An Open Programmable City Scale Testbed for Evaluation of Edge-Cloud Enhanced Advanced Wireless Systems

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

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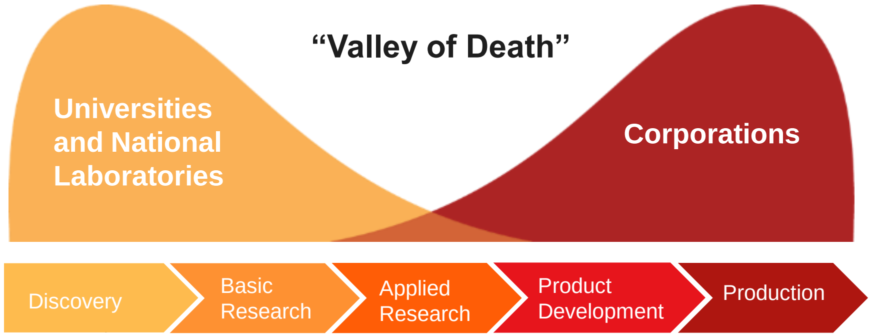
PAWR

Problem Statement: Bridging the "Valley of Death"

- NSF historically funds over $50M annually in fundamental, pre-competitive wireless research
- This research could be greatly strengthened if:
  - Researchers had access to mid-scale, end-to-end research platforms
  - Industry collaborated earlier in helping to define and focus research areas



Courtesy: RAWR PPO

PAWR Vision

What is the PPO trying to do?

Large gap between basic research and industry

Too often research results don't make it out of the lab

Challenges

Experimental Research in Wireless: Small scale, ad hoc and disconnected platforms, lack of rigor, **results not reproducible**

PAWR is an unprecedented opportunity to change this state of affairs!

Create evidence-driven community of wireless experimenters with shared culture and high standards

Bridge gap between academic research community and industry

OBJECTIVES

Foster innovation through involvement of local communities

PAWR Guiding Principles

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.

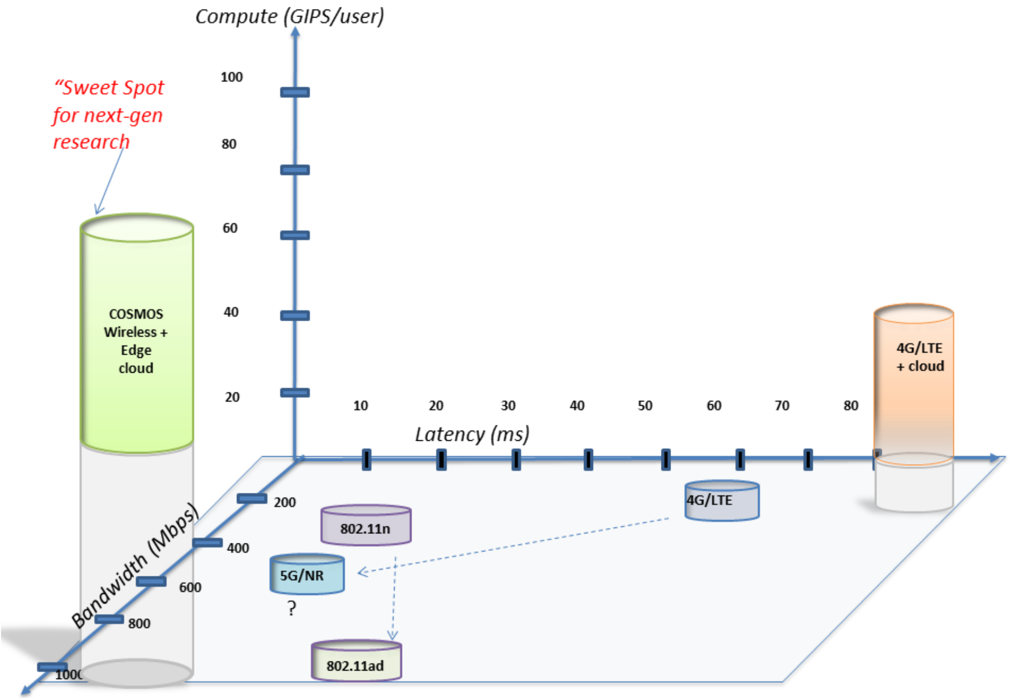
Diversity
- Broad range of topics
- spectrum, mmWave, internet of things, wide-area wireless backhaul, measurements etc.

COSMOS

(CLOUD ENHANCED OPEN SOFTWARE DEFINED MOBILE WIRELESS TESTBED FOR CITY-SCALE DEPLOYMENT)

COSMOS 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 speed (~Gbps), low latency (<5ms), and edge computing (~10-100 GIPS)
- COSMOS = Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment

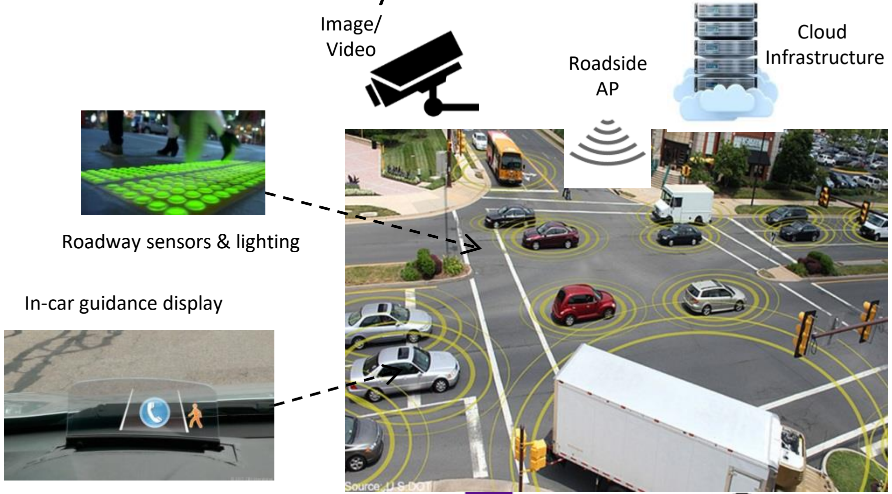


COSMOS Project Vision

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

Augmented Reality

Smart City + Connected Car



Industrial Control

COSMOS Project Vision

- Living lab research platform
  - Bring together research addressing critical technological, social, and civic challenges facing the world's mega-cities
- Research & innovation engine of NYC ecosystem
  - Smart city projects
  - Broadband community initiatives
  - Applications-focused startups

Top 25 hot spots by 2025

Cityscope 2025 city rankings

Bold text Developing regions
Normal text Developed regions[1]

Rank	GDP[2]	Per capita GDP[2]	GDP growth[2]	Total population	Children[3]	Total house-holds	Households with annual income over $20,000[4]
1	New York	Oslo	**Shanghai**	Tokyo	**Kinshasa**	Tokyo	Tokyo
2	Tokyo	**Doha**	**Beijing**	**Mumbai**	**Karachi**	**Shanghai**	New York
3	**Shanghai**	Bergen	New York	**Shanghai**	**Dhaka**	**Beijing**	London
4	London	**Macau**	**Tianjin**	**Beijing**	**Mumbai**	**São Paulo**	**Shanghai**
5	**Beijing**	Trondheim	**Chongqing**	**Delhi**	**Kolkata**	**Chongqing**	**Beijing**
6	Los Angeles	Bridgeport	**Shenzhen**	**Kolkata**	**Lagos**	New York	Paris
7	Paris	Hwasŏng	**Guangzhou**	**Dhaka**	**Delhi**	London	Rhein-Ruhr
8	Chicago	Asan	**Nanjing**	**São Paulo**	**Mexico City[5]**	**Mumbai**	Osaka
9	Rhein-Ruhr	San Jose	**Hangzhou**	**Mexico City[5]**	New York	**Delhi**	**Moscow**
10	**Shenzhen**	Yŏsu	**Chengdu**	New York	**Manila**	**Mexico City[5]**	**Mexico City[5]**

NYC location enables experiments and stress testing at scales and conditions that are unavailable elsewhere

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NYU
NYC
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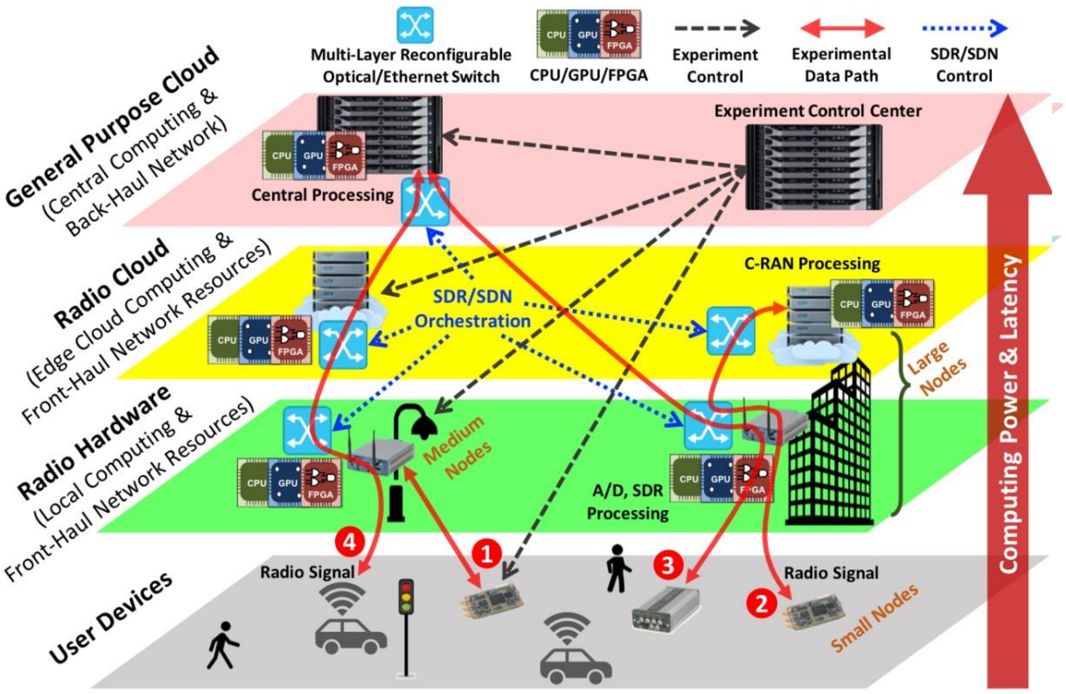
ARIZONA

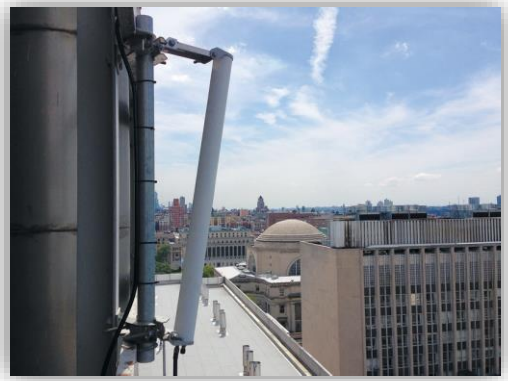
System Architecture

- COSMOS architecture has been developed to realize ultra-high BW, low latency and tightly coupled edge computing
- Key design challenge: Gbps performance + full programmability at the radio level
- Developed a fully programmable multi-layered (i.e. radio, network and cloud) system architecture for flexible experimentation



Planned Deployment

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



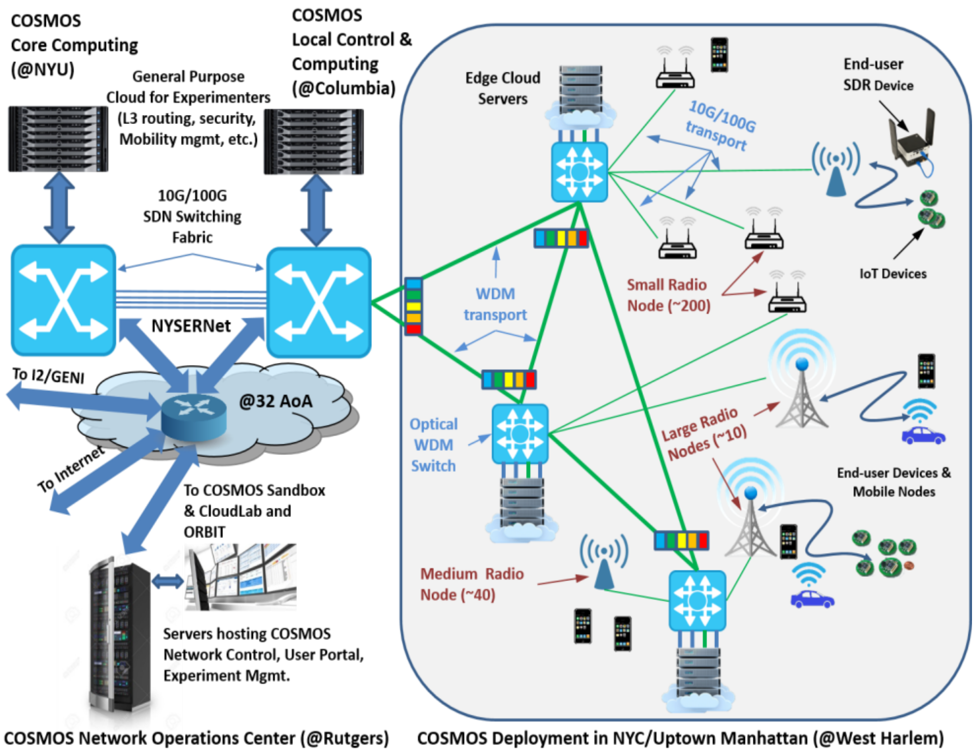
- Fiber optic connection from most sites
- ~200 Small nodes
  - Including vehicular and hand-held

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

COSMOS Technology

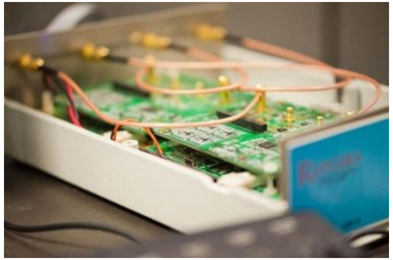
System Architecture

- System design based on three levels of SDR radio node (S,M,L) with M,L connected via fiber to optical WDM transport
- SDN-based backhaul and compute services, with access to ORBIT, GENI…
- COSMOS control center and general purpose cloud at Rutgers via 32 AoA PoP

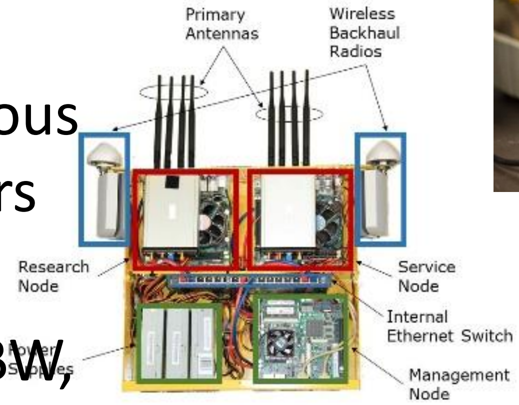


Key Technologies - SDR

- All-software solution adopted for radio technology
- Advanced SDR Radio Nodes at various performance levels and form factors
- Design goal: 400 Mhz – 6 Ghz + 28 Ghz and 60 Ghz bands, ~500 Mhz BW, Gbps
- Signal processing can be spread between radio node & edge cloud RAN

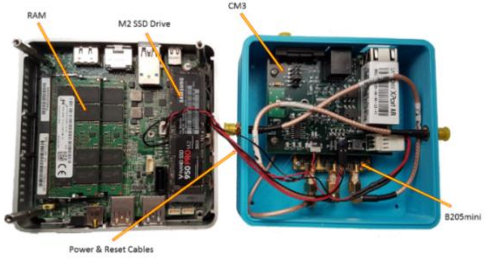


WINLAB SDR circa 2010



Mobile SDR Node (Small)

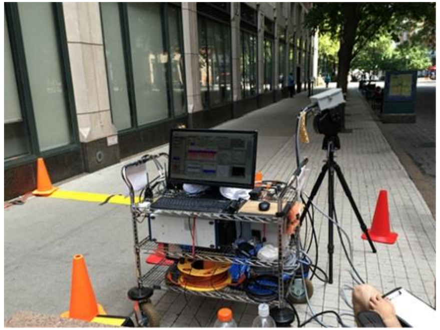
Prototype COSMOS SDR Node (Medium)



Key Technologies – mmWave

- mmWave a key new technology for the testbed, with limited availability of components
- Leveraging ongoing CU collaboration with IBM to provide mmWave phased arrays (64 antennas, 8 beams) for 28 Ghz
- Extensive mmWave systems expertise at NYU, including prototype systems and channel measurements

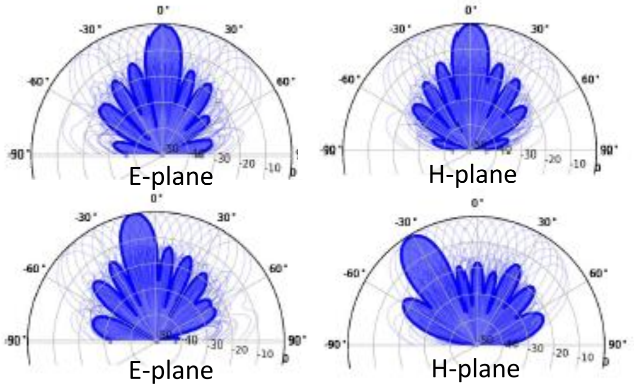
mmWave components from IBM



NYU Channel Measurements

Key Technologies – mmWave (cont’d)

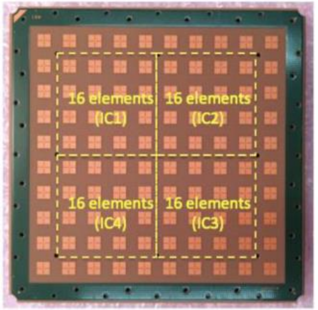
- 4-chip (130nm SiGe, 166 mm2) antenna module with two operation modes: 2 x 64 element beams or 8 x 16-element beams



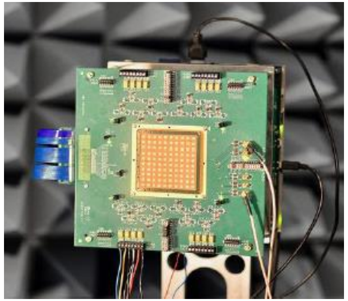
H-pol, ±50°

V-pol, ±50°

Performance Summary	
Elements per chip	32 TX/RX
Elements in package	128 TX/RX
Phase resolution (deg)	5
RMS phase error (deg)	0.8
TX Psat (dBm) per element	16
TX Op1dB (dBm) per element	13.5
TX EIRP per package per pol. @Psat (dBm)	54



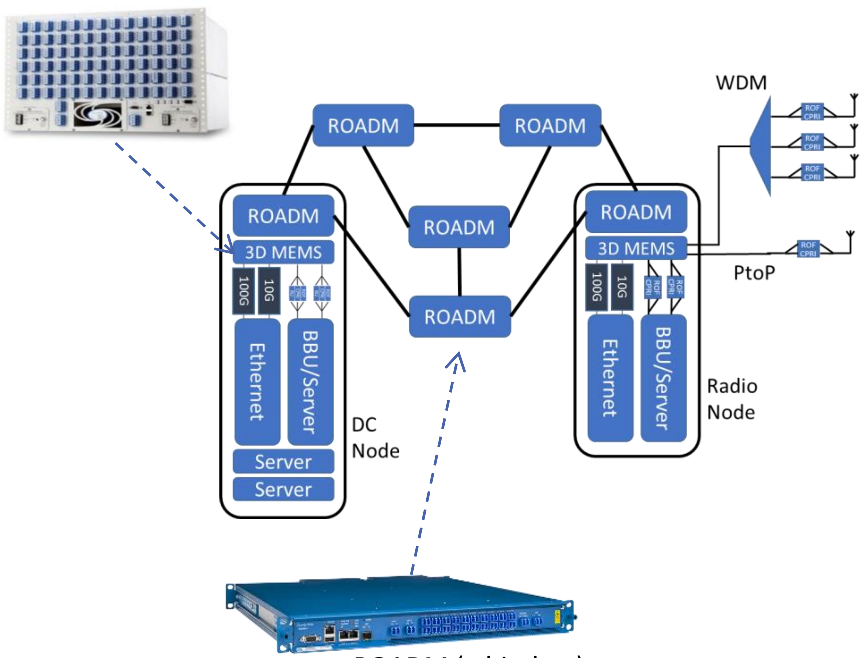
- Package dimensions: 70mm x 70mm x 2.7mm
- Flip-chip assembly for 4 ICs
- 655 BGA w/ 1.27mm pitch supporting multiple power domains, IF (TX & RX) and LO signals, Digital control and ref clock signals



Key Technologies – Optical Net

- Fast and low latency optical x-haul network using 3D MEMS switch and WDM ROADM
  - Configure wide range of topologies
  - Experiment on converged fiber/wireless networks
- Enables fast front-haul/mid-haul/back-haul connectivity between radio nodes and edge cloud
- SDN control plane for both optical and Ethernet switching
- Leverages results from CIAN NSF ERC, EAGER dark fiber project at Columbia

MEMS Switch



ROADM (whitebox)

CIAN

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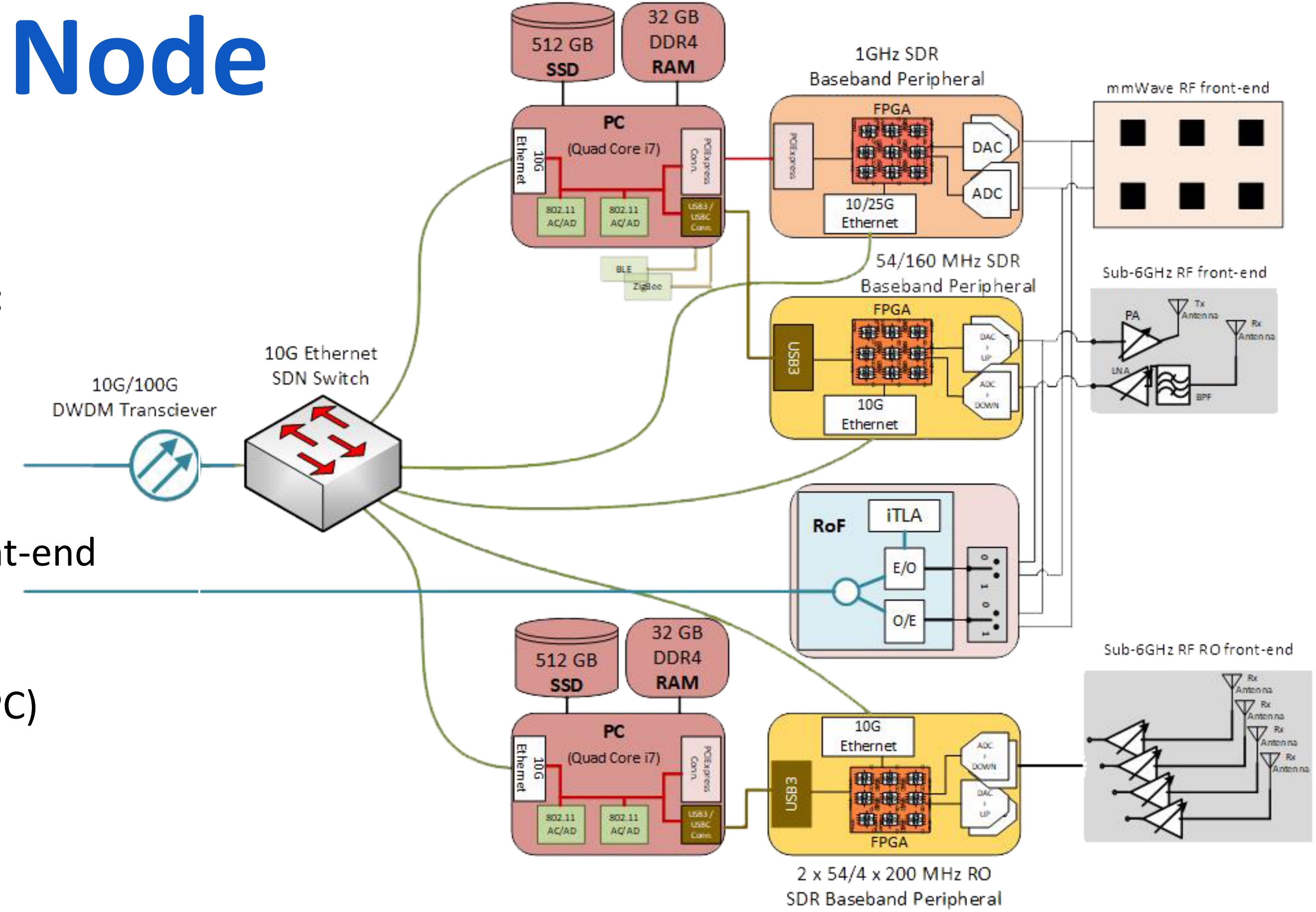
COSMOS

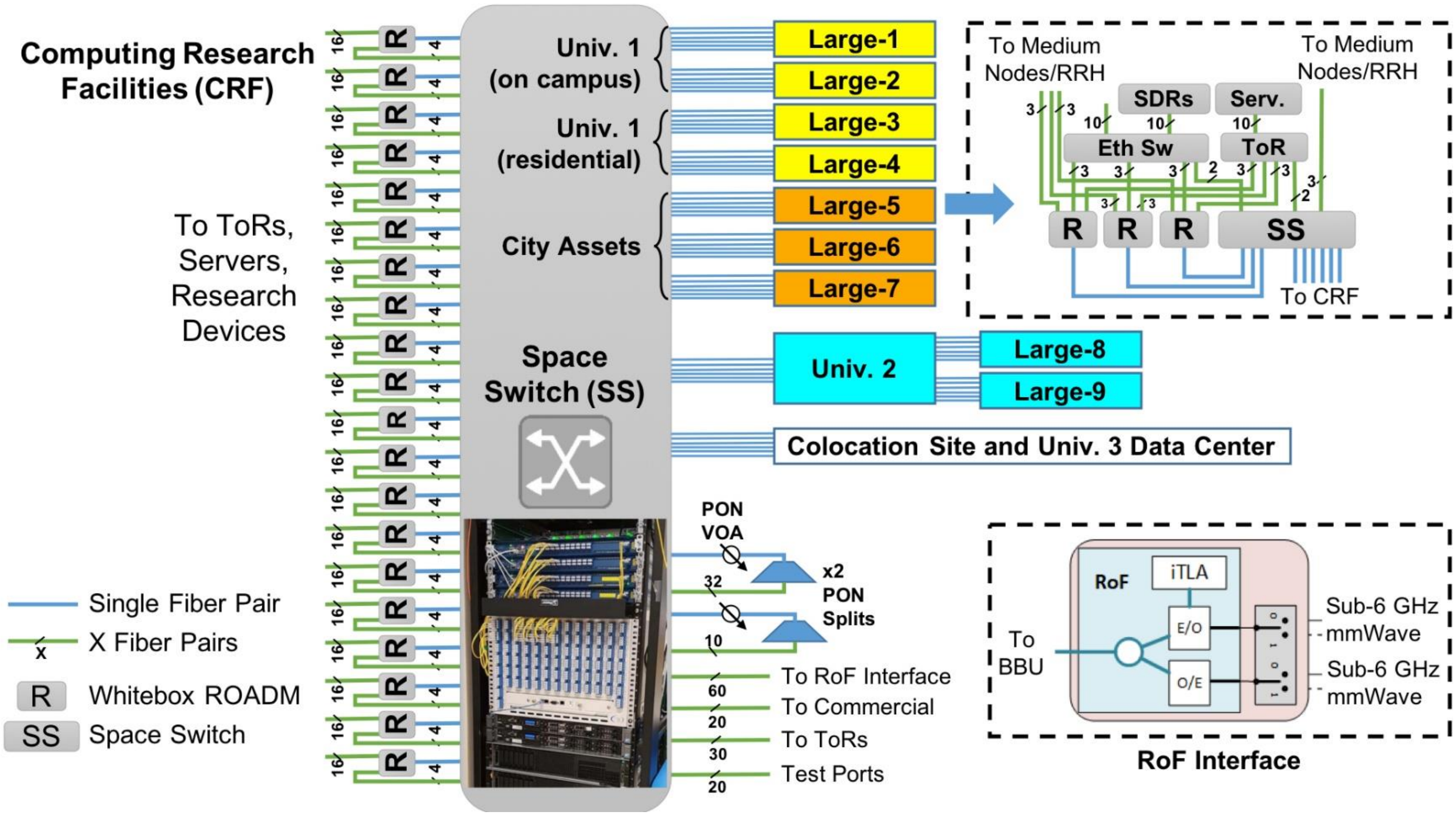
Medium Node

Variants based on building blocks:

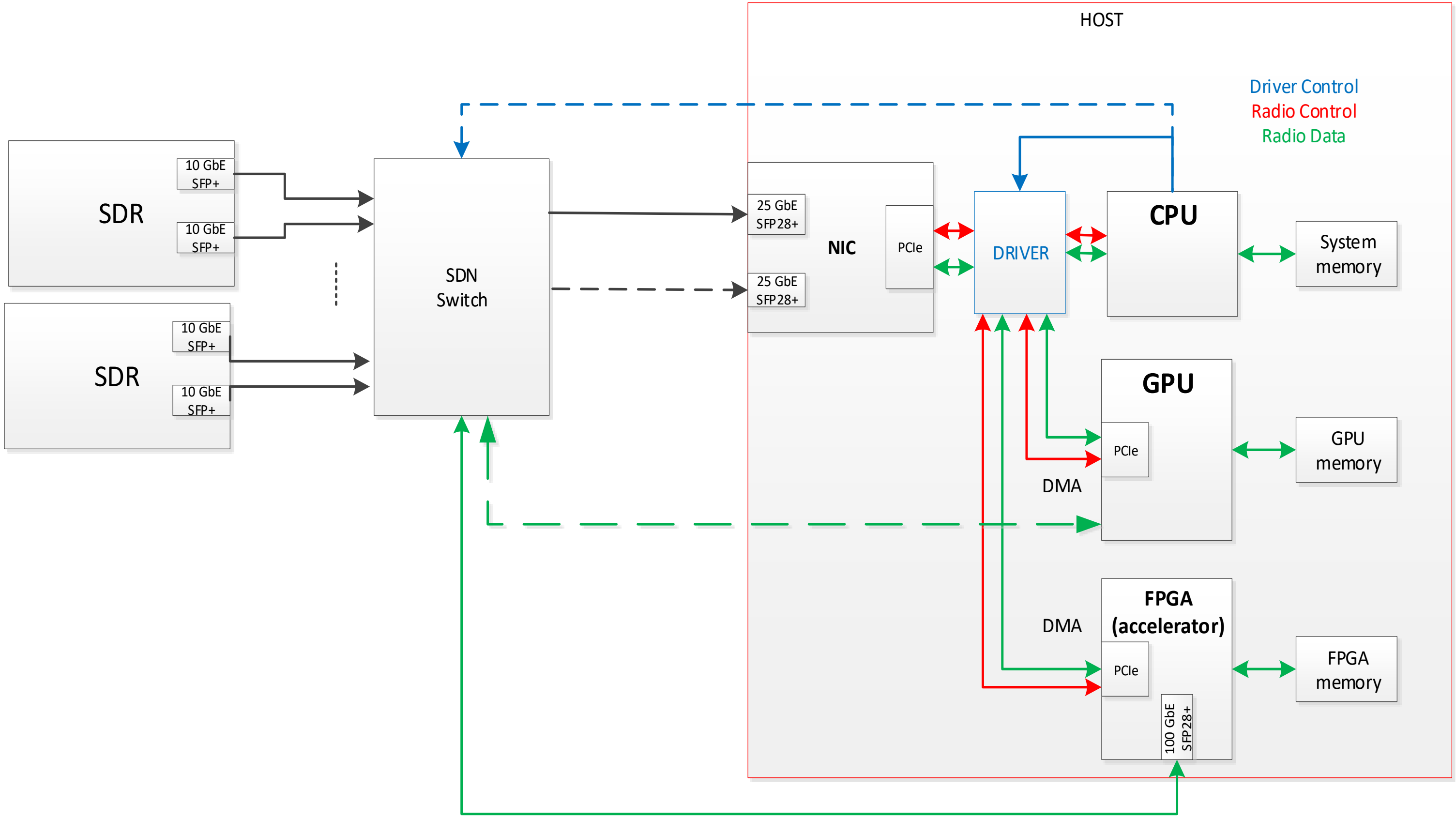
- mmWave RF front-end
- mmWave SDR BB
- Sub-6GHz RF front-end
- Sub-6GHz SDR BB
- Sub 6GHz monintoring RF front-end
- RF-over-fiber
- 10/100G (Ethernet+Optical)
- Standard compute platform (PC)
- WiFI devices



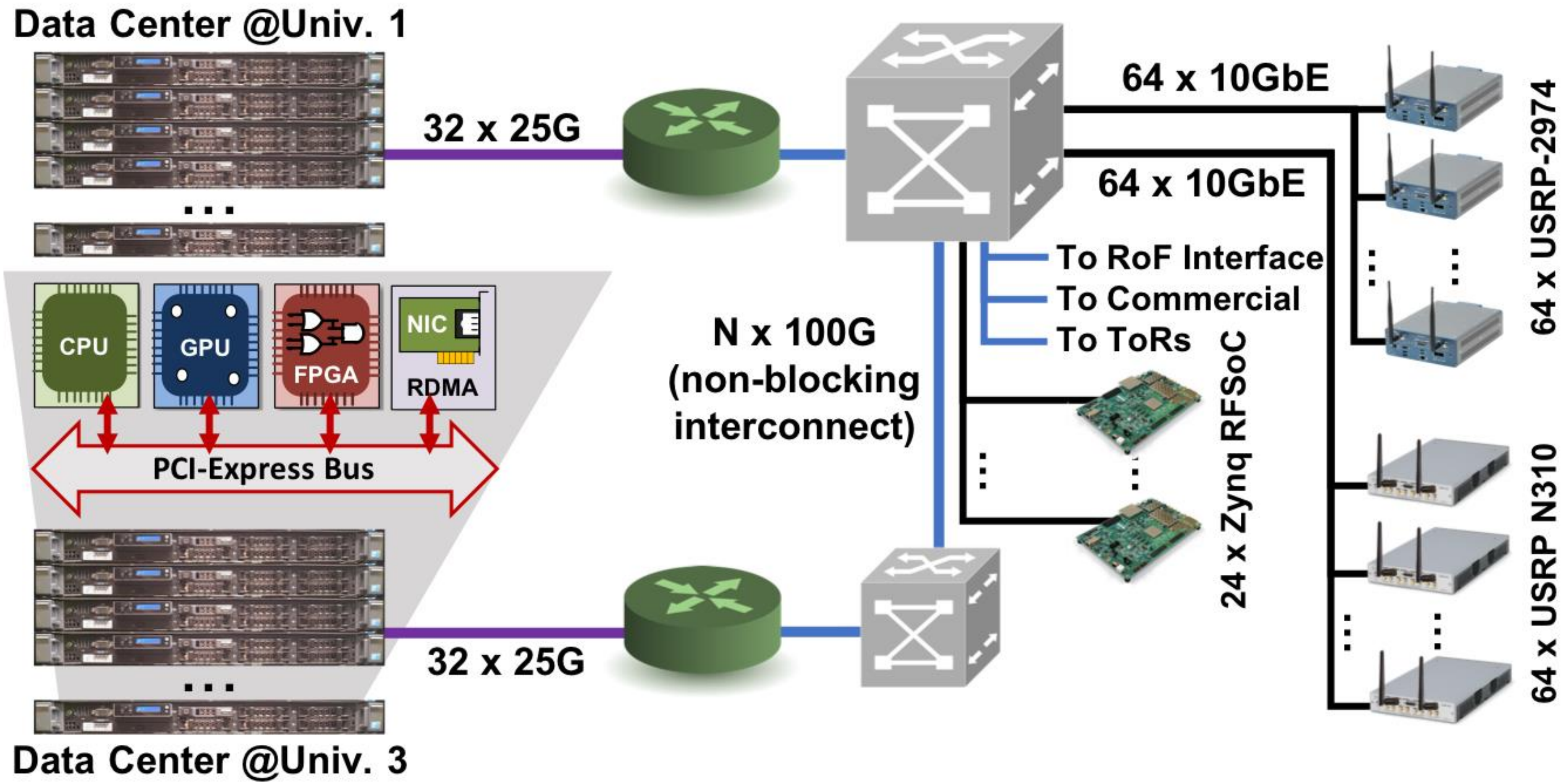
Optical Deployment View



Layer-2 Deployment View



Cloud Architecture



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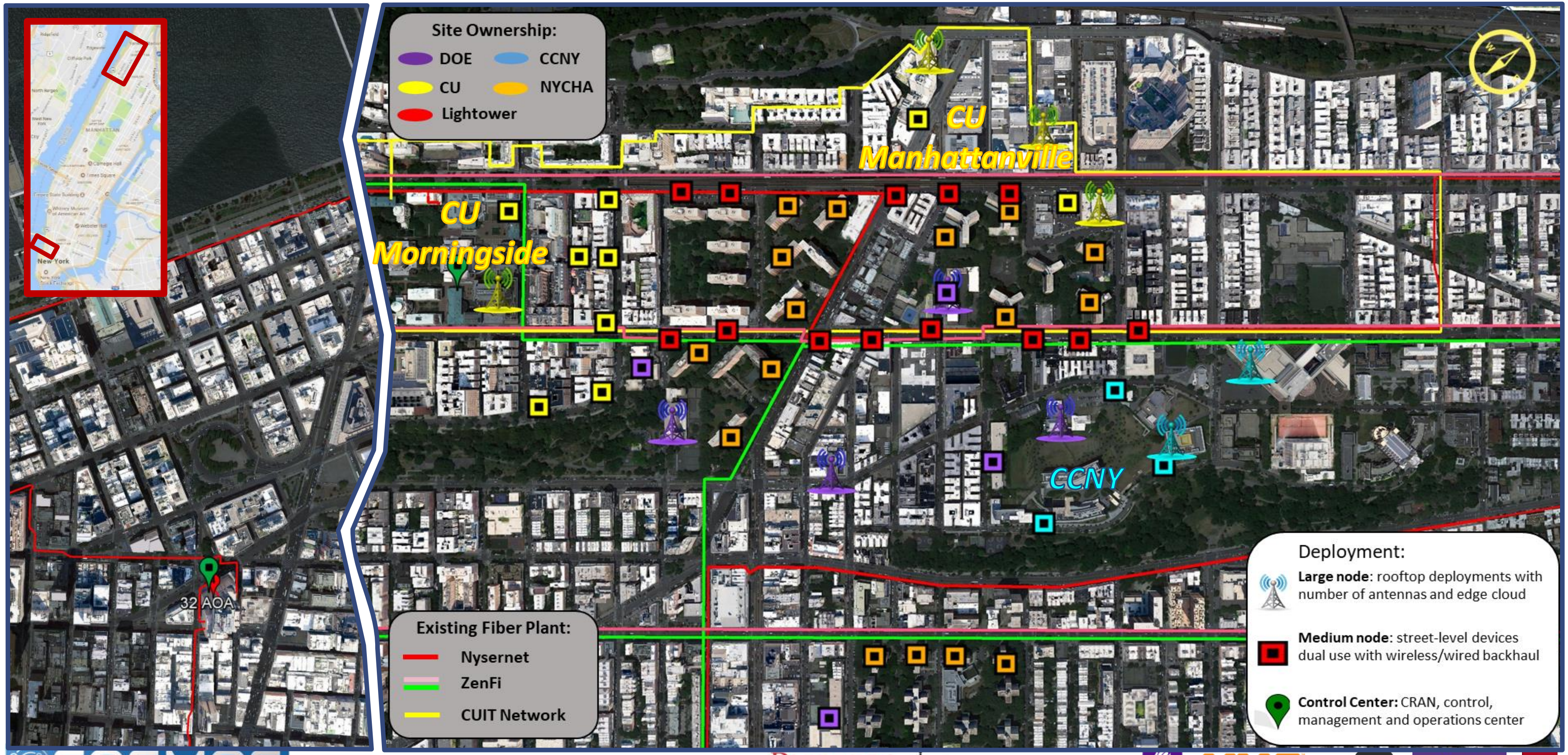
COSMOS - Deployment and Outreach

Objective: Take it Outside

COSMOS Deployment



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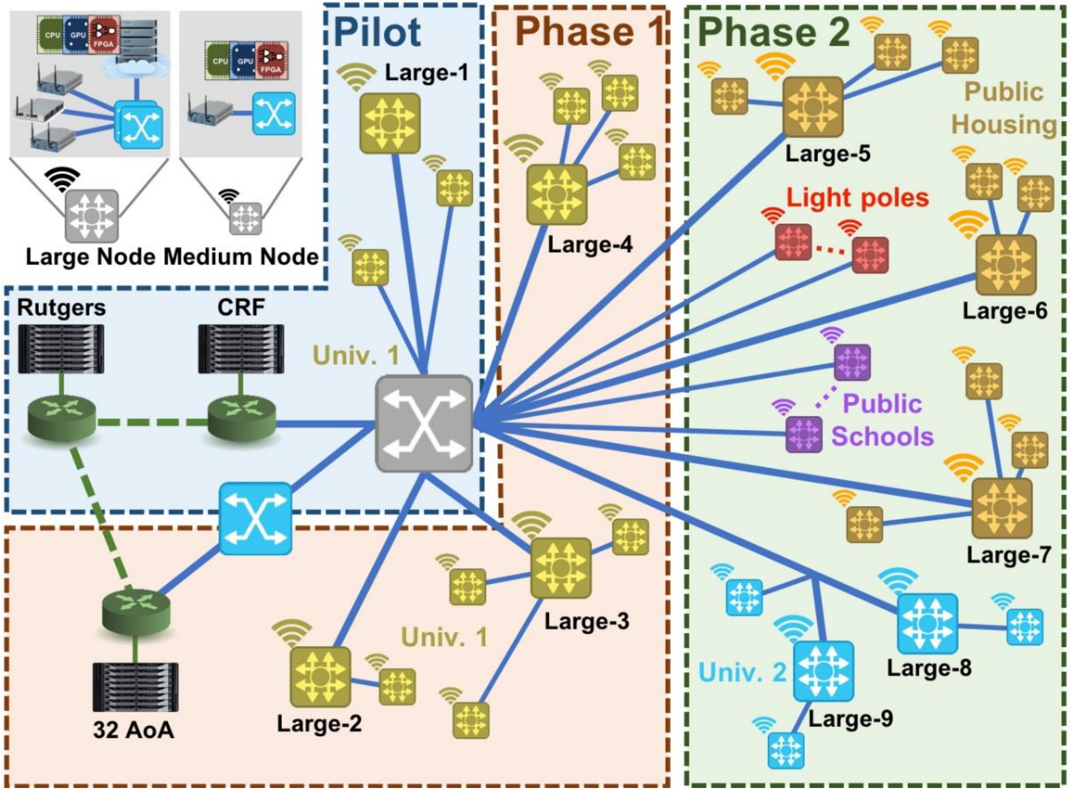
Phased Approach



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Partnerships and Users

- 67 Letters: Industry, Tech and Venture partners shown, Government Local, City and State, Community Boards, School Districts, Local Community and experimenters from the research community
- Additional Companies and Community partners are expressing interest in participation

Community Outreach

- **Silicon Harlem,** a COSMOS partner, is a social venture, designed to transform Harlem into a technology and innovation hub
- **Silicon Harlem** will operate as one of the interfaces between the COSMOS partners and the **local** community aiming to integrate the testbed elements within the community and various relevant smart city programs
- Significant **ongoing local tech-projects** (Gigabit Center, New America Project)

COSMOS Summary

- Focus on ultra high bandwidth, low latency, edge cloud
- Open platform (building on ORBIT) integrating mmWave, SDR, and optical x-haul
- 1 sq mile densely populated area in West Harlem
- Local community outreach
- Research community:
  - Develop future experiments, provide input
  - (short term) get involved in the educational outreach

More information:

http://advancewireless.org http://www.orbit-lab.org http://www.cosmos-lab.org

Contact: seskar (at) winlab (dot) Rutgers (dot) edu