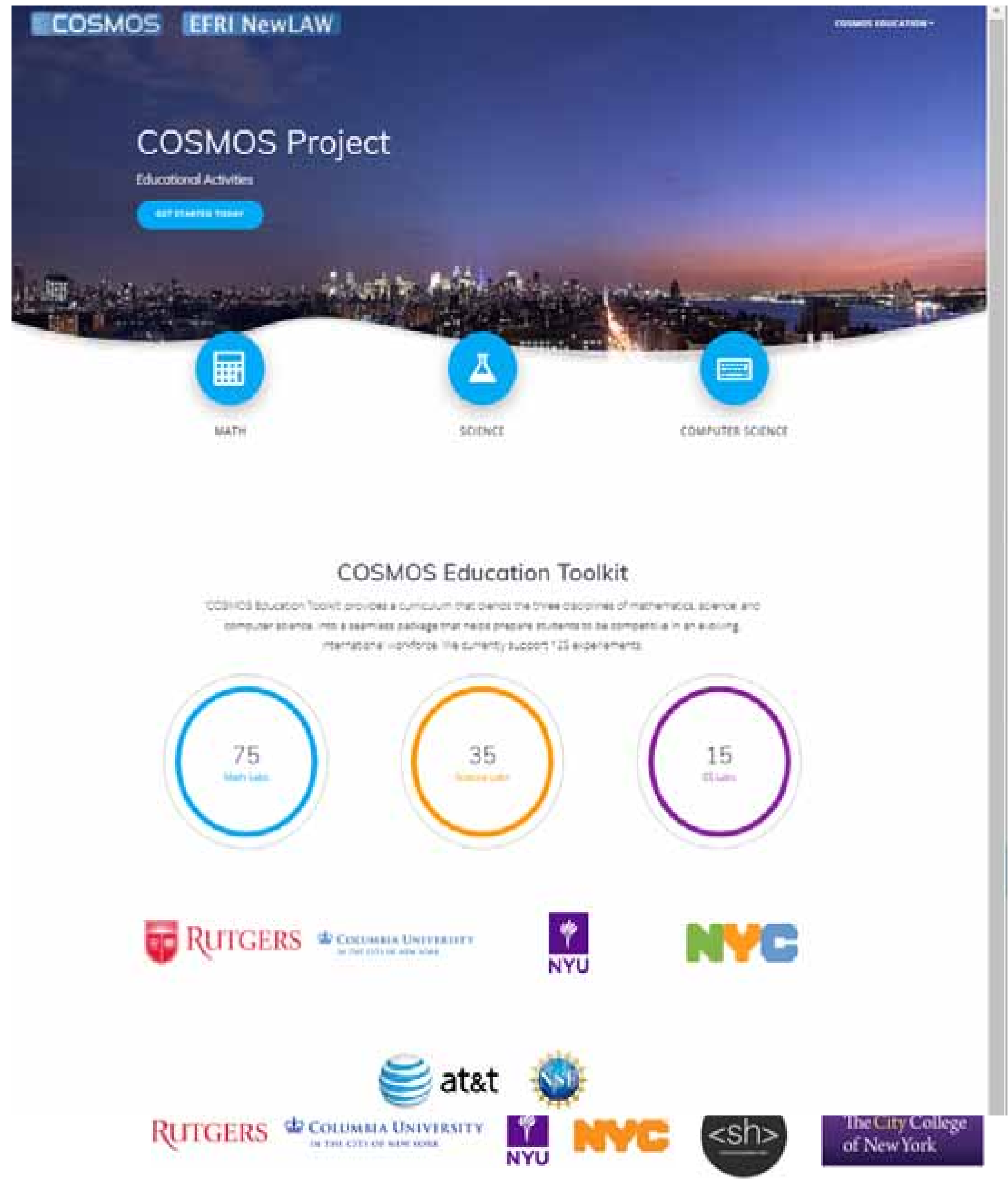
- O-Cloud infrastructure behavior in latency sensitive applications
- RIC demonstration of successful E2AP procedures and measurement collection via E2 Service Model: Key Performance Metrics (E2SM KPM)
- RAN Slice Service Level Assurance (SLA)
- AI-enabled management of multiple-operator / multi-vendor RAN with O-RU pooling & multi-vendor slices (a series of demonstrations)

PF3 PoC: SMO Deployments



COSMOS Educational Toolkit – 2021 Enhancements

https://www.cosmos-lab.org/cosmos-toolkit/



COSMOS Wireless Testbed – Summary

- Focus on ultra-high bandwidth, ultra-low latency, and edge cloud
- Open platform integrating SDRs, mmWave, and optical x-haul
- 1 sq. mile densely populated area in West Harlem
- Industry and local community outreach

COSMOS website: https://cosmos-lab.org
Tutorials: https://wiki.cosmos-lab.org/wiki/tutorials
Twitter: #pawrcosmos

Related links:

- PAWR: https://advancedwireless.org/
- ORBIT: https://www.orbit-lab.org/
- O-RAN Pf/PoC: https://www.o-ran.org/testing-integration/#Anchor_PLUGFEST
- TMForum PoC: https://myaccount.tmforum.org/networks/25844/index.html
- Open Wireless Lab https://wiki.onap.org/display/DW/Open+Wireless+Lab

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