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
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
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

VPN Gateway to Wide-Area Testbed

Gigabit backbone

Front-end Servers

Application Servers
(User applications/
Delay nodes/
Mobility Controllers/
Mobile Nodes)

Data switch

80 ft (20 nodes)

70 ft (20 nodes)

Control switch

Back-end servers

RF/Spectrum Measurements

Interference Sources

Internet VPN Gateway/
Firewall

SA1  SA2  SA3  IS1  IS2  IS3

SA

IS

P

Q

WINLAB

Gigabit backbone
**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 2\textsuperscript{nd} generation node:

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

- 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
- 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

* Driver using Contiki OS
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

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

- 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 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:

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP48 Blocks</td>
<td>58K</td>
</tr>
<tr>
<td>Block Rams (18 kB)</td>
<td>14K</td>
</tr>
<tr>
<td>Logic Cells</td>
<td>7.2M</td>
</tr>
<tr>
<td>Slices (LUTs)</td>
<td>1.5M</td>
</tr>
</tbody>
</table>

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

Rt. 1 Campus WiMAX Coverage

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

Android based portable platform
HTC EVO 4G
Nexus 5
Galaxy 6
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
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 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
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
Planned Deployment

- West Harlem
- Area: ~1 sq. mile
- ~9 Large Sites
- ~40 Medium sites
- ~200 Small nodes
  - Including vehicular and hand-held
- Fiber optic connection from most sites
- Fiber connection to NYU Data Center, Rutgers, GENI/I2
- Interaction with smart community & innovation initiatives (Gigabit center, etc.)
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
# Sub-6GHz SDR Devices

## USRP-N310 (Main Monitoring SDR)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>System on Chip</td>
<td>Zynq-7100 (Dual-core ARM Cortex-A9 @ 800 MHz)</td>
</tr>
<tr>
<td>RAM</td>
<td>1 GB DDR3</td>
</tr>
<tr>
<td>Ethernet</td>
<td>2 x 10 Gbps</td>
</tr>
<tr>
<td>ADC/DAC</td>
<td>4 x {122.88, 125, 153.6 MS/s} @ 16 bit/@ 14 bit</td>
</tr>
<tr>
<td>RF</td>
<td>4 x 10 MHz to 6 GHz / 100 MHz BW</td>
</tr>
<tr>
<td>FPGA</td>
<td>Zynq-7100 SoC with 1GB RAM</td>
</tr>
</tbody>
</table>

## USRP-2974 (Main Experimentation SDR)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>System on module</td>
<td>Congatec COM Express conga-TS170 (Quad Core i7 6822EQ @ 2 GHz)</td>
</tr>
<tr>
<td>RAM</td>
<td>8GB DDR4</td>
</tr>
<tr>
<td>Ethernet</td>
<td>2 x 10 Gbps</td>
</tr>
<tr>
<td>ADC/DAC</td>
<td>2 x 200 MHz @ 14 bit/200 MHz @ 16 bit</td>
</tr>
<tr>
<td>RF</td>
<td>2 x 10 MHz to 6 GHz / 160 MHz BW</td>
</tr>
<tr>
<td>FPGA</td>
<td>Kintex-7 XC7K410T with 1GB RAM</td>
</tr>
</tbody>
</table>
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

Performance Summary

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

- 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
**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

<table>
<thead>
<tr>
<th>Device</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF-ADC</td>
<td>8 x 4.096 Gsps @ 12 bit</td>
</tr>
<tr>
<td>RF-DAC</td>
<td>8 x 6.554 Gsps @ 14 bit</td>
</tr>
<tr>
<td>Logic Cells</td>
<td>930,000</td>
</tr>
<tr>
<td>Memory (Mb)</td>
<td>60.5 [Mb]</td>
</tr>
<tr>
<td>DSP Slices</td>
<td>4,272</td>
</tr>
<tr>
<td>33G Transceivers</td>
<td>16*</td>
</tr>
</tbody>
</table>
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 monitoring RF front-end
- RF-over-fiber
- 10/100G (Ethernet+Optical)
- Standard compute platform (PC)
- WiFi devices
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
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)
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

Data Center @Columbia

32 x 2 x 25G (CPU) + 32 x 100G (FPGA)

... PCI-Express Bus...

N x 100G (non-blocking interconnect)

... ~7 miles...

64 x 10GbE

To RoF Interface
To BYOD
To ToR Switches

24 x Zynq
RFSoC

32 Servers

32 x 2 x 25G (CPU) + 32 x 100G (FPGA)

32 Servers

Data Center @NYU

64 x USRP-2974

64 x USRP N310

RUTGERS COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

NYU NYC EC-Collaborative eXchange of New York
Layer-2 Deployment View
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: