The COSMOS Wireless Testbed

Rutgers University, Columbia University, New York University

Partners: New York City, Silicon Harlem, City College of New York, University of Arizona, IBM

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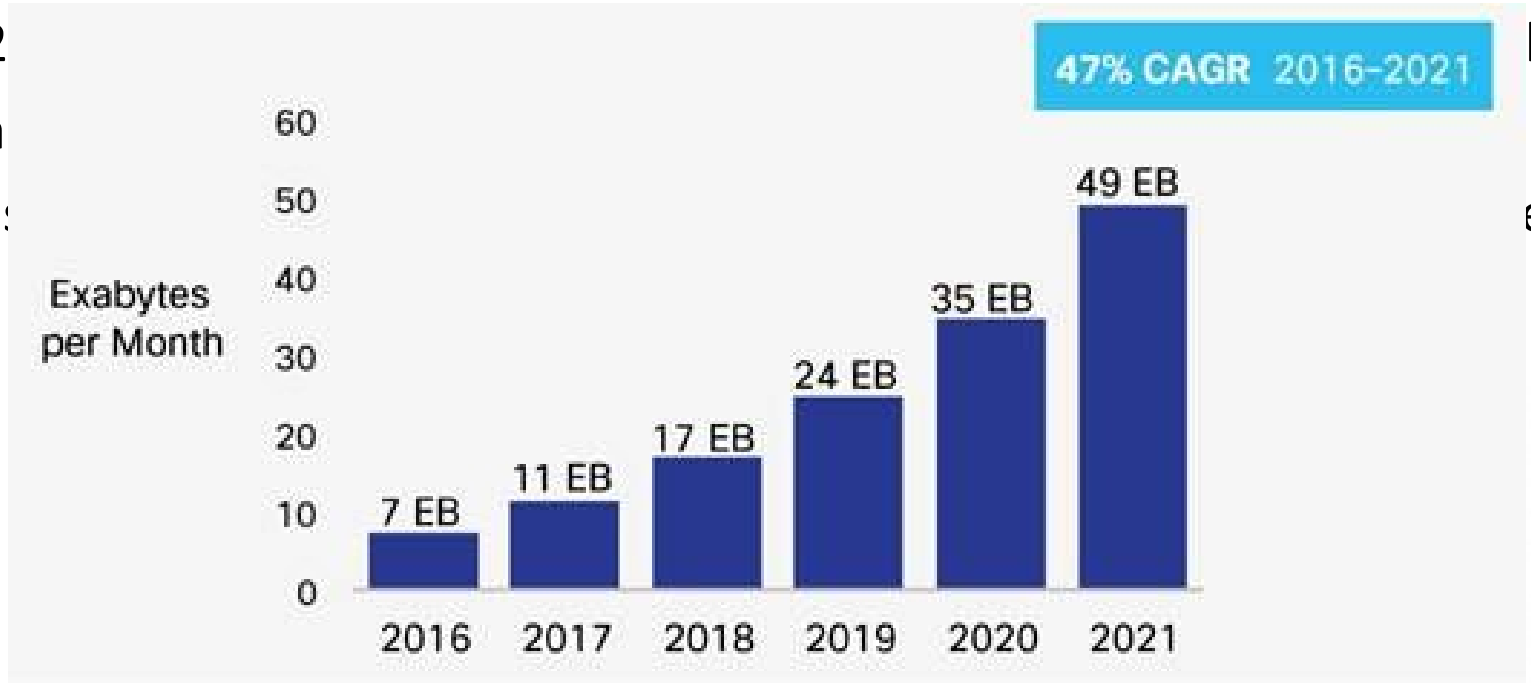
Nov. 2019

COSMOS is part of the NSF PAWR program, and is funded in part by NSF award CNS-1827923, and by the PAWR Industry Consortium

Wireless Networking Research - Motivation

- In 2012 … h users
- Unpara…
- Service… eality, Virtual …



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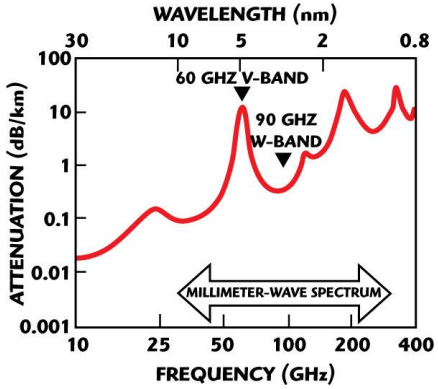
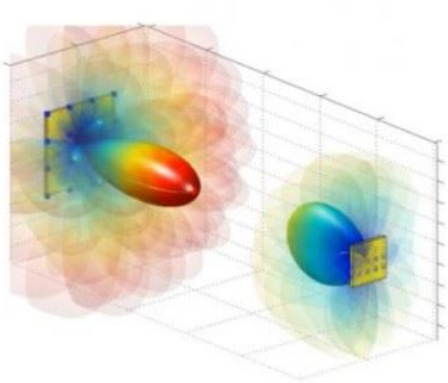
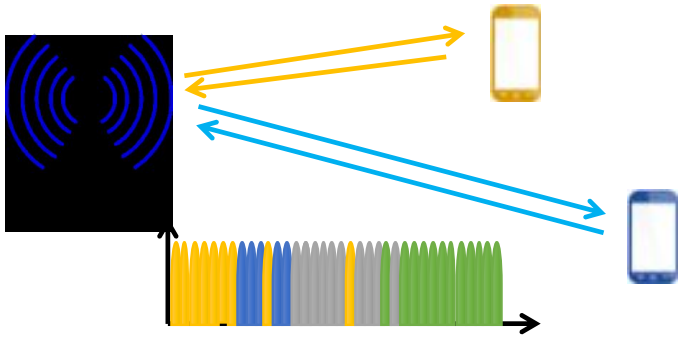
Emerging Wireless Paradigms

mmWave Mobile

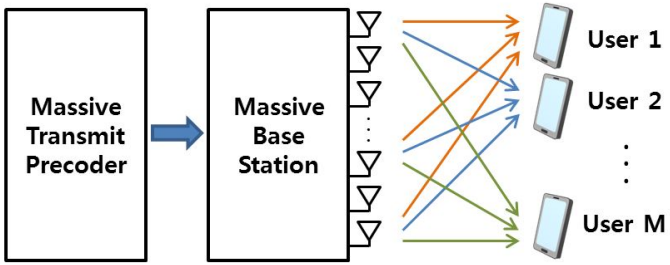




Full Duplex Wireless



Massive MIMO



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Summer 2016: Platforms for Advanced Wireless Research (PAWR)

- NSF will invest in 4 city scale testbeds
- Testbed – outdoor lab for future wireless technologies
  - These testbeds will be used to support wireless research by industry and academia
  - Contributions from ~30 Industry consortium members

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PAWR Consortium Members

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Project Team

Core Team: Rutgers, Columbia, NYU
Partners: New York City, Silicon Harlem, CCNY, U. Arizona, IBM

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Science Institute, Columbia U.

Alan Crosswell
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Harlem

Bruce Lincoln
Co-Founder, Silicon Harlem

Sundeep Rangan
Associate Professor, ECE, NYU
Director, NYU Wireless

Thanasis Korakis
Research Assistant Professor,
ECE, NYU

Shivendra Panwar
Director, CATT
Professor & Chair, ECE, NYU

Myung Lee
Professor ECE, CCNY

Rosemarie Wesson
Professor and Associate Dean,
CCNY

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Video

https://engineering.columbia.edu/news/nsf-cosmos-testbed

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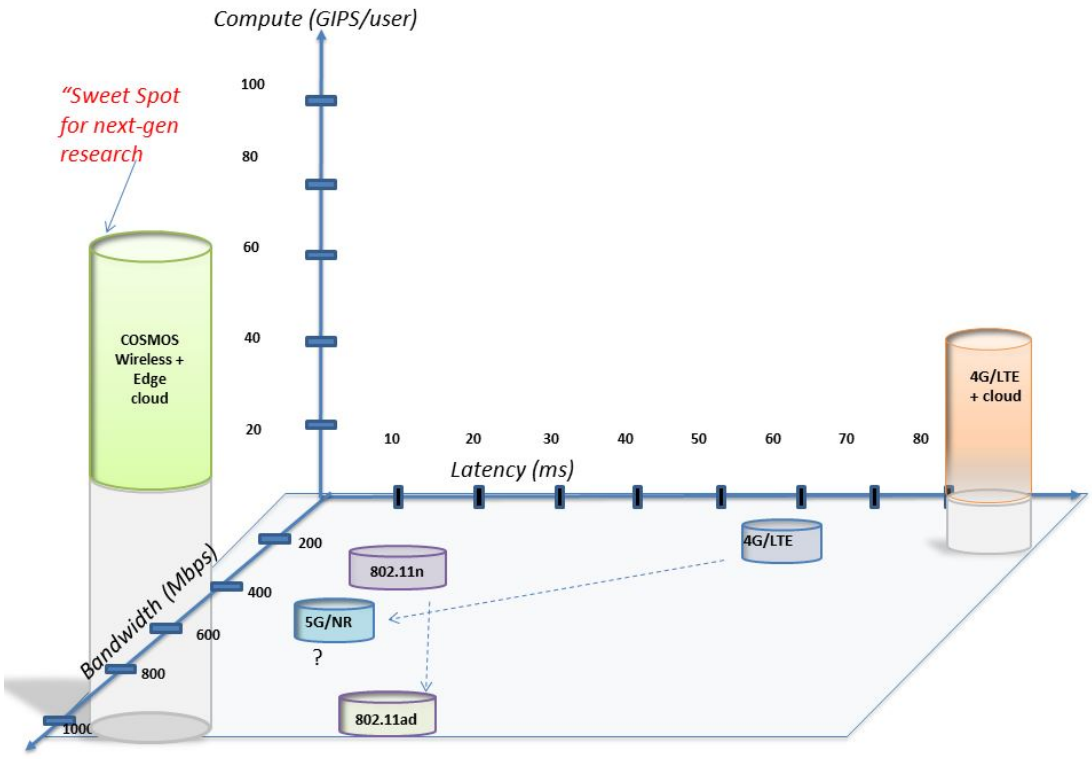
Project Vision

- Latency and compute power are the two new dimensions for characterizing wireless access
- Latency for 4G cellular > 50 ms, while targets for 5G are <10 ms
- Edge computing is an enabler for real-time services
- COSMOS will enable researchers to investigate ultra-high bandwidth (~Gbps), low latency (<5ms), and edge computing (~10-100 GIPS)
- COSMOS = Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment



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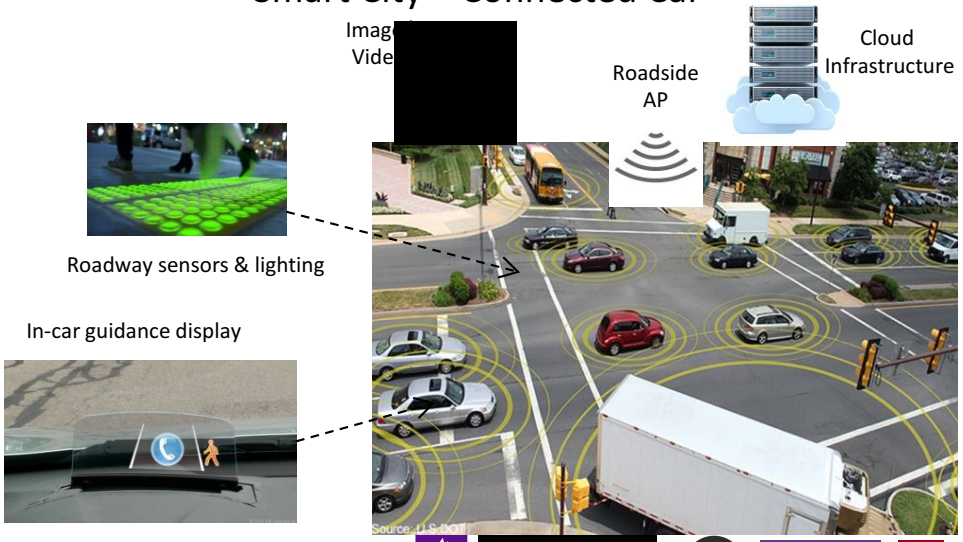
Project Vision

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

Augmented Reality

Smart City + Connected Car



Industrial Control

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Objective: Take it Outside

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Objective: Take it Outside

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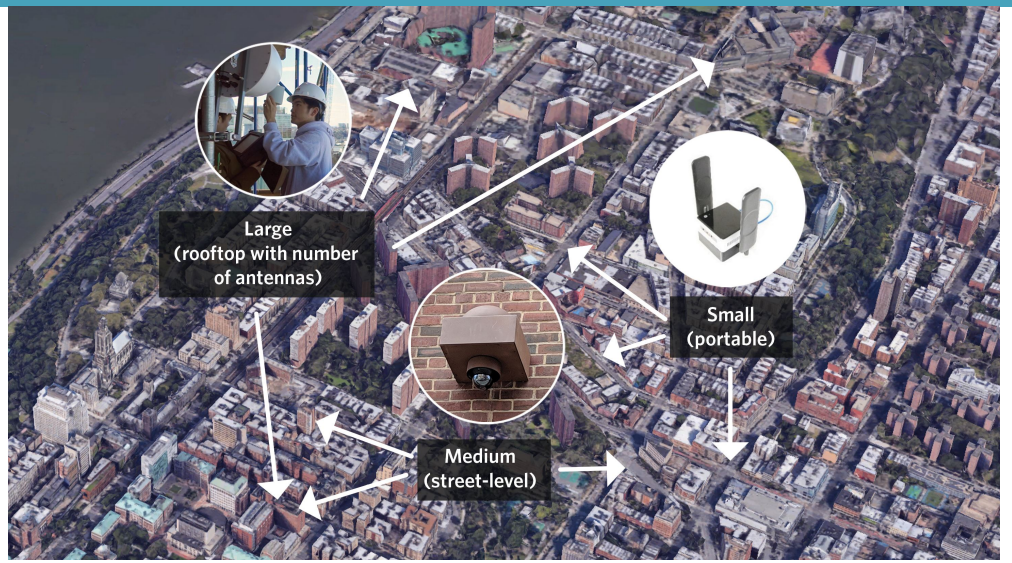
Planned Deployment - Vision

- West Harlem
- Area: ~1 sq. mile
- ~9 Large Sites ~40 Medium sites

- Fiber optic connection from most sites
- ~200 Small nodes
  - Including vehicular and hand-held



- Fiber connection to NYU Data Center, Rutgers, GENI/I2
- Interaction with smart community & innovation initiatives (Gigabit center, etc.)

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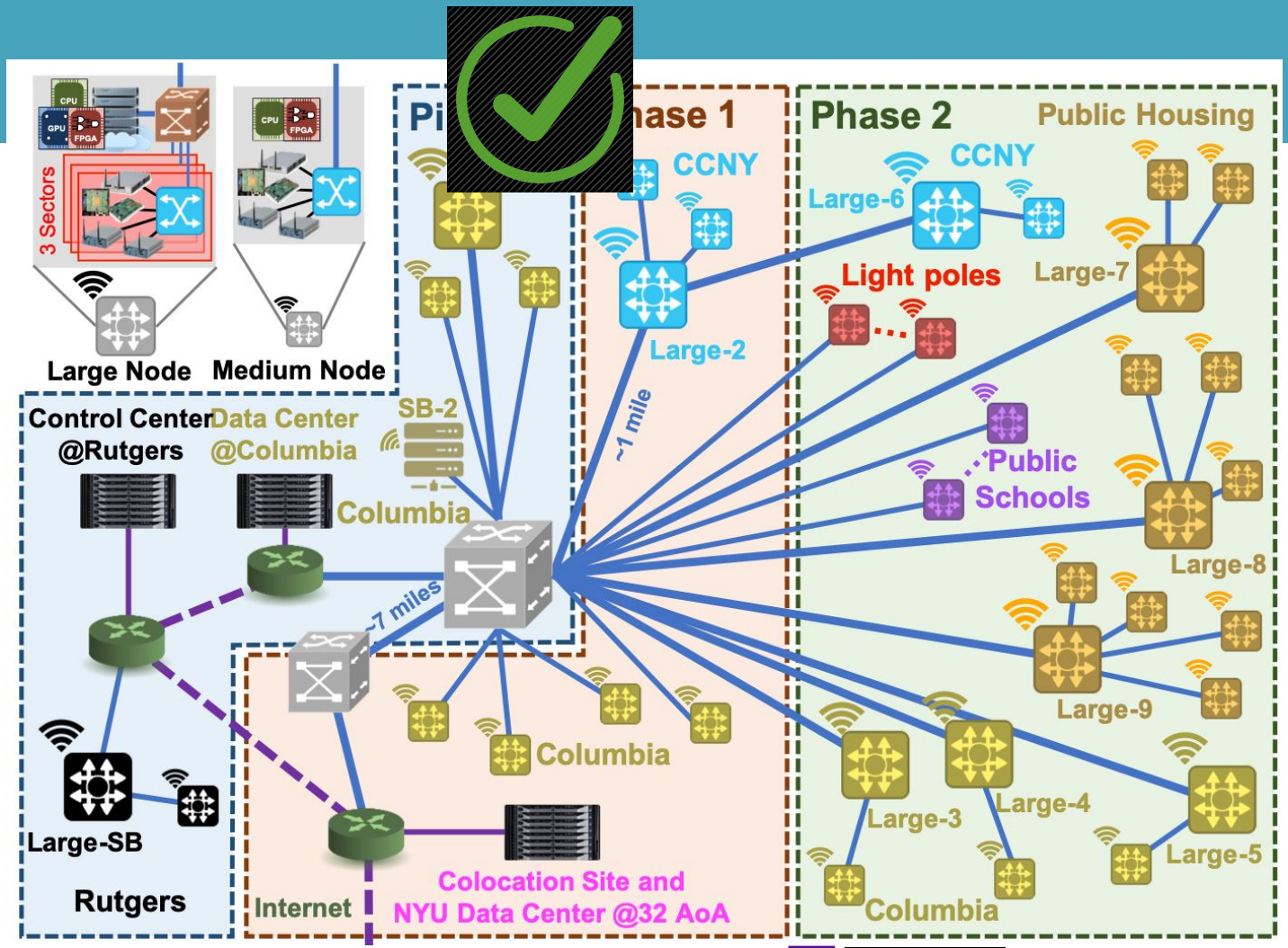
COSMOS Deployment

- Pilot – May 2019
- Phase 1 – Oct. 2020



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COSMOS Pilot – May 2019

- 2 Large, 3 medium, and ~30 small nodes
- Fiber connection: internally and to/from downtown
- Optical core and compute

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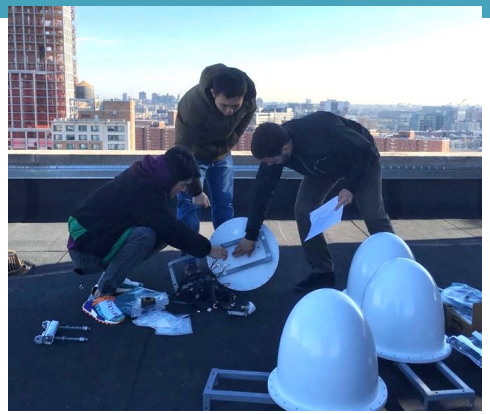
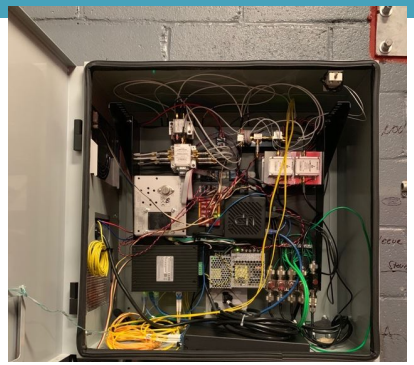
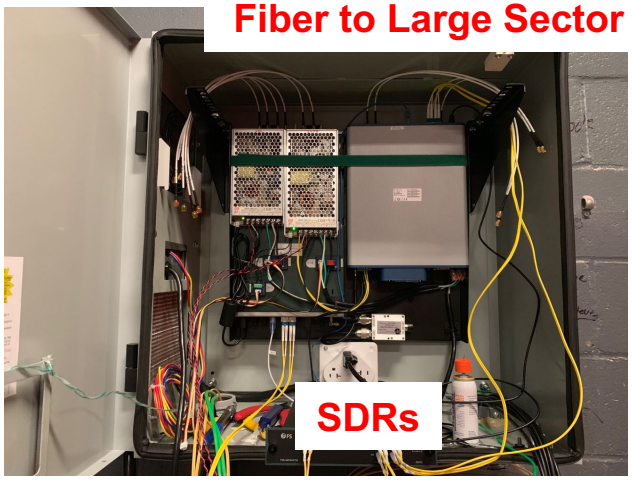
COSMOS Pilot – May 2019 (Large)





RF Front-ends and Fiber to Large Sector



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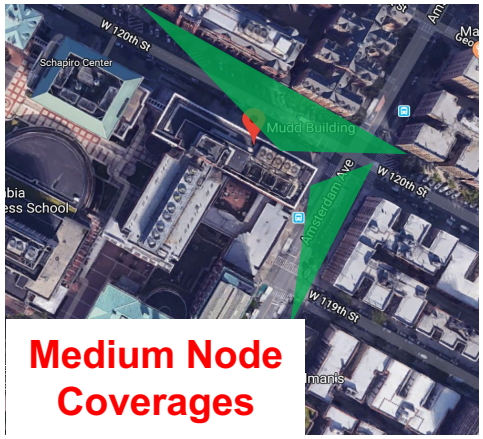
COSMOS Pilot – May 2019 (Medium)

200-Level (Amsterdam Ave.)

100-Level (West 120th St.)

Medium Antenna w/ GPS



Medium Node Coverages

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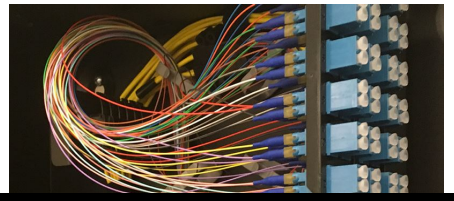
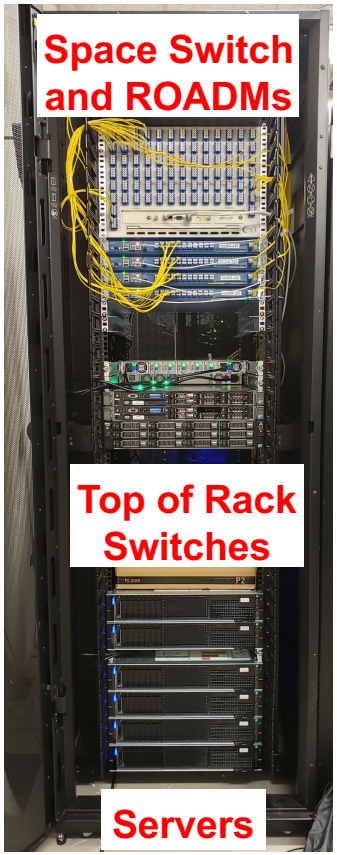
COSMOS Pilot – May 2019 (Fiber and Optical Core)

- Fiber connection:
  internally and to/from downtown
- Core optical switching and compute
  (ToRs, servers, etc.)





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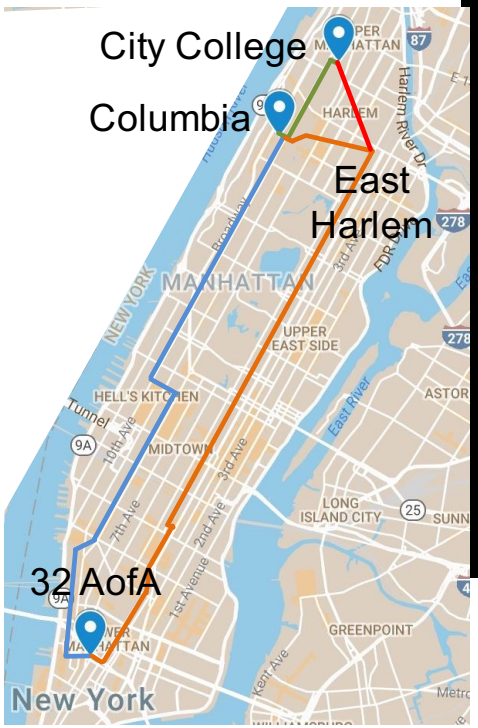
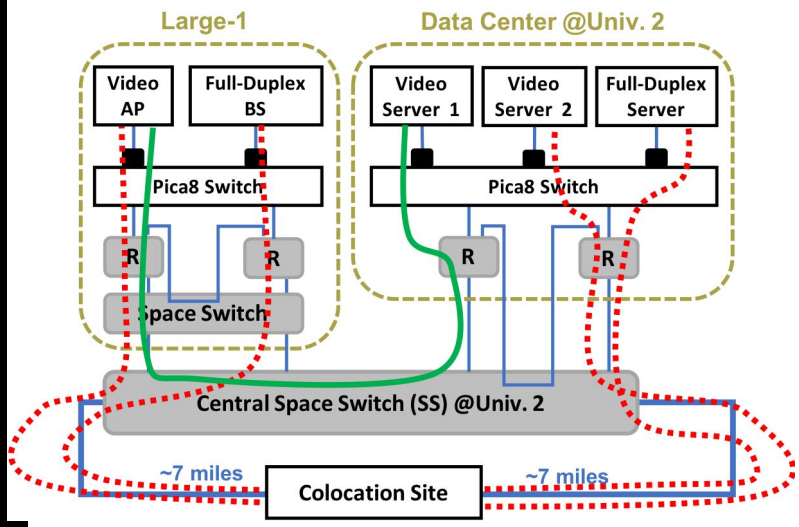
COSMOS Pilot – May 2019 (Fiber and Optical Core)

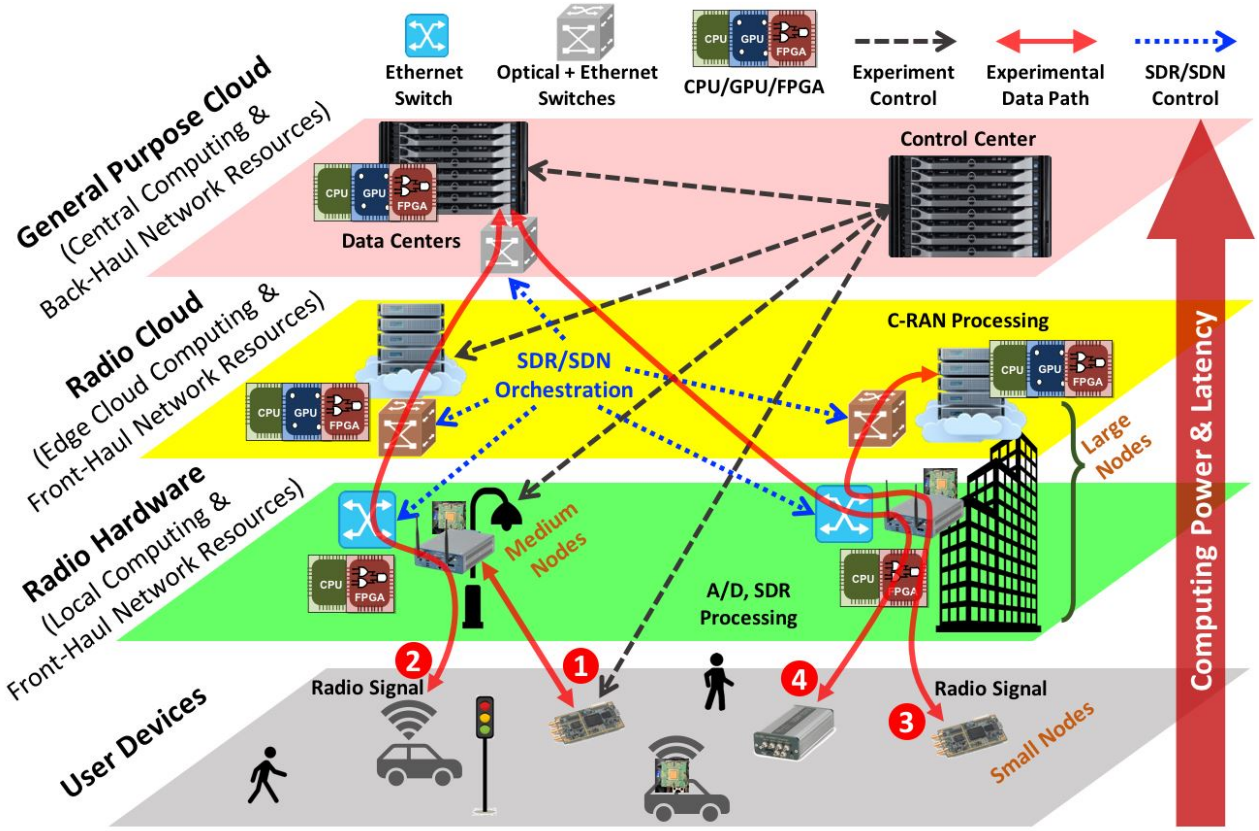




- Fiber to 32 Ave of Americas facilitated by the city and ZenFi

System Architecture

- Key design challenge: Gbps performance + full programmability at the radio level
- Fully programmable multi-layered architecture for flexible experimentation
- Key technologies:
  - Software defined radio
  - mmWave
  - Optical networks
  - Software defined networking and cloud
  - Control and measurement



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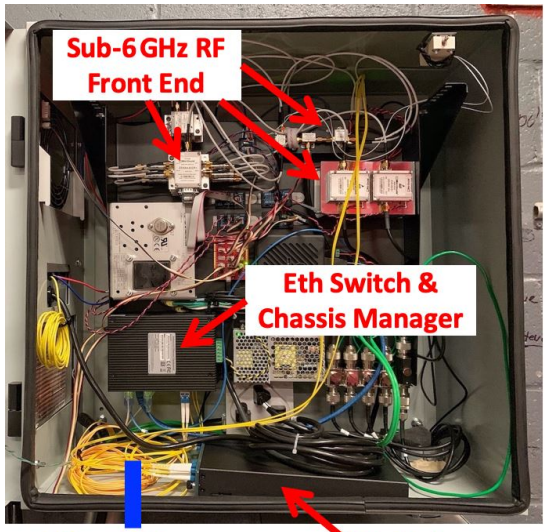
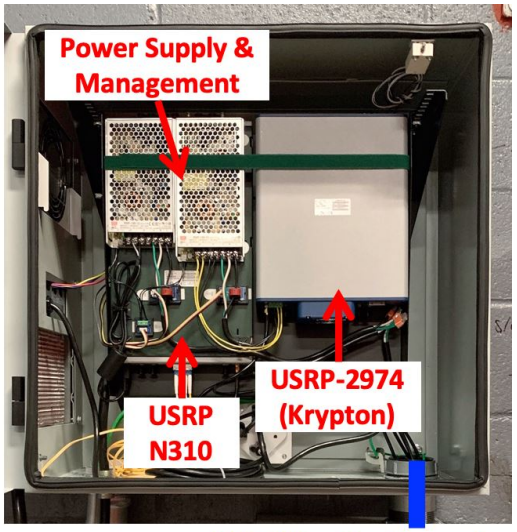
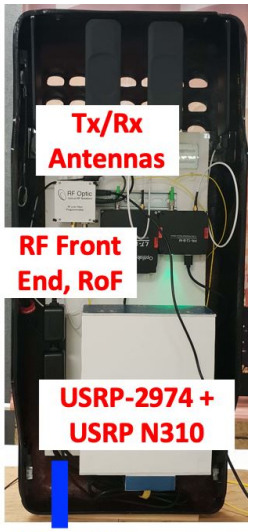
COSMOS Key Technologies – Software-Defined Radio (SDR)

- All-software solution adopted for radio technology
- Advanced SDR nodes at various performance levels and form factors
- Design goal: 400 MHz – 6 GHz + 28/60 GHz bands (with up to ~500 MHz bandwidth), Gbps
- Signal processing can be spread between radio node & edge cloud RAN



A large node sector or a medium node





Medium-light node (lightpole-mounted)

Small mobile node

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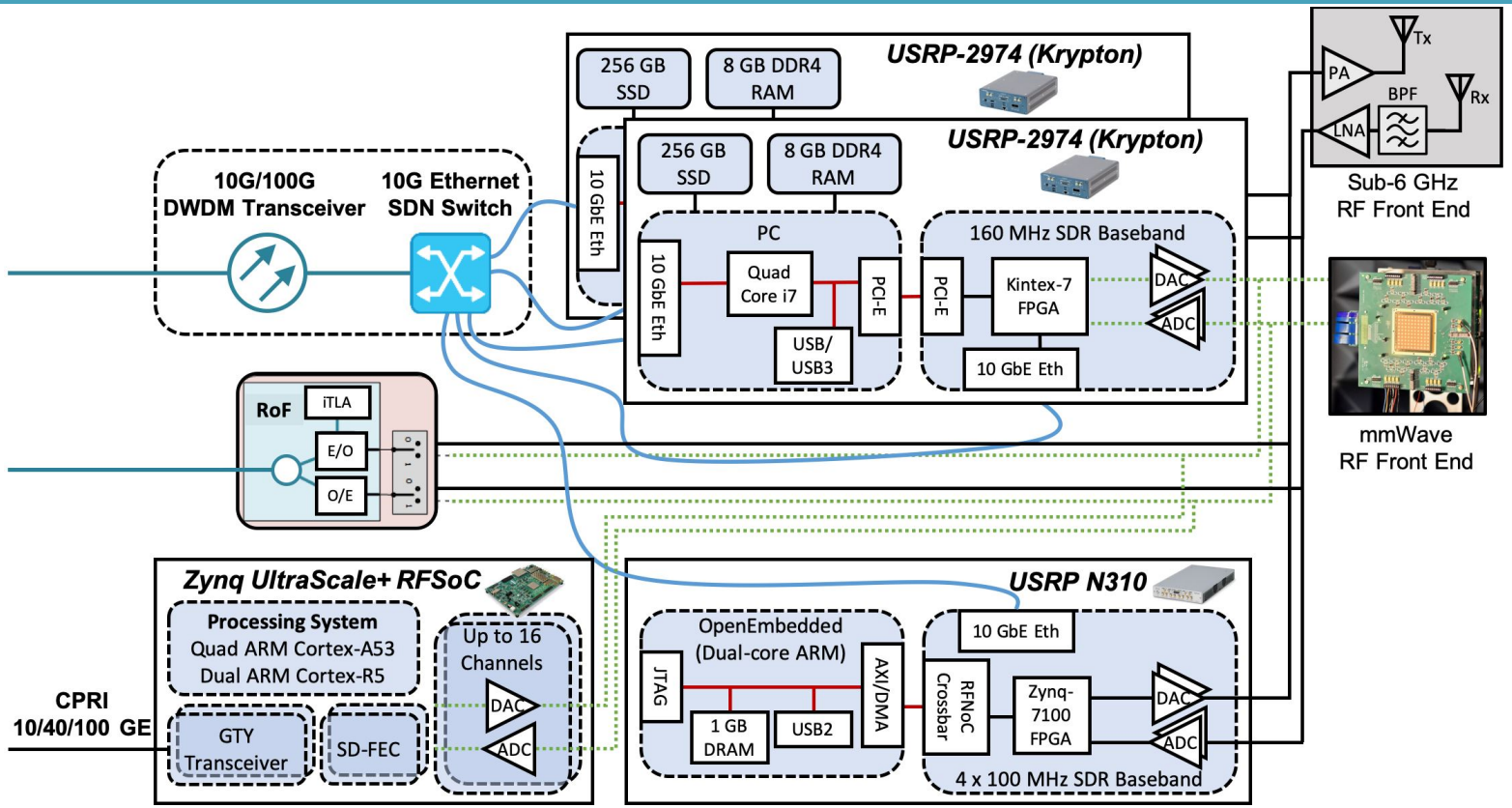
COSMOS Large/Medium Nodes



- Different large/medium node configurations have a *subset* of these major components

COSMOS Key Technologies – mmWave

- IBM to provide 28 GHz mmWave phased array modules
  - Up to ~500 MHz BW using the Zynq UltraScale+ RFSoC platform
  - Experiment with adaptive beamforming and MIMO
  - Alpha version is being integrated in the sandbox

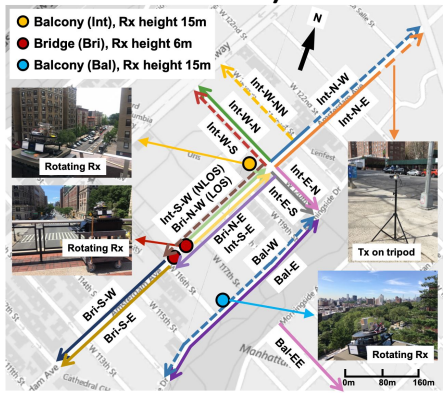
USRP-2974 (Krypton)

Zynq RFSoC

- 28 GHz channel measurements in the COSMOS testbed area (collaboration with Bell Labs)

mmWave (28 GHz) phased array antenna module from IBM

NYU channel measurements



Channel measurements in the COSMOS testbed

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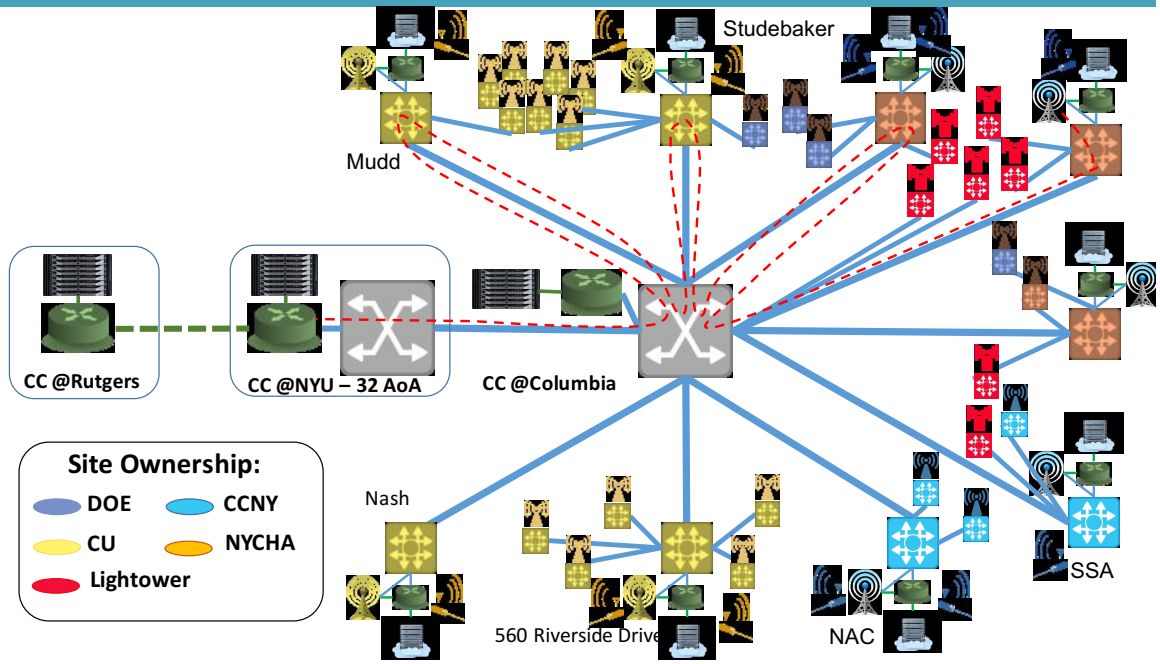
Key Technologies – Optical Networking

- Enables fast connectivity between radio nodes and edge cloud
- Fast and low latency optical x-haul network
  - Configure wide range of topologies
  - Experiment on converged fiber/wireless networks



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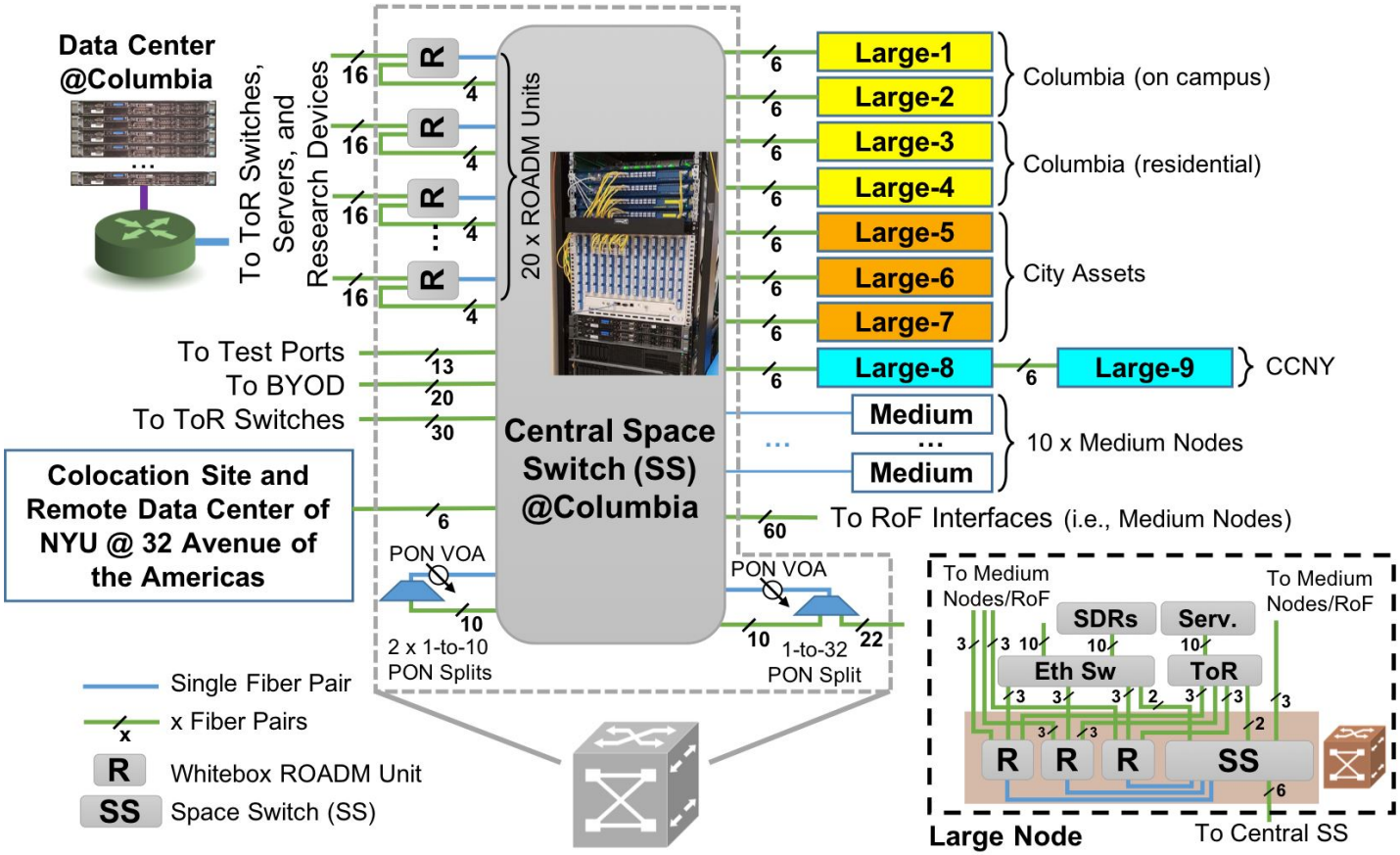
Key Technologies – Optical Networking



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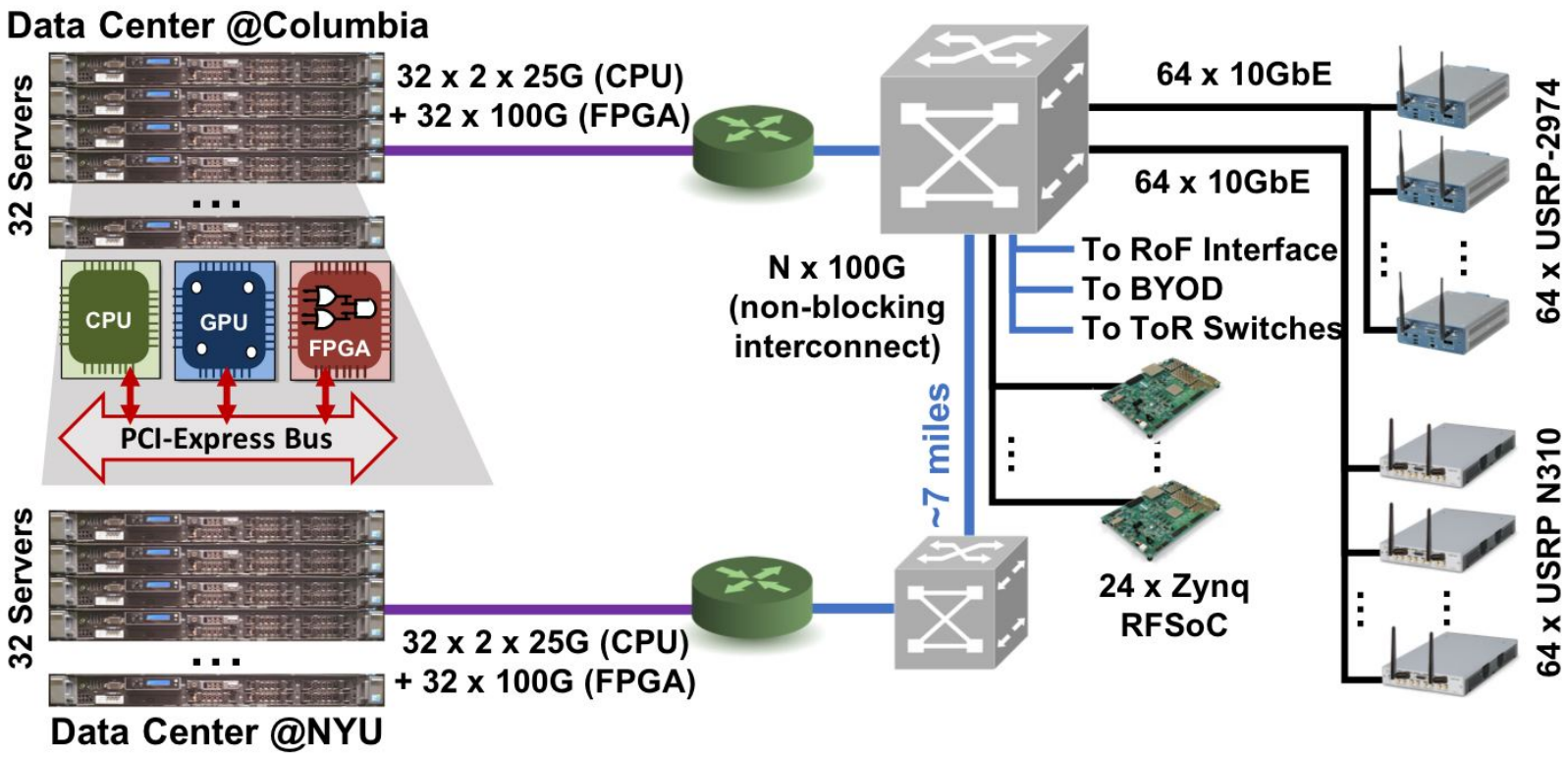
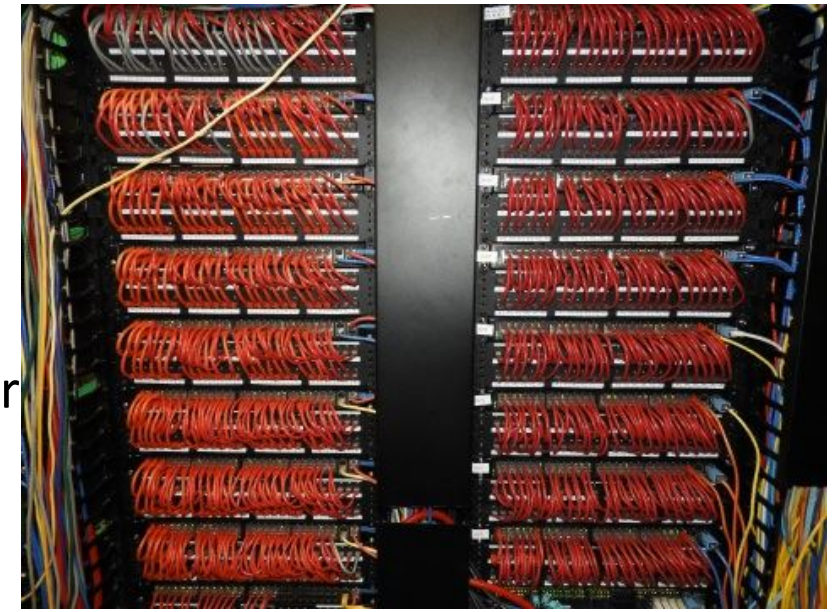
COSMOS Key Technologies – Cloud Architecture



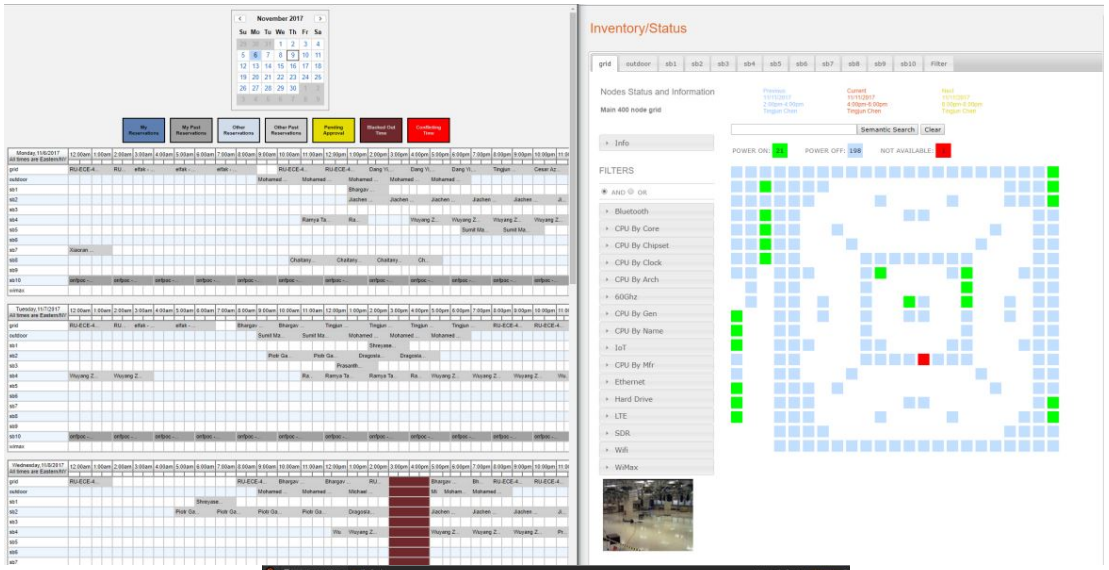
Key Technologies – SDN & Cloud

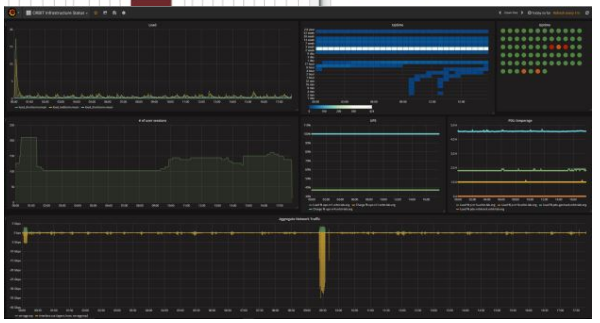
- SDN control plane used to control x-haul and cloud server connectivity
- Compute clusters collocated with radio nodes (M,L) with choice of CPU, GPU and FPGA accelerators
- Users will have access to regular cloud racks for L3→ applications (GENI & CloudLab clusters at WINLAB)



Key Technologies - OMF

- Testbed software is a critical component
- OMF control & management software leveraged from ORBIT
- Provides tools for experiment scripting, execution, measurements and data collection
- Supports high-level experiment scripts for ease of use
- Mature open-source technology, proven in multiple research testbeds worldwide





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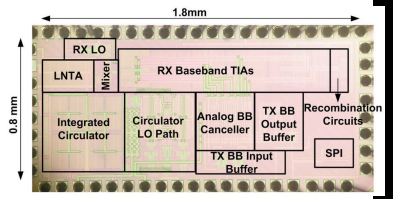
Experimental Research - Example

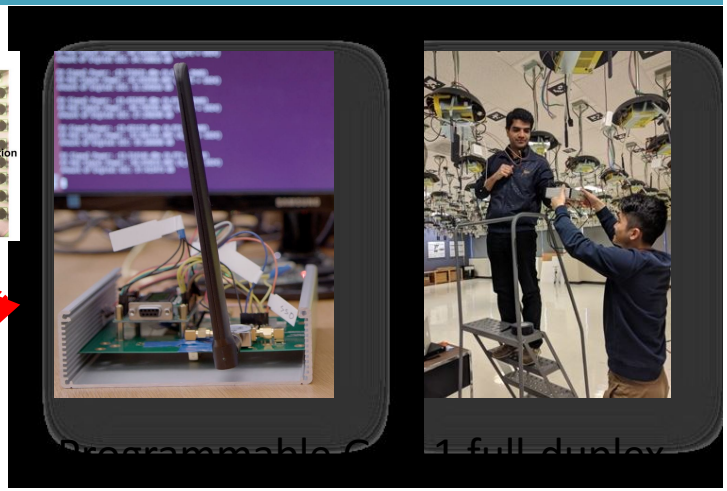
Eight internal "**Test Experiments**" to help drive design requirements

Experiment on Full-Duplex Wireless:

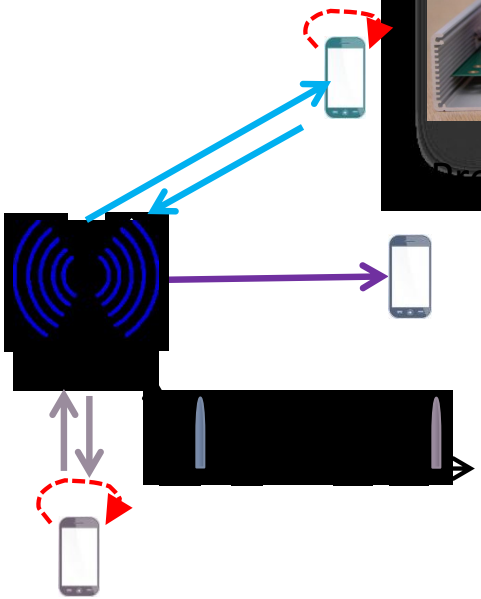
FlexICoN

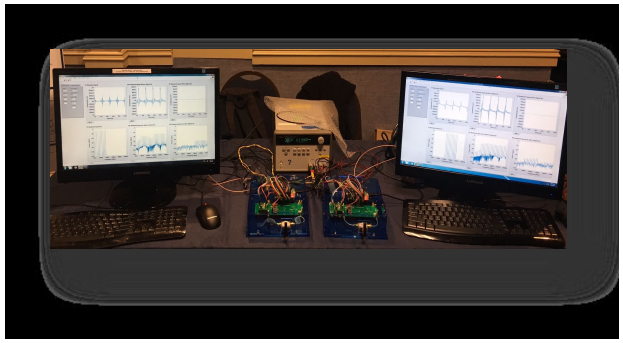
– Goal: design and evaluate network protocols for **IC-based full-duplex nodes**





node installed in ORBIT





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Test Experiment - Example

- Deep learning for smart intersections (Kostic)
- Challenges:
  - Pedestrian detection from a bird's eye view
  - Data aggregation
  - Sufficiently deep trajectory prediction (in time)
  - Low latency (edge cloud, optics)

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Outreach and Education

Video

https://engineering.columbia.edu/news/verizon-edtech-challenge

K-12 Education

- Developing a K12 STEM education programs exposing students to **hands-on experience** and **research activities applied to the real world**
  - 20 teachers participated in an RET program in Summers 2018 and 2019 (support by AT&T foundation and NSF RET supplements to the PIs grants)
  - Defined scientific areas/existing curriculum that can be supported by labs run remotely on the testbed
  - Built the labs collaboratively (teachers, undergrad/graduate students, postdocs, and faculty)
  - Follow up work as part of Verizon's 5G Education Challenge

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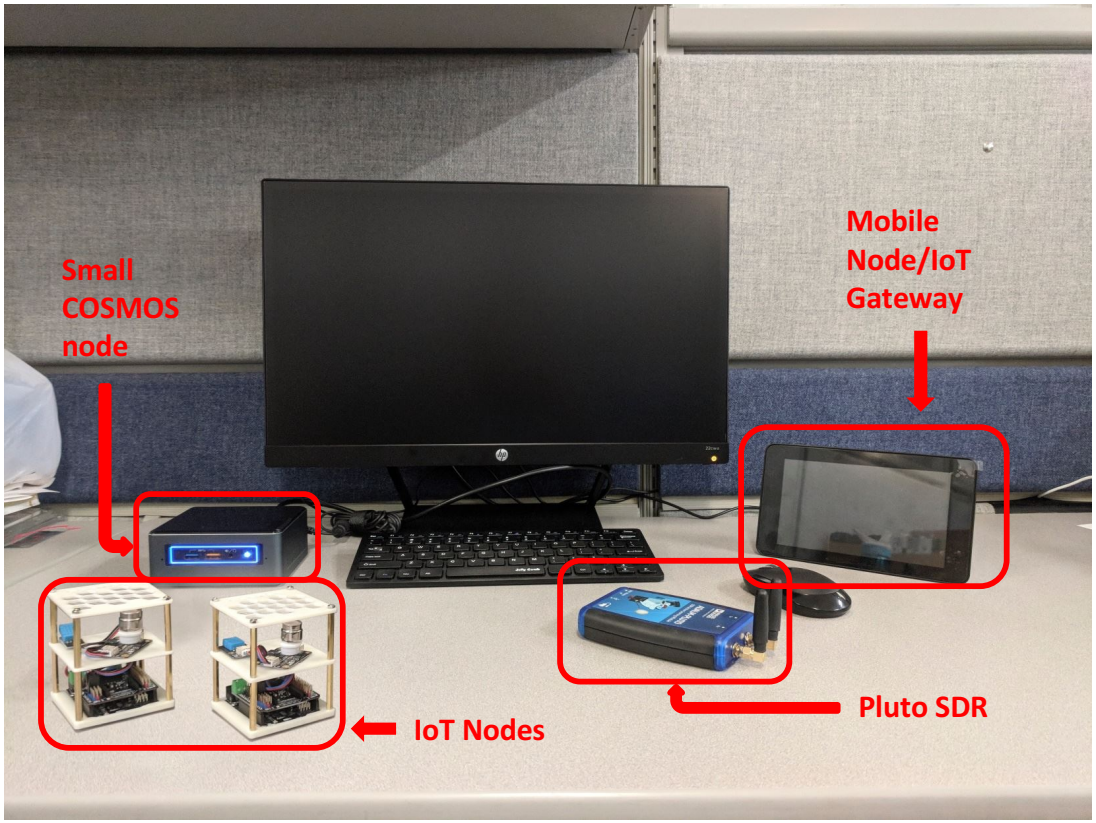
2018 COSMOS RET Program Outcome

- The COSMOS Education Toolkit
  - A small scale testbed that the teachers will get back to their school to run experiments
  - A software suite for the teachers/student to run the labs trough a web-based GUI



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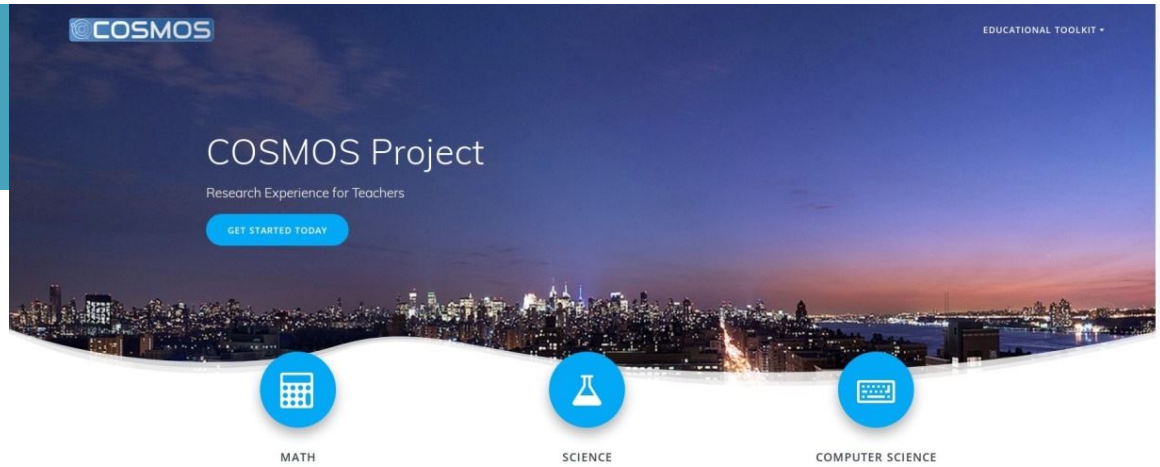
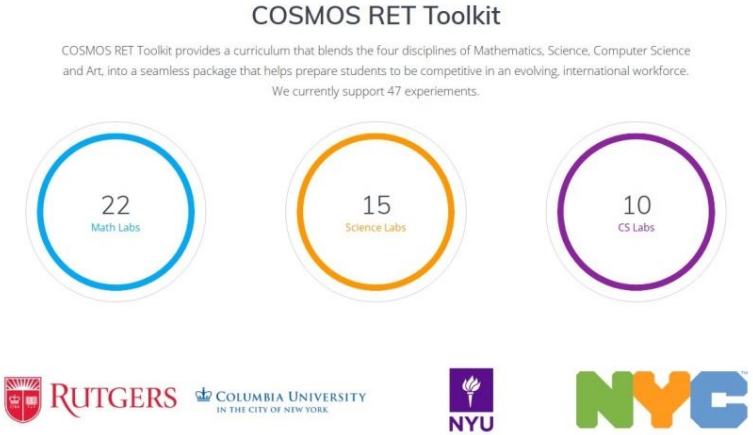
COSMOS Educational Toolkit – The web based Curriculum





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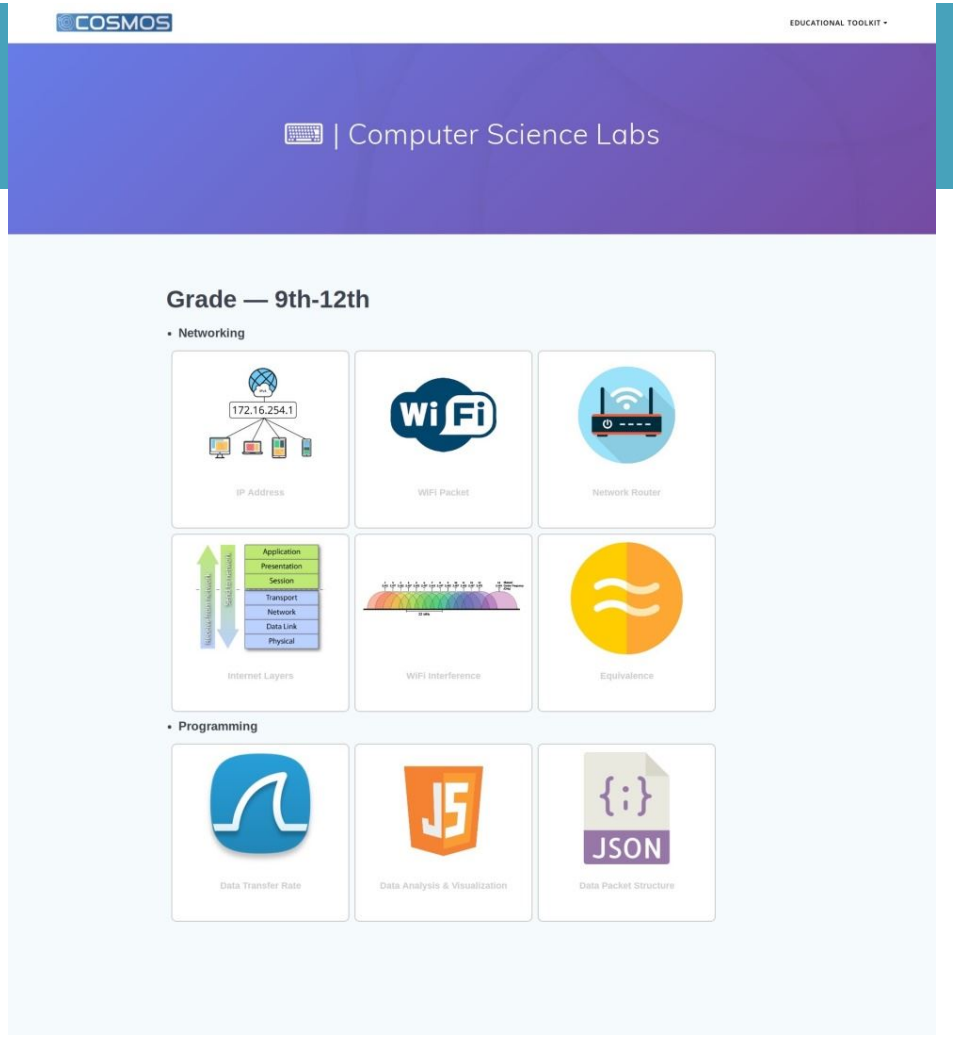
Examples of CS modules created for grades 9-12



COSMOS

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Summary

- Focus on ultra high bandwidth, low latency, edge cloud
- Open platform (building on ORBIT) integrating mmWave, Software Defined Radio, and optical x-haul
- Strong community outreach and education component

- For more details:

www.cosmos-lab.org , ray@winlab.rutgers.edu, gil@ee.columbia.edu

#pawrcosmos

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