MERIF WORKSHOP ORBIT/COSMOS INTRODUCTION

(OPEN ACCESS RESEARCH TESTBED FOR NEXT-GENERATION WIRELESS NETWORKS)/(CLOUD ENHANCED OPEN SOFTWARE DEFINED MOBILE WIRELESS TESTBED FOR CITY-SCALE DEPLOYMENT)

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Slides from Ivan Seskar

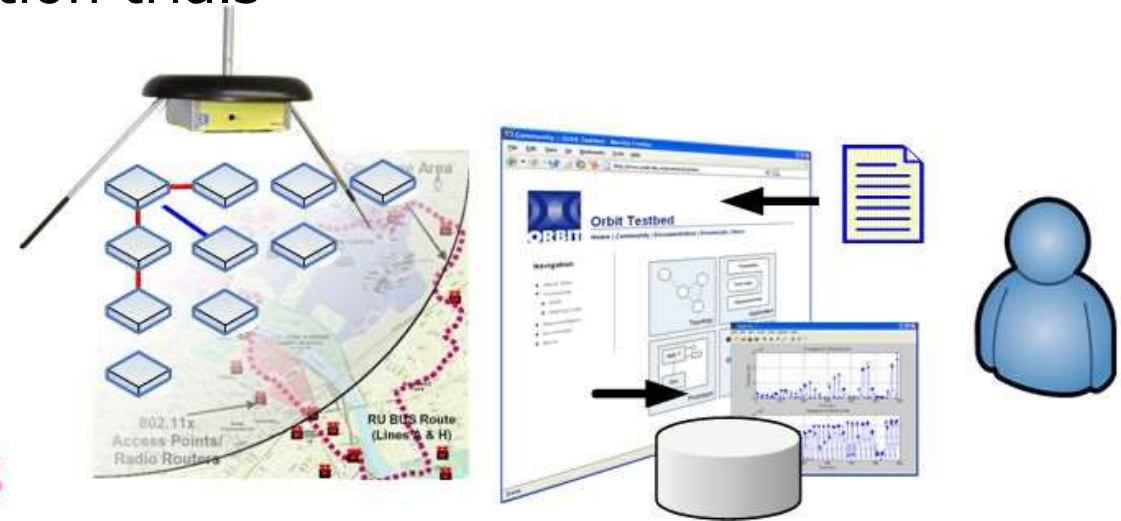
COSMOS RUTGERS COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK NYU NYC IBM

Orbit Project Rationale (2003)

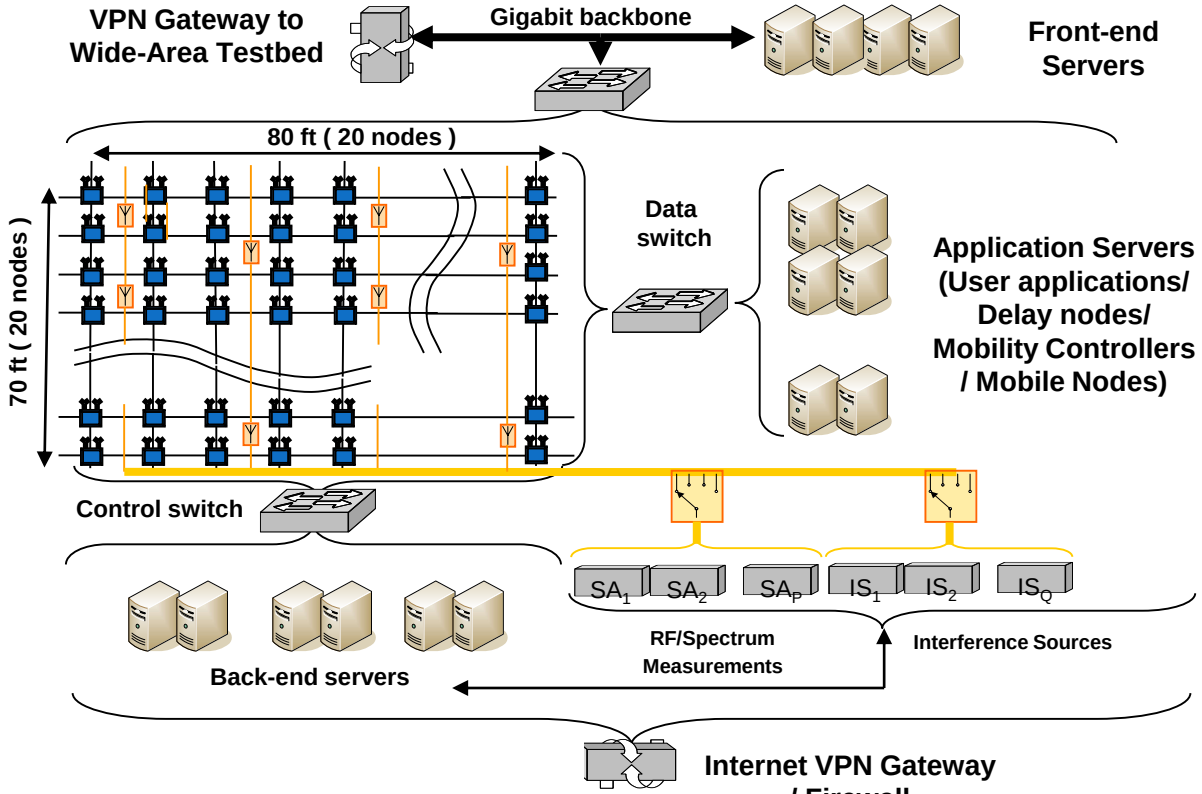
- Wireless testbeds motivated by:
  - cost & time needed to develop experimental prototypes
  - need for reproducible protocol evaluations
  - large-scale system studies (...emergent behavior)
  - growing importance of cross-layer protocol studies
  - creation of communities for wireless network research
- ORBIT: open-access multi-user facility for experimental wireless networking research primarily in unlicensed bands
  - ~24/7 service facility with remote access
  - open interfaces for flexible layer 2,3 & cross-layer protocols
  - extensive measurements at PHY, MAC and Net layers
  - support for wide range of radio system scenarios

ORBIT

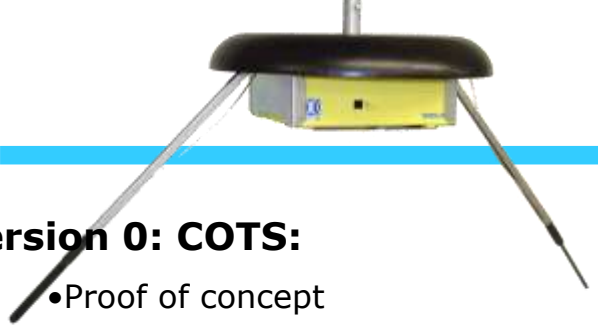
- Proposal: Build radio grid emulator (phase I) and field trial network (phase II)
- Emulator used for detailed protocol evaluations in reproducible complex radio environments
- Field trial network for further real-world evaluation & application trials



Orbit Hardware



ORBIT Radio Node (2004/2005)



Version 0: COTS:

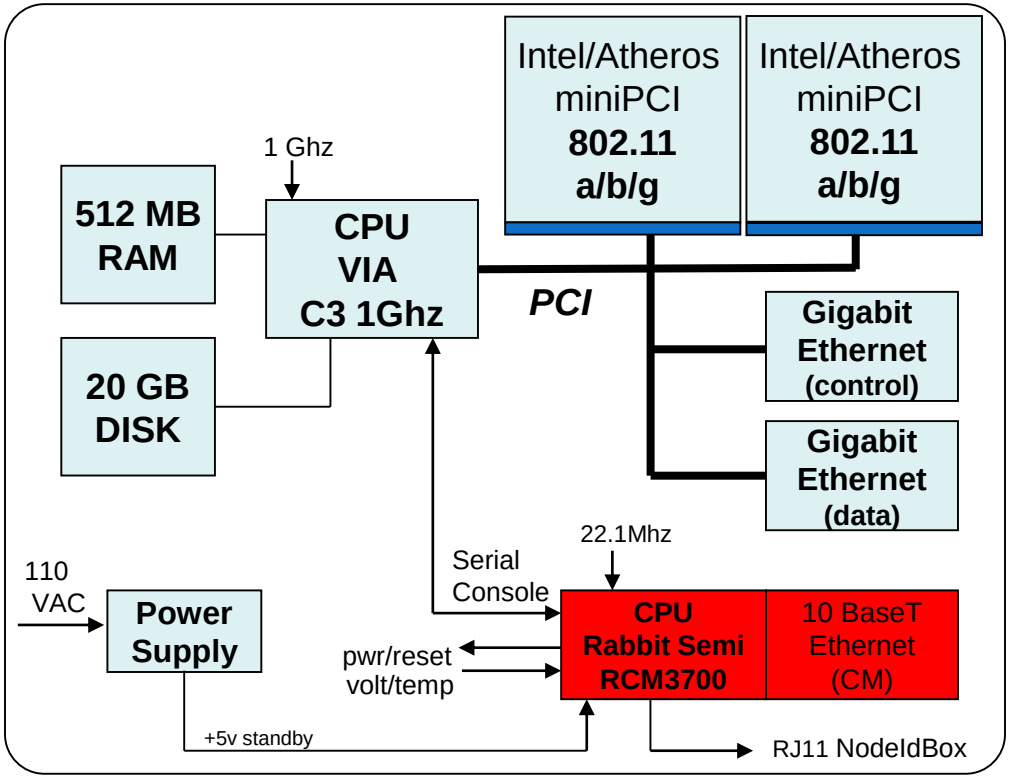
- Proof of concept
- Prototyping platform

Version 1: Custom design:

- Functional requirements
- Manageability
- Power consumption
- Cost

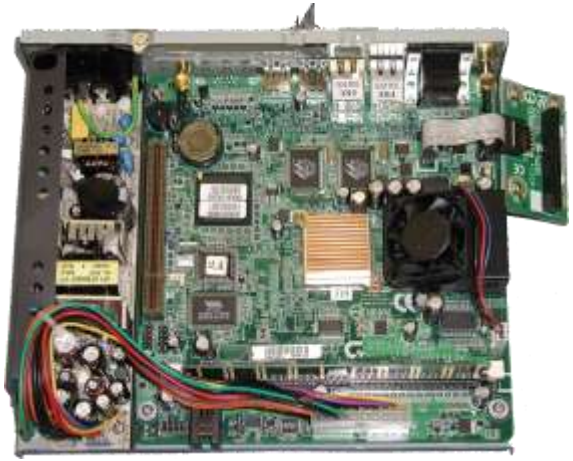
Version 2: Custom design with other attached devices:

- Bluetooth
- ZigBee
- GNU Radio



ORBIT Radio Node Gen 2 Photo Album

ORBIT Radio Node
with integrated Chassis Manager



Non-Grid Node
Chassis Manager

Version 2.5: Back to COTS (2007)

The COTS 2nd generation node:

- Off the shelf motherboard
- Custom indoor or outdoor (weatherproof) enclosure
- Control manager (CM) with optional GPS and GPRS

ORBIT Radio Node Versions

Version 3 (2010/2011)

- Core 2 Quad with Q35 Express chipset
- 4 GB DDR2
- 2 x Gigabit Ethernet ports
- PCI-Express X16
- Mini-PCI socket
- 8 x USB 2.0
- 2 x COM

- Core 2 Duo with GM45 chipset
- 8 GB DDR3
- 2 x Gigabit Ethernet ports
- PCI-Express X16
- PCI Express mini socket
- Mini-PCI socket
- 8 x USB 2.0
- 2 x COM

Version 4 (2015/2016)

- I7-4770 3.4 GHz Q87T Express chipset
- 16 GB DDR3
- 2 x Gigabit Ethernet ports
- PCI-Express 2.0 X16
- 2 x Mini-PCIexpress socket
- 8 x USB 3.0
- OOB Mgmgt.

- Xeon E5-2600v3 with 18 cores
- 64 GB DDR4
- 2 x 10G Ethernet ports
- 2 x Gigabit Ethernet ports
- PCI-Express 3.0 X16
- 8 x USB 3.0
- OOB Mgmgt.

Fixed Function Radio Devices: 802.11 (a,b,g,n,ac,ad), Zigbee, BT/BLE

- Atheros Dual Band (5212)
- Dual-diversity with 0-18 dBm (1 dBm steps)
- PCI 2.3 and PC Card 7.1
- Drivers: madwifi and ath5k

- Intel Dual Band 2915ABG
- Dual-diversity with -12-+20 dBm (1 dBm steps)
- Drivers: ipw2200

- Netgear WNDA3100
- Based on Atheros AR9170+AR 9104
- 2x2 MIMO
- 6.5 - 300 Mbps
- Driver: ath9k

- D-LINK DWA-140
- Based on Ralink RT2870
- 2x2 MIMO
- 20/40 MHz support
- 6.5 - 300 Mbps
- Driver*: rt2x00

- Atmega (4MHz), MSP430 (8MHz)
- CC2420 250kbps 2.4GHz IEEE 802.15.4 (ZigBee) Chipcon Wireless Transceiver
- Sensors - Temperature, Light, Humidity
- Driver: Motes (Contiki)

- Belkin F8T003 and F8T010
- Bluetooth v1.1 compliant
- Range of 10m (100m)
- Driver: BlueZ

SDR Devices: USRP/USRP2/B210/X310

- IF 0-100 MHz (50 MHz transmit)
  - 128 MS/s DAC
  - 64 MS/s ADC
- USB bus (W = 8 MHz)
- Channelizer code in Altera Cyclone FPGA
- 2 RF board slots

- IF -200 MHz (80 MHz receive)
  - 100 MS/s 14-bit dual (IQ) ADCs
    400 MS/s 16-bit dual (IQ) DACs
- Gigabit Ethernet (W = 25 MHz)
- FPGA w/Multipliers (Xilinx Spartan 3), 1 MB SRAM
- 1 RF board slot

- Xilinx Spartan-6 FPGA
- Dual channel AD9361 RFIC transceiver (70 MHz – 6 GHz with 56 MHz baseband)
- USB 3.0 connectivity

- Xilinx Kintex-7 FPGA (XC7K410T)
- 2 x 10 Gigabit Ethernet
- 1 x SBX RF Daughterboard (400-4400 MHz Rx/Tx with 120 MHz baseband)
- 1 x CBX RF Daughterboard (1200-6000 MHz Rx/Tx with 120 MHz baseband)

Latest ORBIT Nodes

Movable mini-racks in four corners

8 USRP X310s:

- **Dual 160 MHz baseband**
- **2 x 10G optical Ethernet interconnects**
- **Large Kintex FPGA with:**

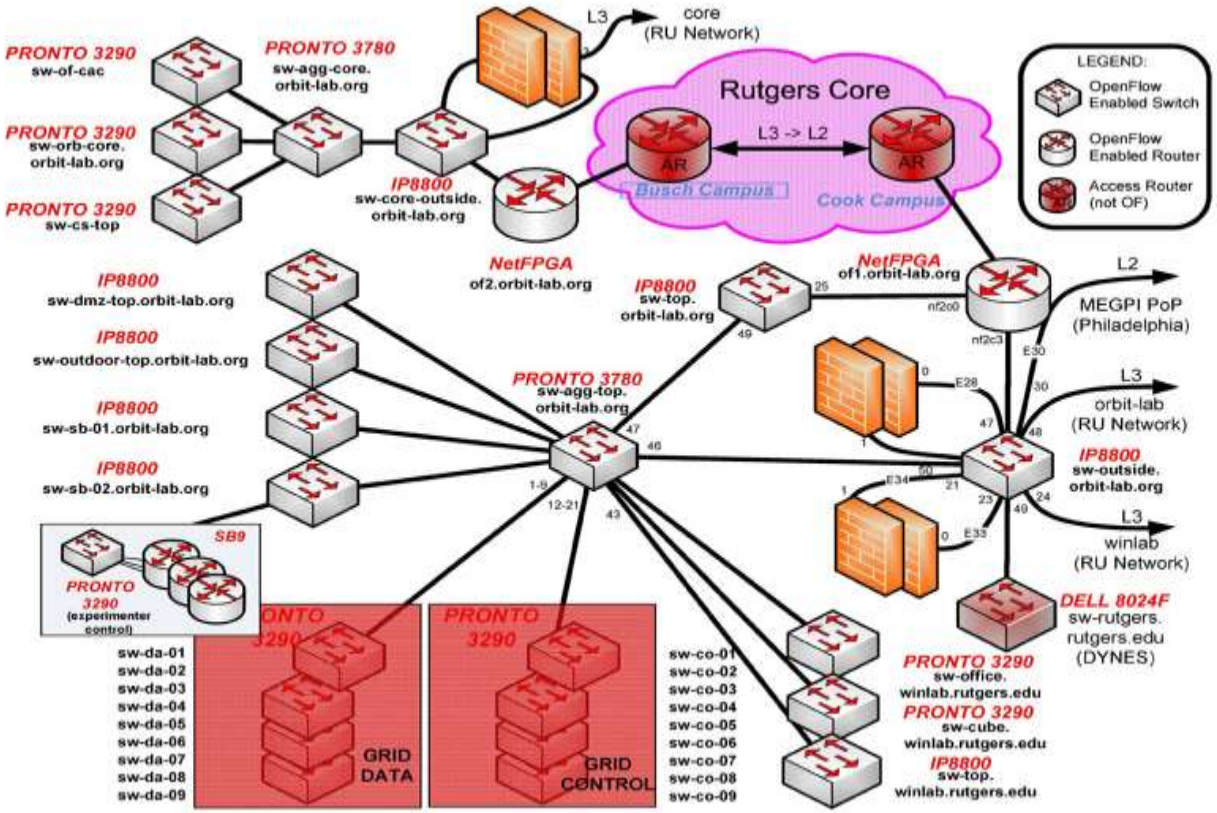
Resource Type	Number
DSP48 Blocks	58K
Block Rams (18 kB)	14K
Logic Cells	7.2M
Slices (LUTs)	1.5M

Core Computing with SDN

Rack with 32 machines:

- **2 x 12 core CPU**
- **2 x 25G optical Ethernet interconnects**
- **100G TOR SDN switch**

ORBIT SDN Deployment



ORBIT Grid

Sandboxes

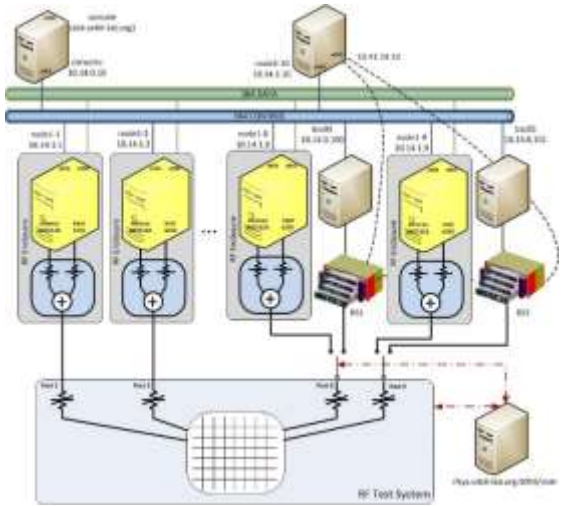
To support development and reduce pressure on the grid

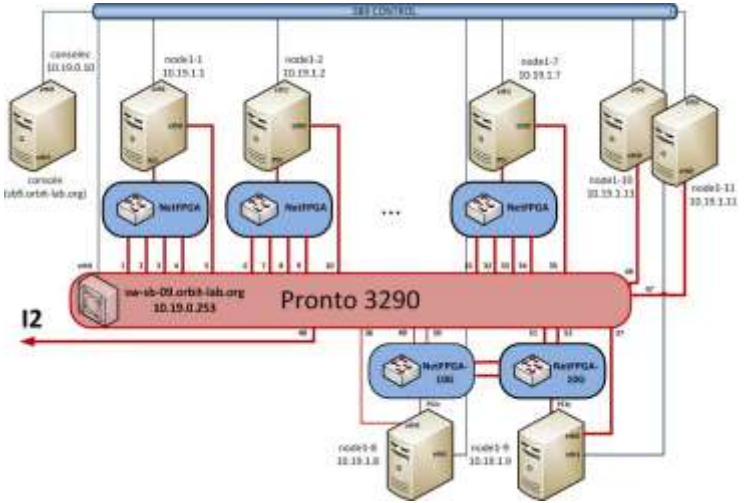
- Console and a pair of nodes and devices focused on particular technology

Except for two specialized sandboxes:

SB4

Tight topology control

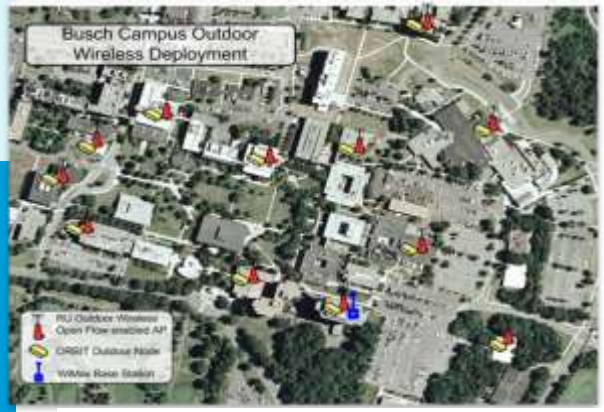




SB9

Software Defined Networking

ORBIT Outdoor Infrastructure (WiMAX/LTE)



RF Module
(sector)

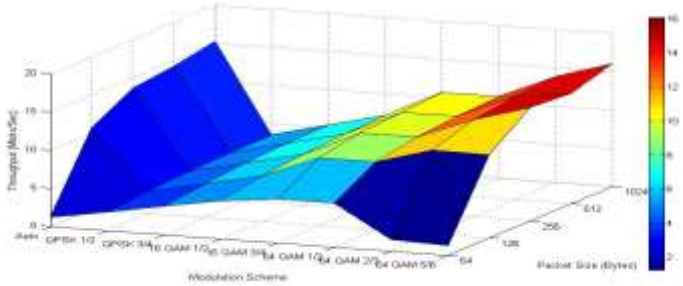
Base
Module

Outdoor Unit (ODU)

Omni-directional
antenna
(elev. < 6ft above roof!)

**ORBIT
Vehicular
Node**

**WiMAX: Intel
5150/5350/6250
LTE: Netgear AC341U**



Experimental readings at one location
CINR = 29 RSSI = -51

Rt. 1 Campus WiMAX Coverage

Android based
portable
platform

**HTC EVO 4G
Nexus 5
Galaxy 6**

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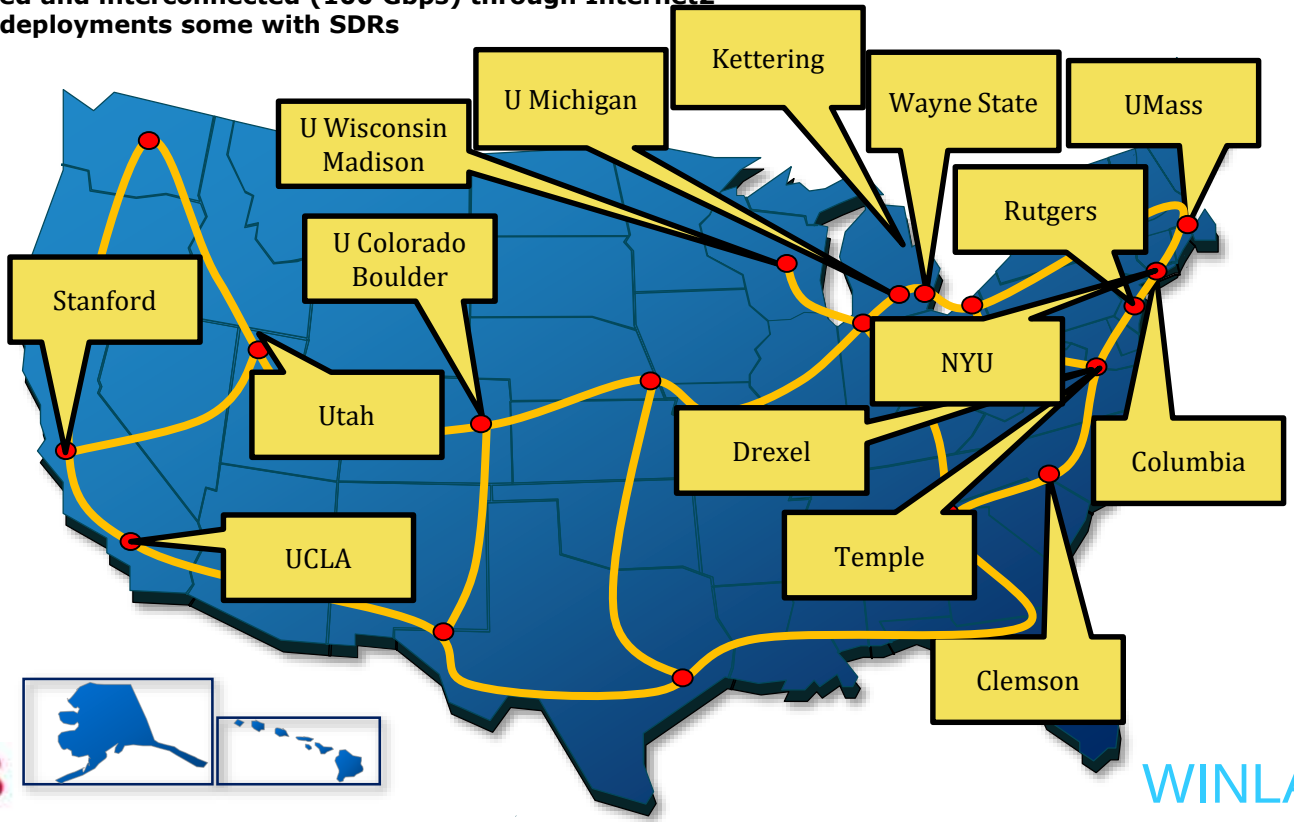
GENI Wireless Deployment

- **32 LTE and WiMAX BS on 14 campuses**
- **SDN (Click and OVS based) datapath/backbone**
- **Sliced, virtualized and interconnected (100 Gbps) through Internet2**
- **10 mini-ORBIT deployments some with SDRs**



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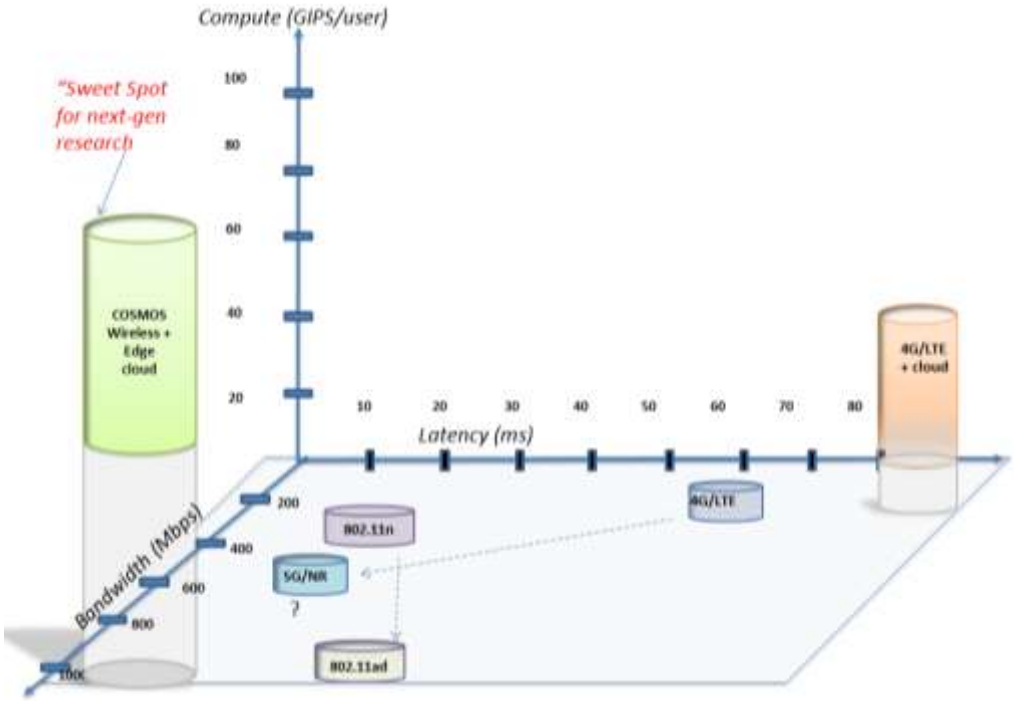
COSMOS Project Vision

- 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



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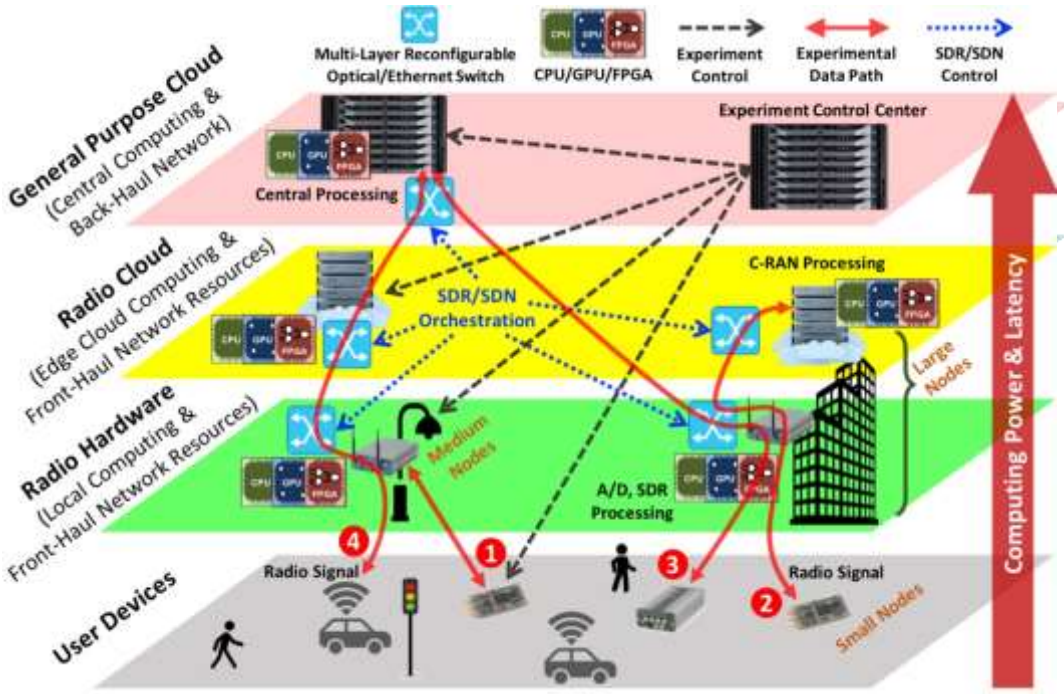
System Architecture

- 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



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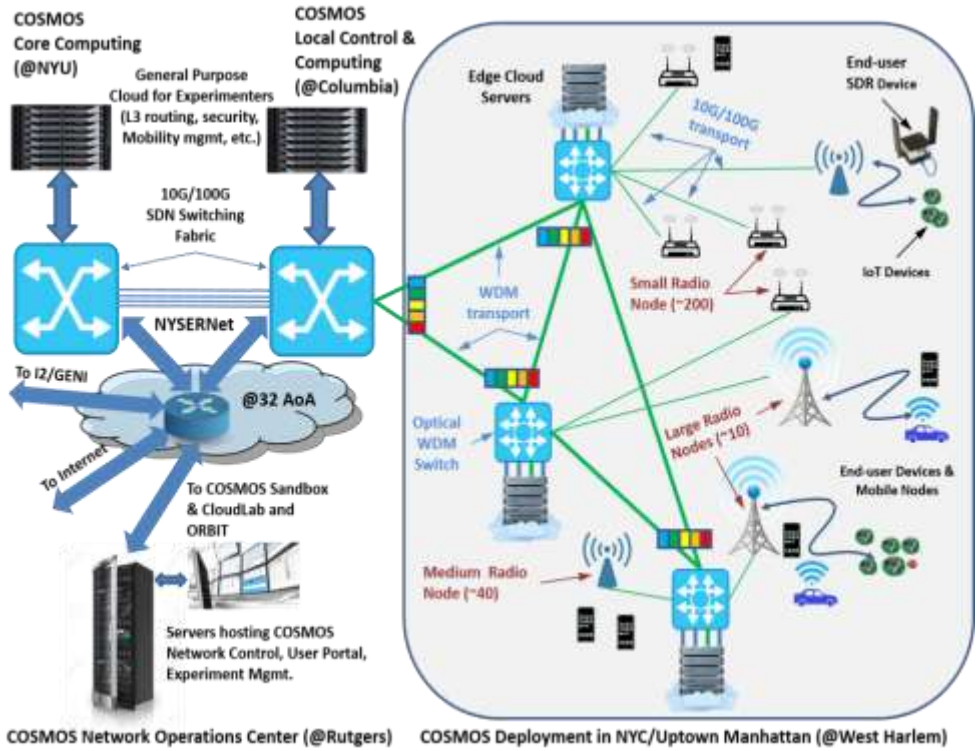
System Architecture (cont'd)

- 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



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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.)

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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

COSMOS SDR Node, SDR Tray and RF Frontend Tray

Mobile SDR Node with: B210, B205

Ettus E312

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Sub-6GHz SDR Devices

USRP-N310 (Main Monitoring SDR)	
System on Chip	Zynq-7100 (Dual-core ARM Cortex-A9 @ 800 MHz)
RAM	1 GB DDR3
Ethernet	2 x 10 Gbps
ADC/DAC	4 x {122.88, 125, 153.6 MS/s} @ 16 bit/@ 14 bit
RF	4 x 10 MHz to 6 GHz / 100 MHz BW
FPGA	Zynq-7100 SoC with 1GB RAM

USRP-2974 (Main Experimentation SDR)	
System on module	Congatec COM Express conga-TS170 (Quad Core i7 6822EQ @ 2 GHz)
RAM	8GB DDR4
Ethernet	2 x 10 Gbps
ADC/DAC	2 x 200 MHz @ 14 bit/200 MHz @ 16 bit
RF	2 x 10 MHz to 6 GHz / 160 MHz BW
FPGA	Kintex-7 XC7K410T with 1GB RAM

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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

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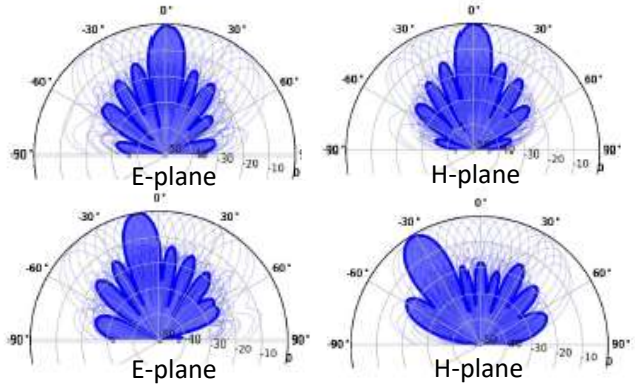
Key Technologies – mmWave (cont'd)

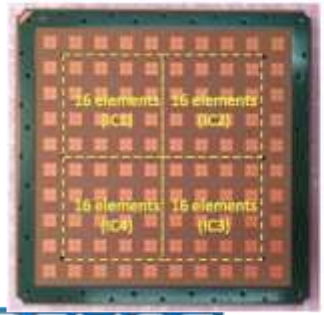
- 4-chip (130nm SiGe, 166 mm2) antenna module with two operation modes:
  2 x 64 element beams or 8 x 16-element beams

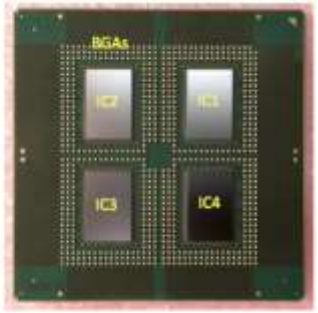


H-pol, ±50°

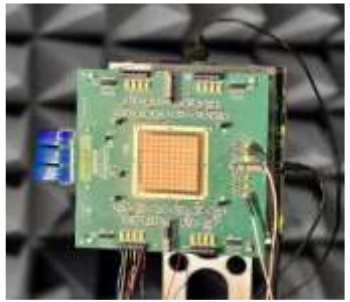
V-pol, ±50°

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



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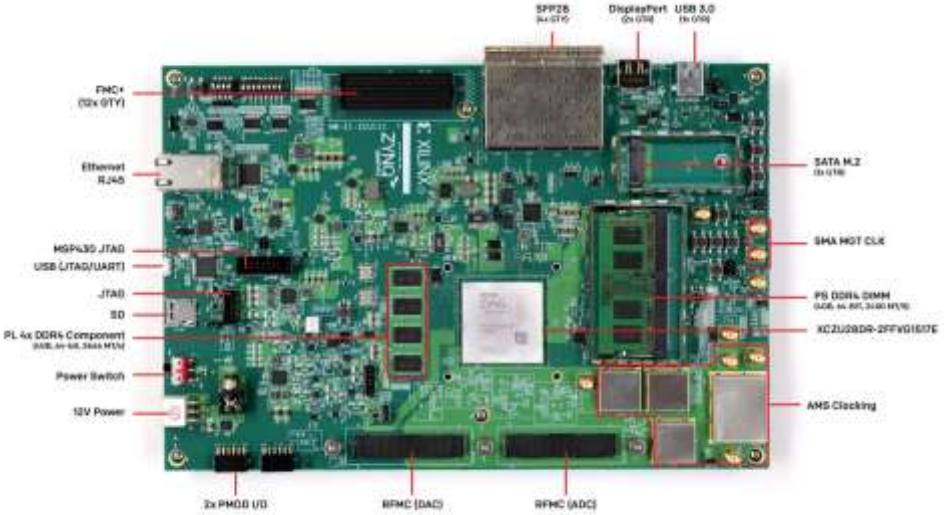
mmWave Baseband Devices

- Initially: USRP based BB (2 channels @ 100 MHz) with 2 x 10 Gbps
- Full deployment: RFSoC based (up to 8 channels @ 400 MHz) with 100 Gbps

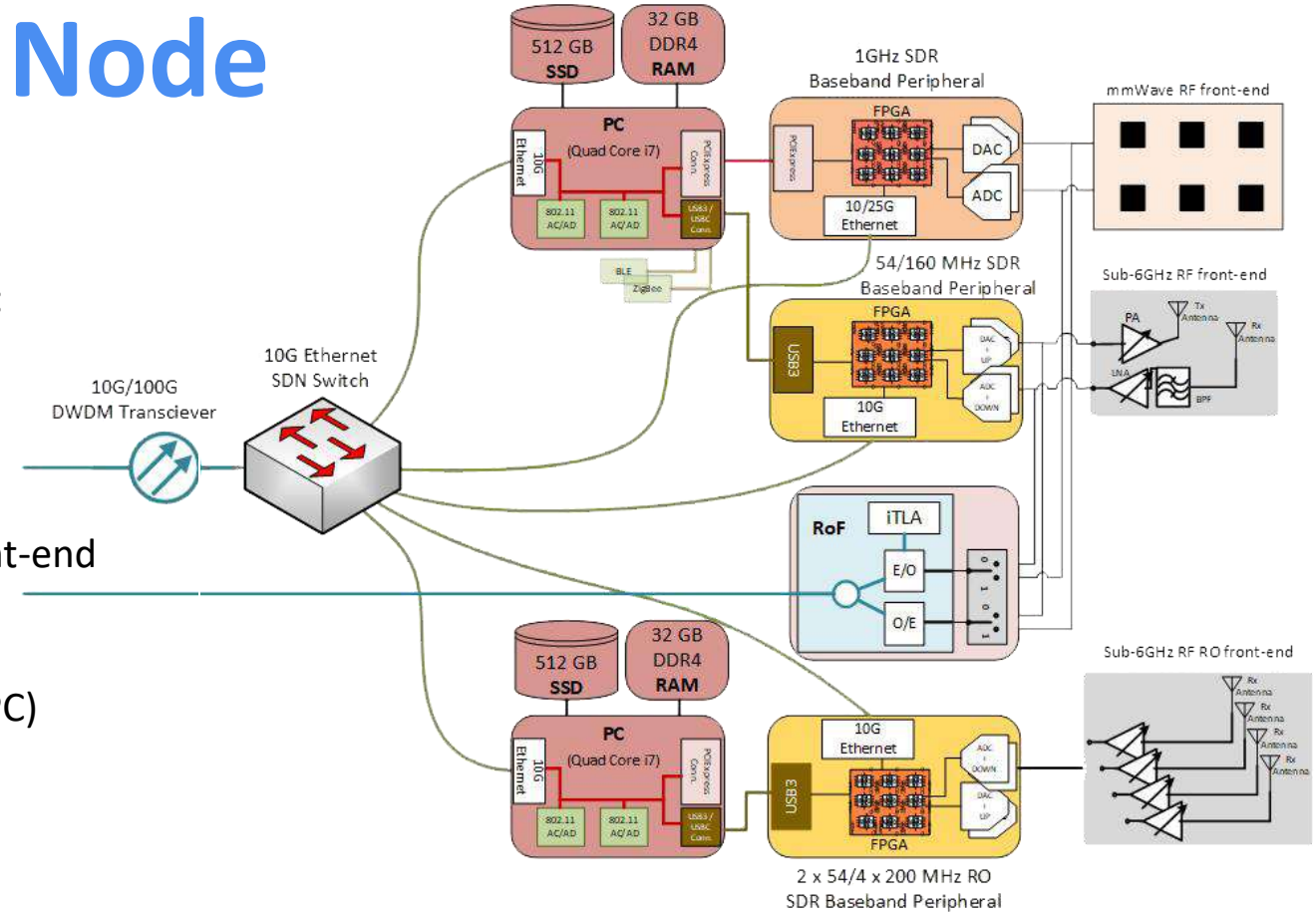
RF-ADC	8 x 4.096 Gsps @ 12 bit
RF-DAC	8 x 6.554 Gsps @ 14 bit
Logic Cells	930,000
Memory (Mb)	60.5 [Mb]
DSP Slices	4,272
33G Transceivers	16*



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



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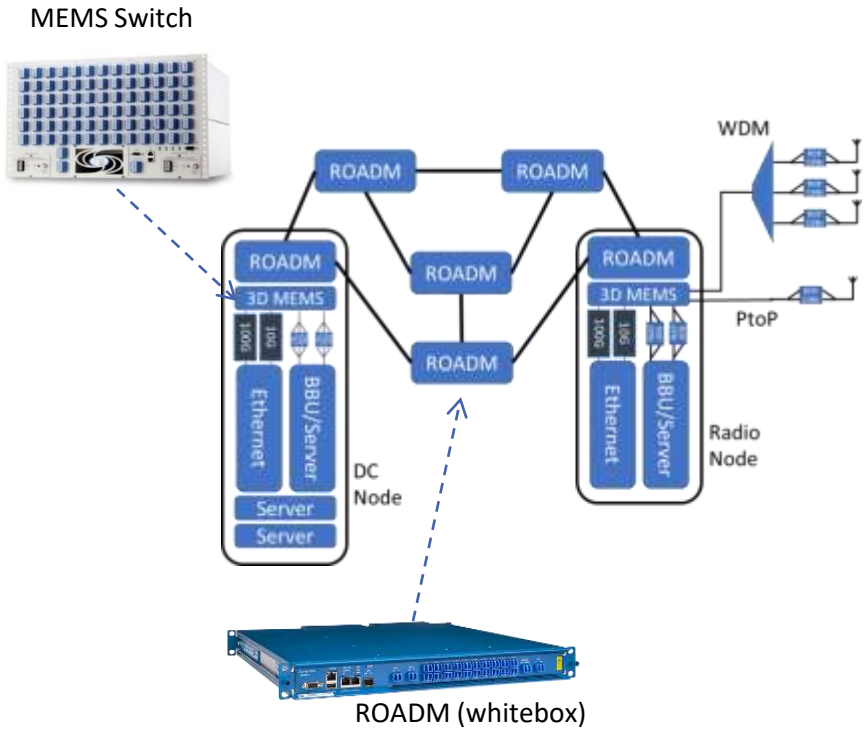
Key Technologies – Optical Net

- 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



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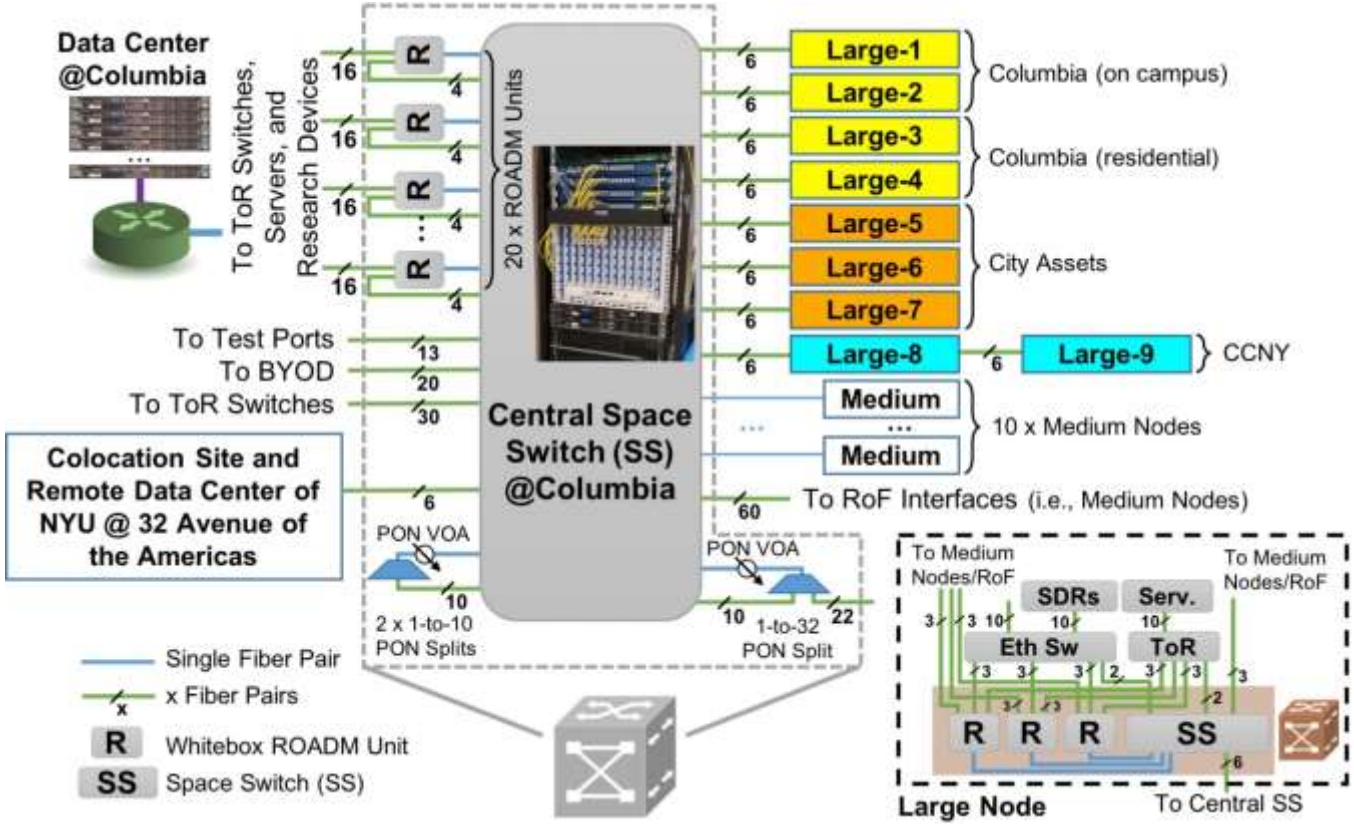
CALIENT & Lumentum

- Calient MEMS Space switch
  - 320x320 any to any optical circuit switch
  - ~2db loss, ~25ms switching time
  - Openflow, netconf, etc.
- Lumentum Whitebox20
  - 20 port degree 1 ROADM
  - C band DWDM
  - Supports netconf

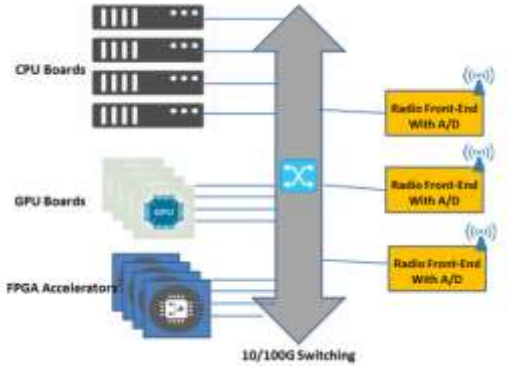
Optical Deployment View



Key Technologies – SDN & Cloud

- SDN control plane used to control x-haul and cloud server connectivity
- Open Network Operating System (ONOS) with radio API extensions
- Compute clusters collocated with radio nodes (M,L) with choice of CPU, GPU and FPGA accelerators
- Also, users have access to regular cloud racks for L3→ applications (GENI & CloudLab clusters at WINLAB)

SDN Switching Rack

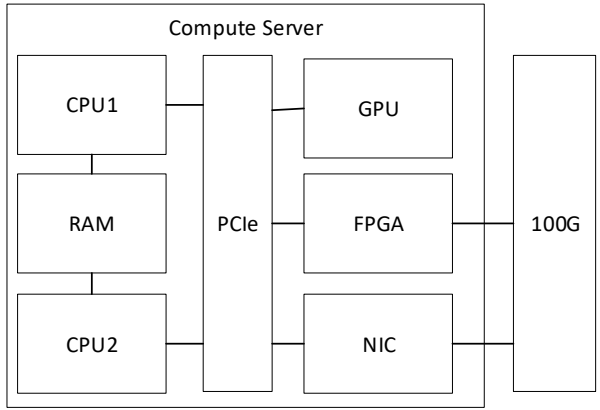


DELL Switches

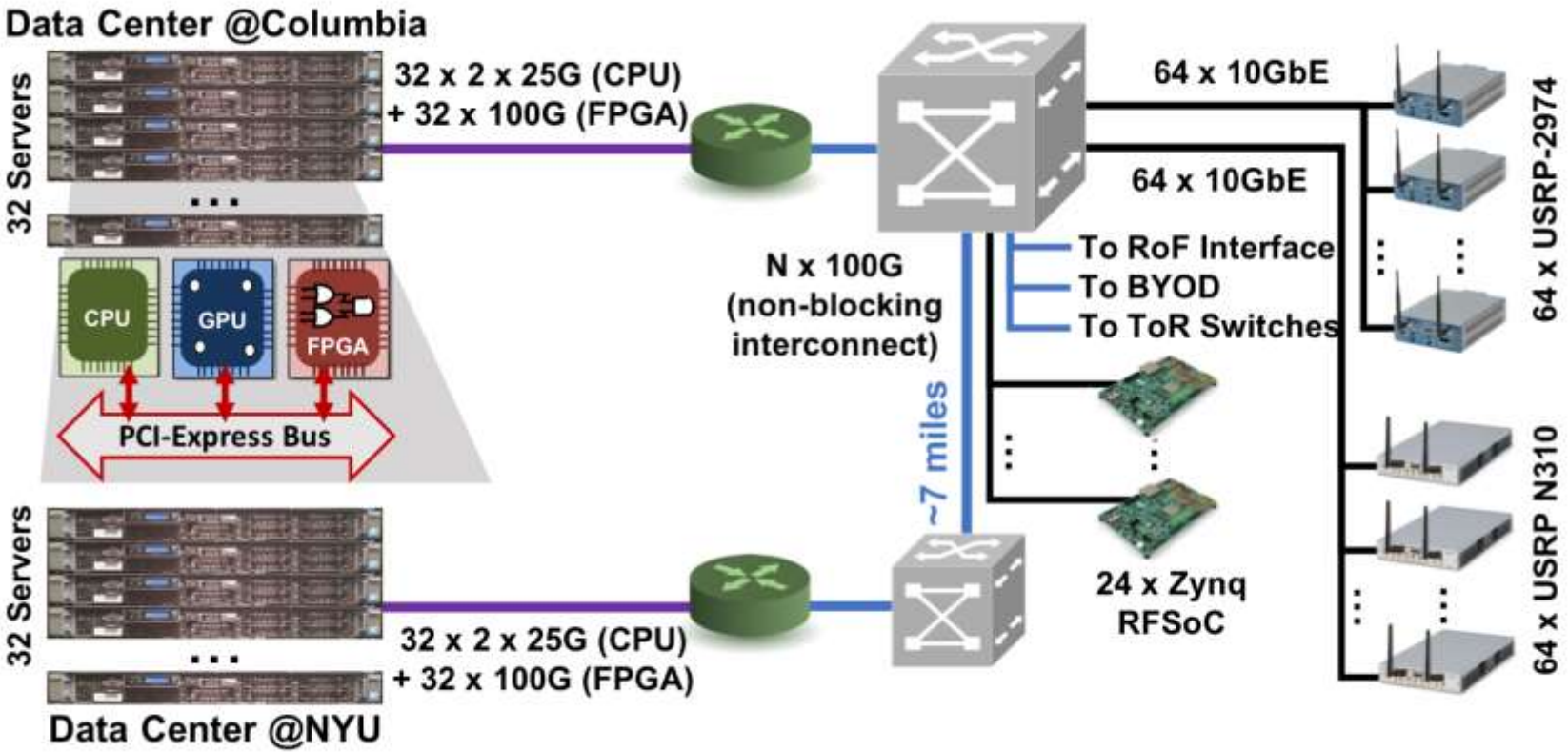
- Data Plane switching:
  - Dell Z9100-ON Switches
  - Commodity 100g ethernet switching
  - Broadcom Tomahawk Chipset
  - Openflow 1.3
  - Supports alternate operating systems via ONIE
- Control Plane switching:
  - Dell S4048-ON
  - Cost effective 10g switching
  - Used for physically separate control plane

Compute Nodes

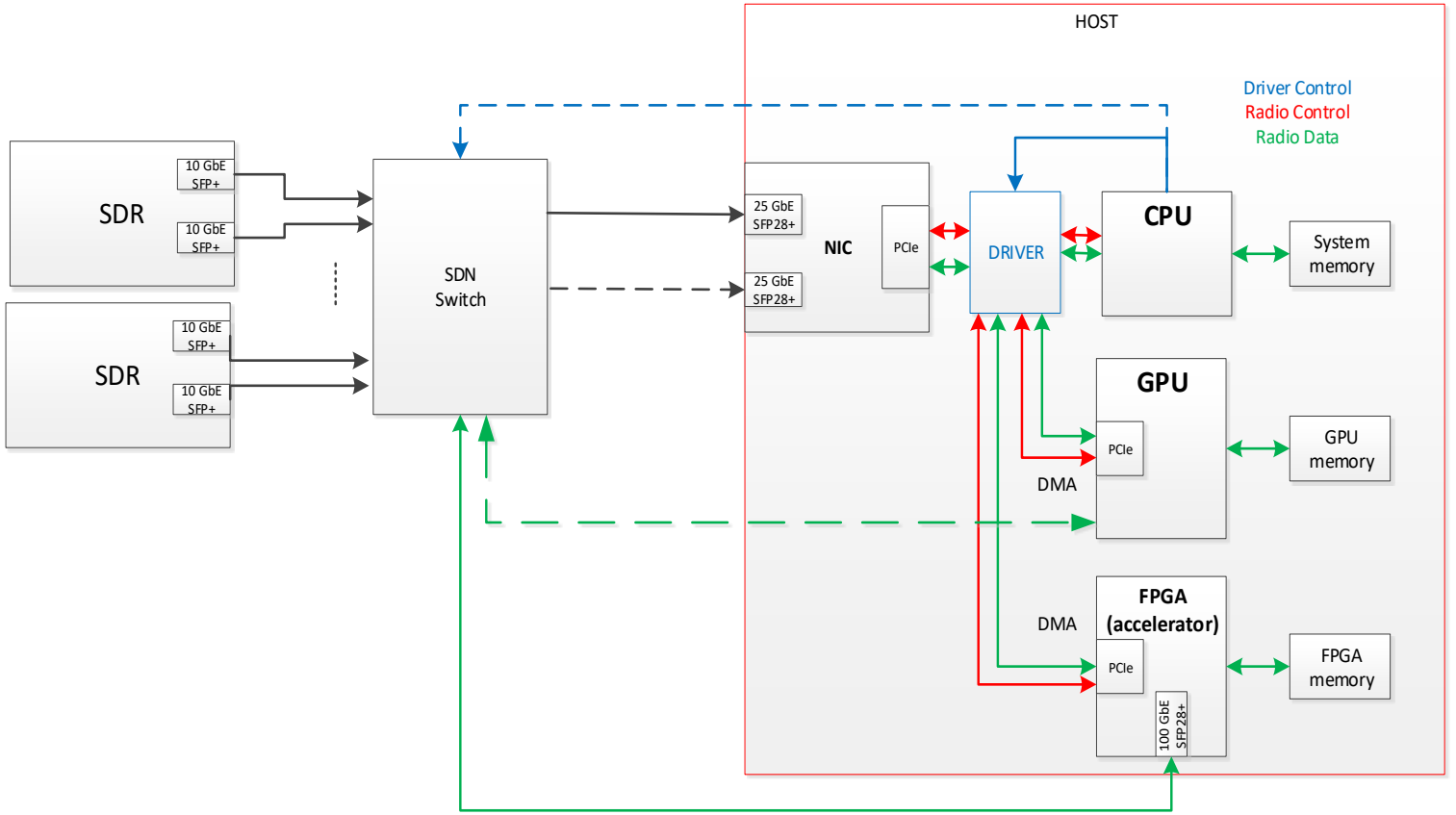
- Dell R740XD
  - Dual 12 Core CPU
  - 192GB Ram
  - Dual 25G NIC w RDMA
  - Nvidia V100 GPU
  - Xilinx Alveo U200 FPGA,
    - 2x 100g port



Cloud Architecture



Layer-2 Deployment View



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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:

https://advancedwireless.org/ https://www.orbit-lab.org https://www.cosmos-lab.org

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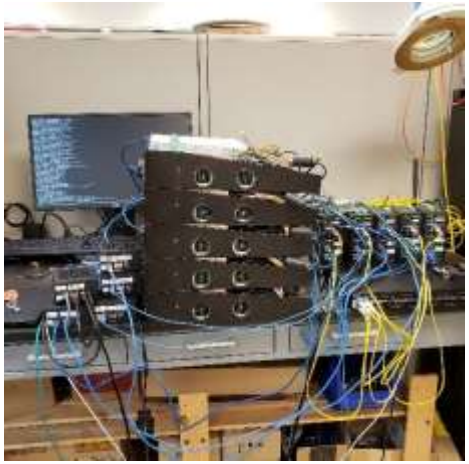

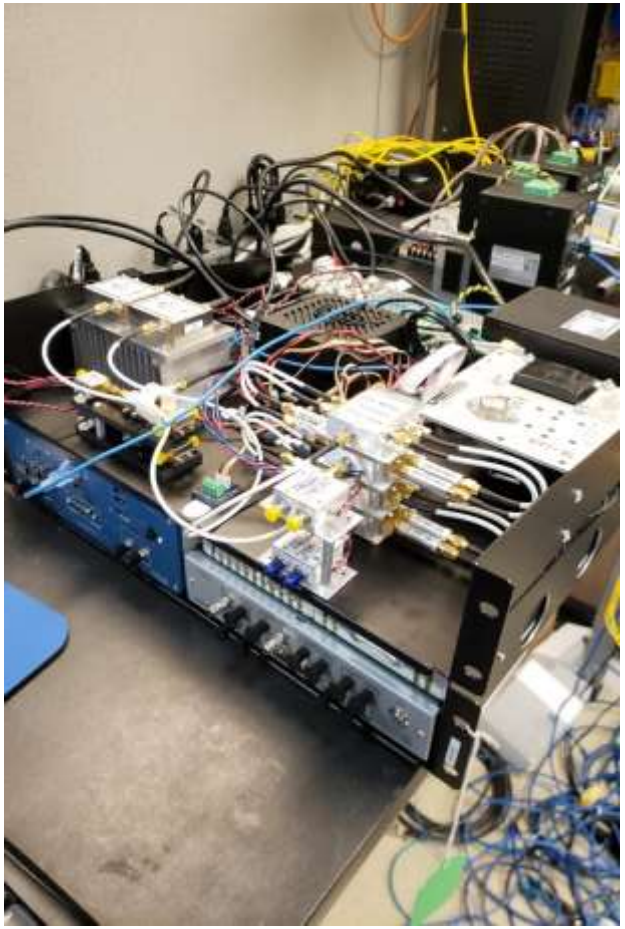

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