Confessions of a Serial (Wireless) Experimenter

GREE-SC 2013

WINLAB

Rutgers University

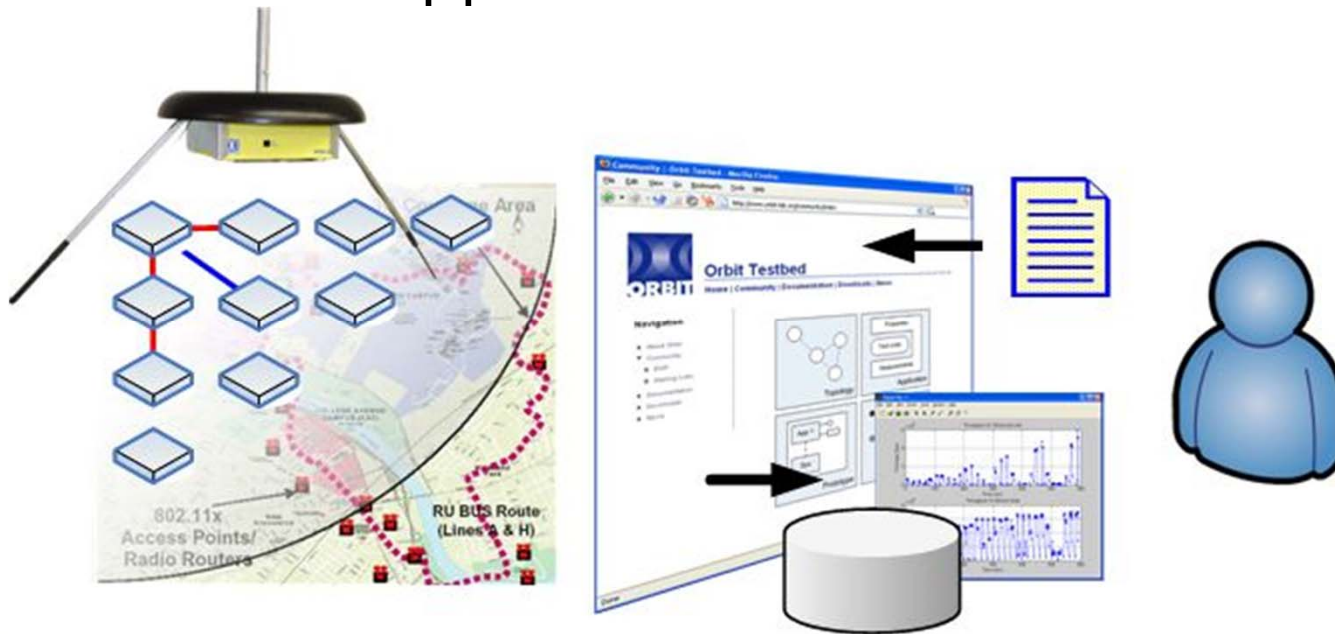Ivan Seskar, Associate Director
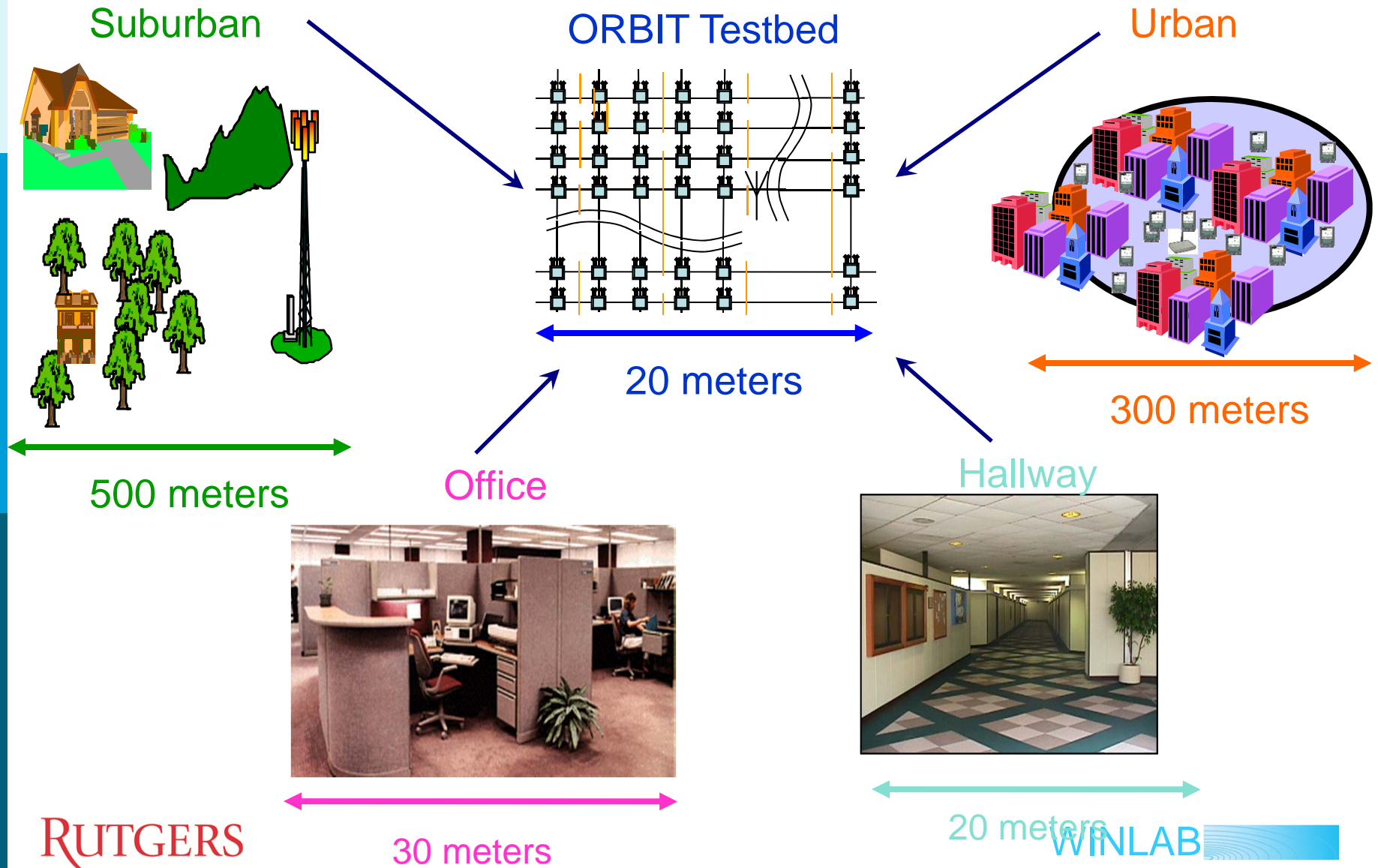seskar (at) winlab (dot) rutgers (dot) edu

Acknowledgments

- Dipankar Raychaudhuri, Marco Gruteser, Sachin Ganu, Kishore Ramachandran, Haris Kremo, Predrag Spasojevic Gautam Bhanage, Larry Greenstein, Wade Trappe, Yanyong Zhang and Kiran Nagaraja (Rutgers University)

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- Fraida Fund and Thanasis Korakis (NYU-Poly)

- Surat (Au) Teerapittayanon, Kerim Fouli, Muriel Medard, Marie-Jose Montpetit, Xiaomeng Shi (MIT)
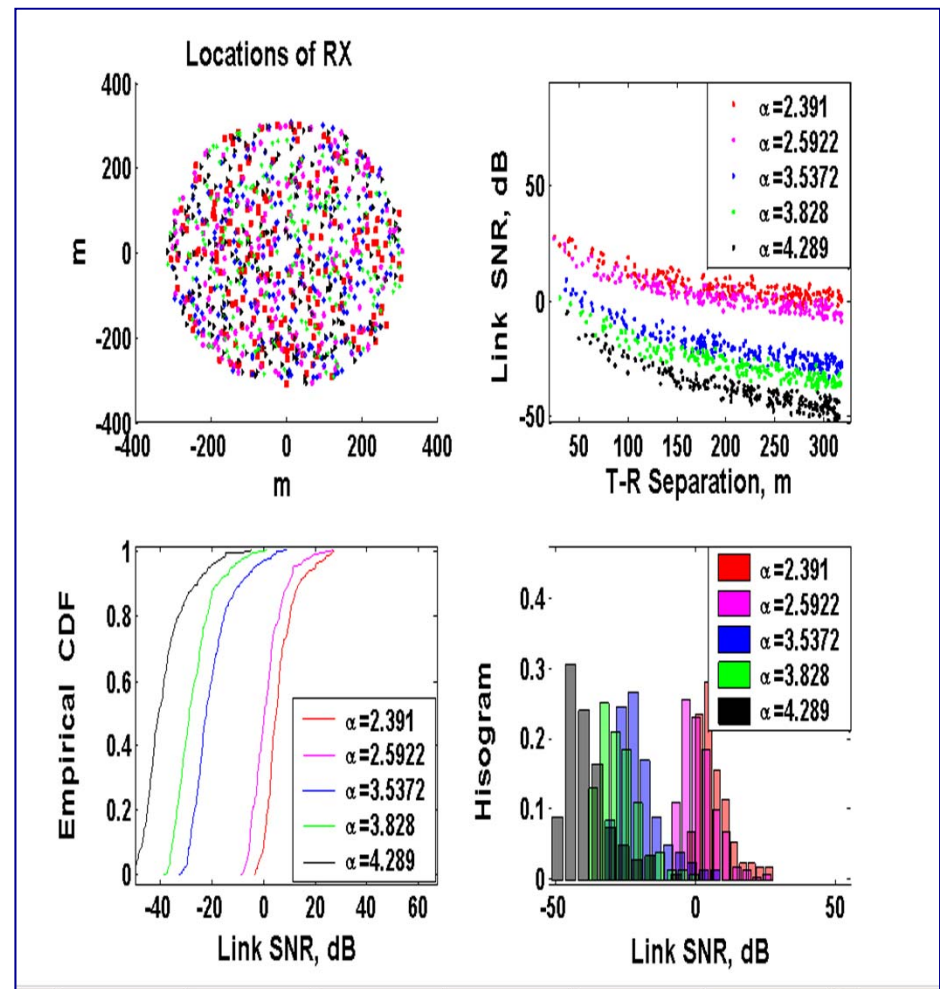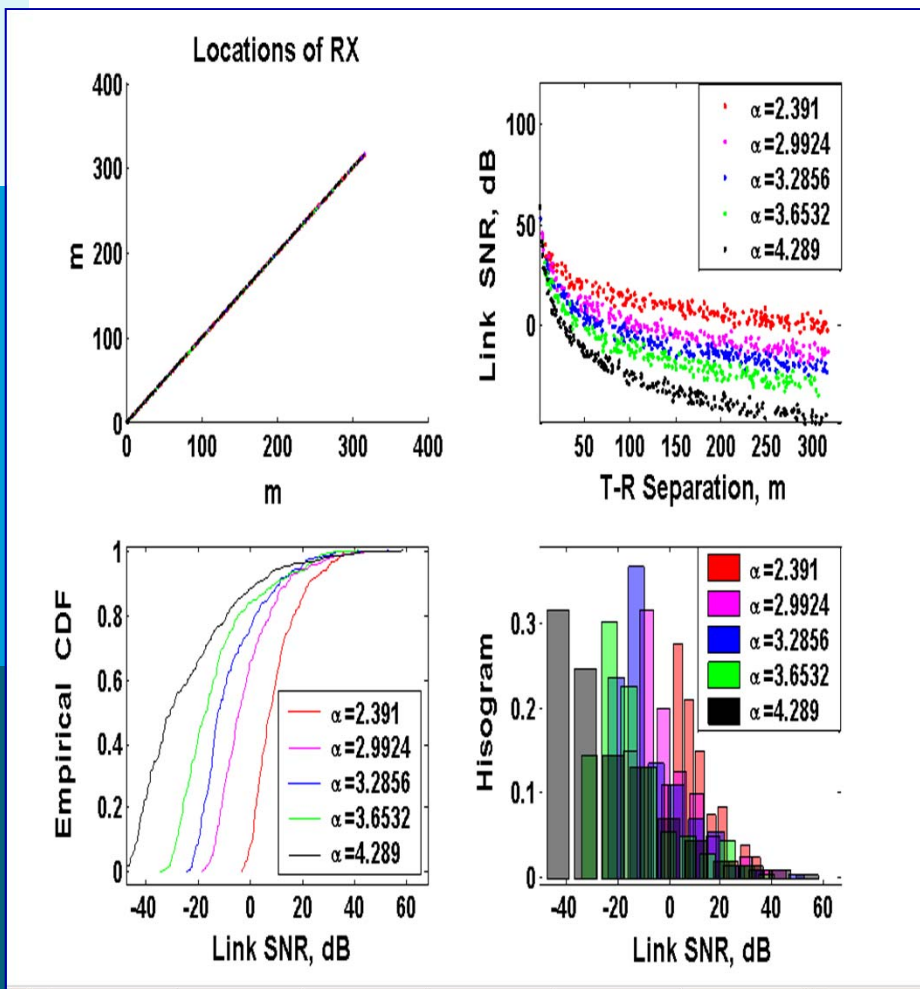
- Kumar Ramaswamy (Thomson)

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Orbit

- ORBIT consists of radio grid emulator + field trial network
- Emulator used for detailed protocol evaluations in reproducible complex radio environments
- Field trial network for further real-world evaluation & application trials
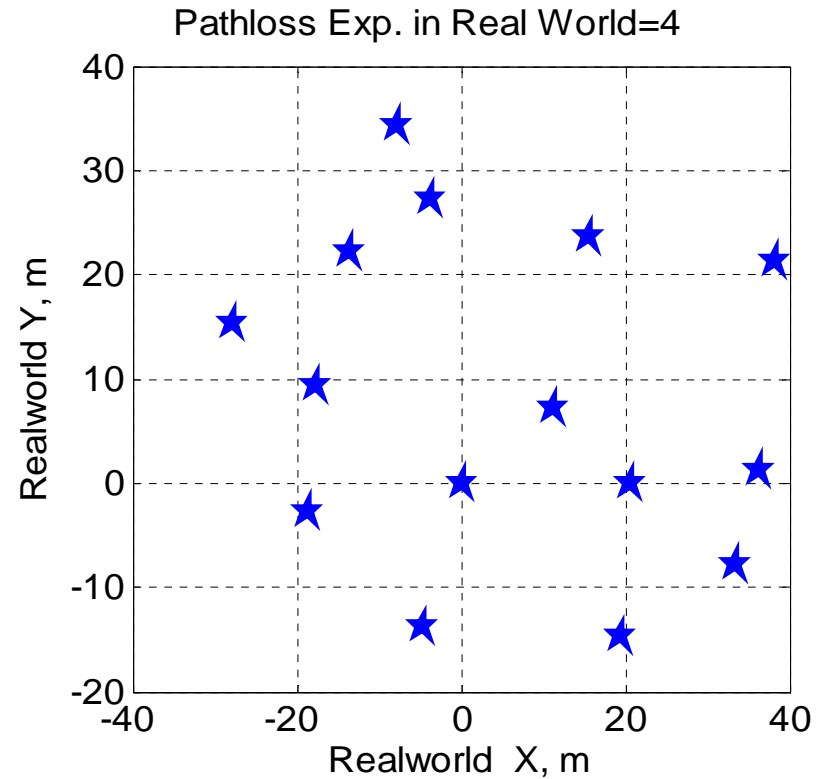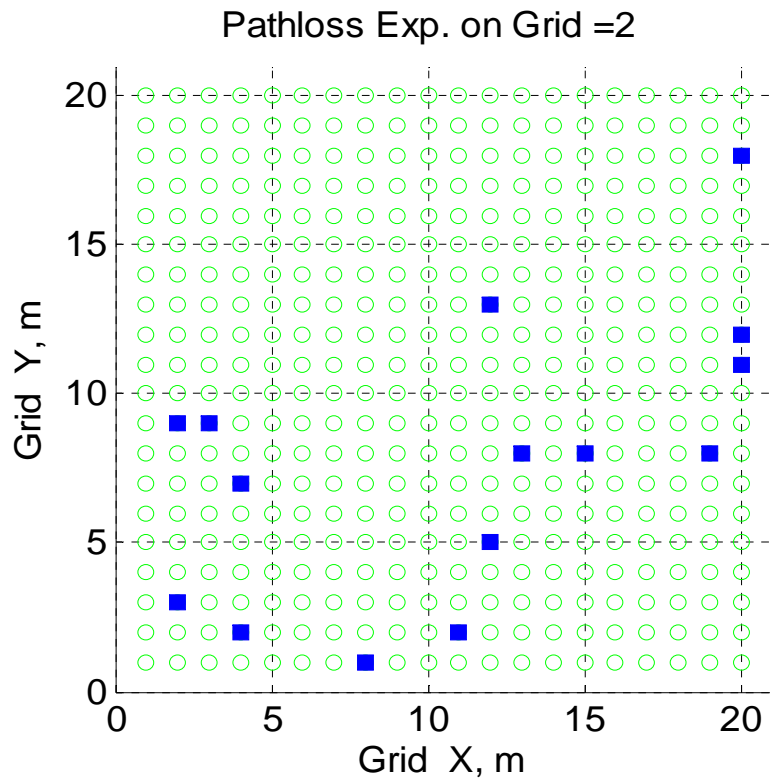
Radio Mapping Algorithm

Suburban

ORBIT Testbed

Urban

20 meters

500 meters

300 meters

Office

Hallway

30 meters

20 meters

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Link SNR of a Real NLS/RES Environment
Using the Ghassemzadeh/Greenstein Model

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Configuration of 15 Grid Nodes to Real World
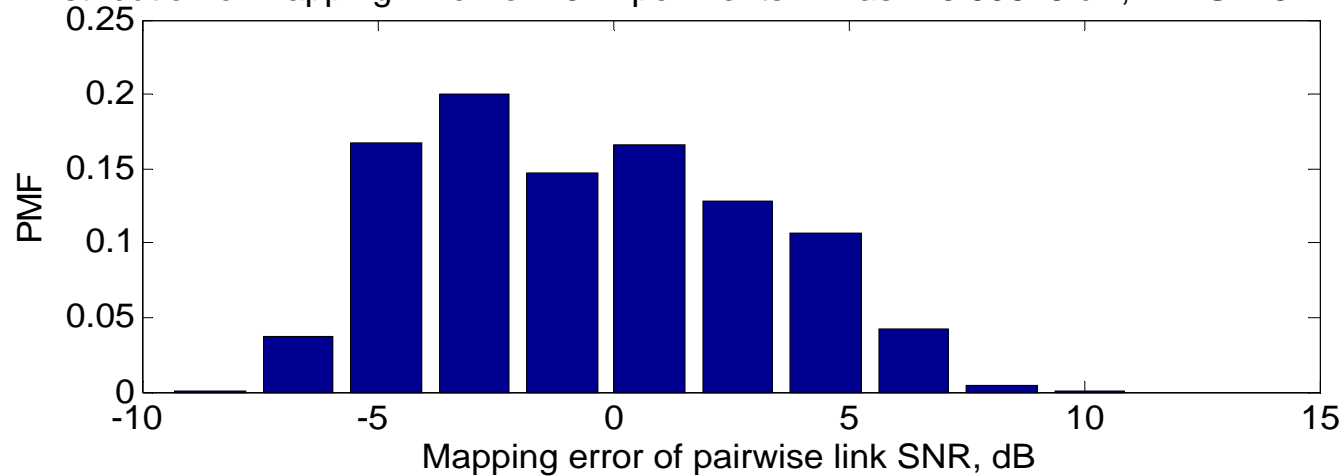

Pathloss Exp. on Grid =2

Pathloss Exp. in Real World=4

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Reverse Mapping Error
12 Node Networks: 70 Experiments

RMS Mapping Error for Each Experiment
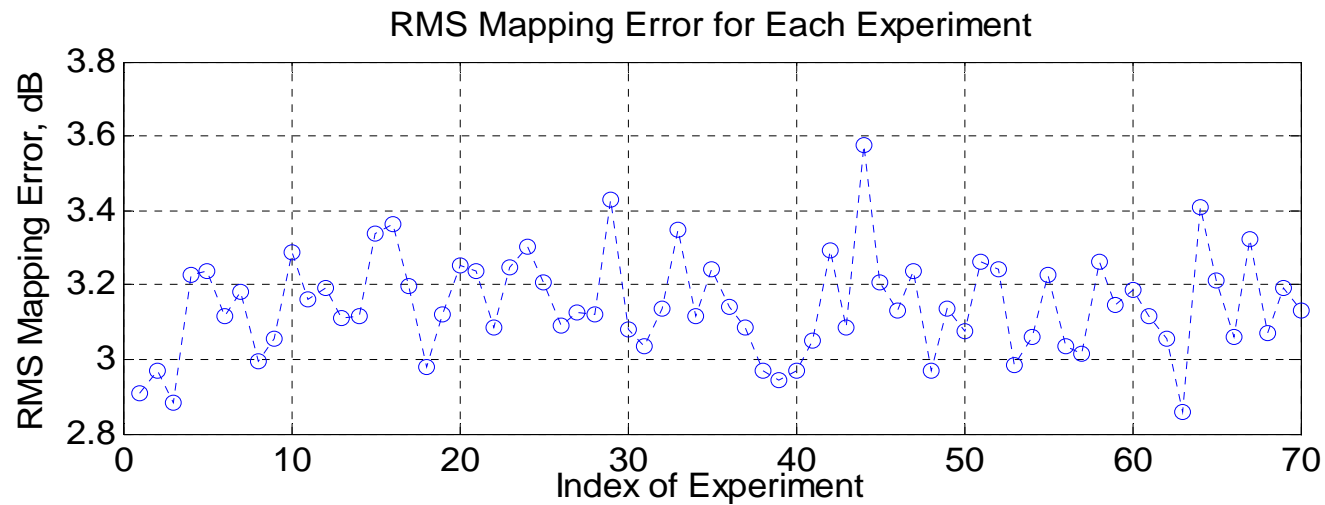
Distribution of Mapping Error for 70 Experiments: Bias =-0.59873 dB, RMS =3.4789 dB

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"Card Calibration Procedure"

• Calibrate transmit and receive side of the cards

• Record corrections to be applied for each card based on the discrepancies observed
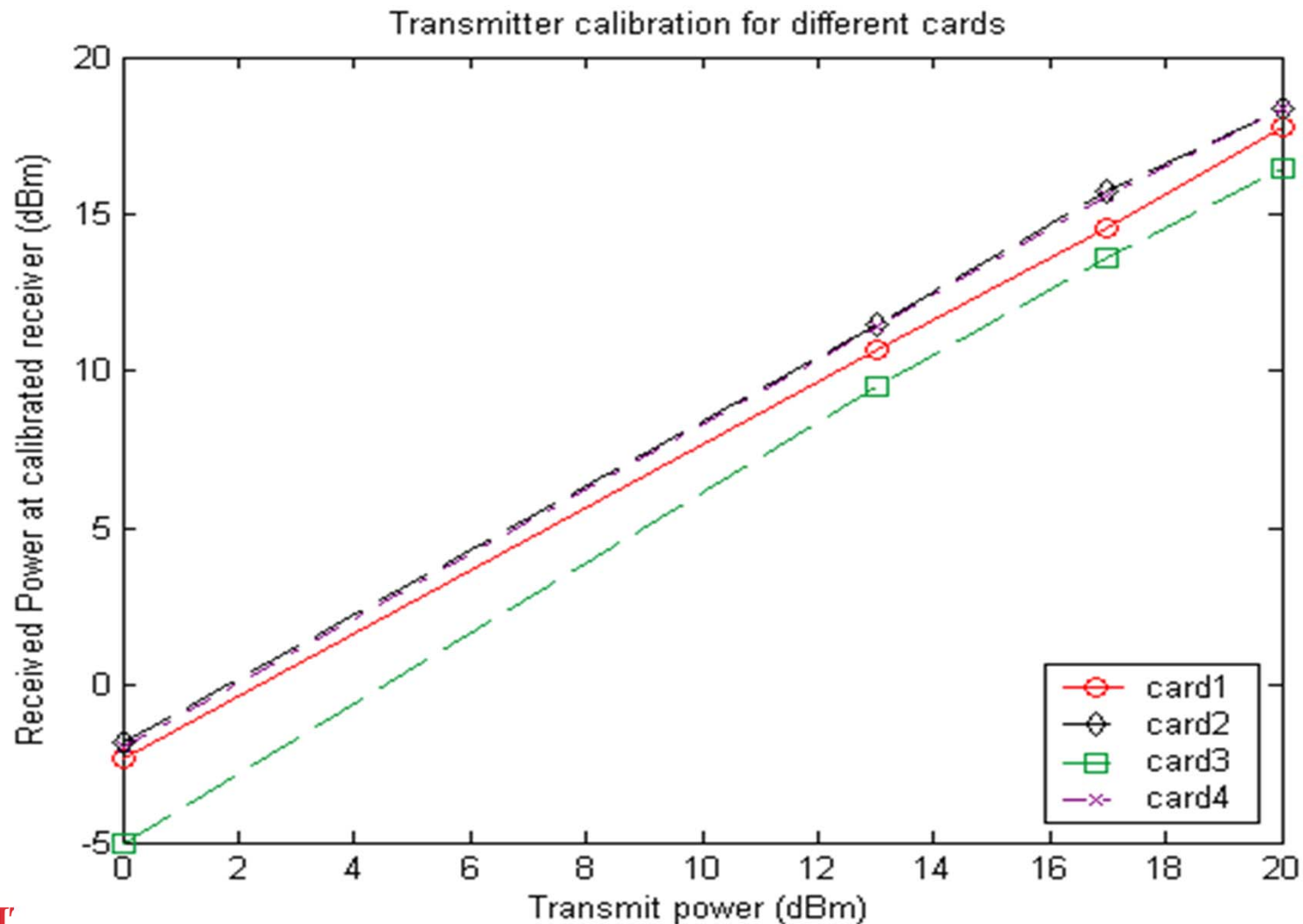
Card Calibration Setup

Vector Signal Analyzer

ORBIT Wireless Node under test

Vector Signal Generator

RF Connector
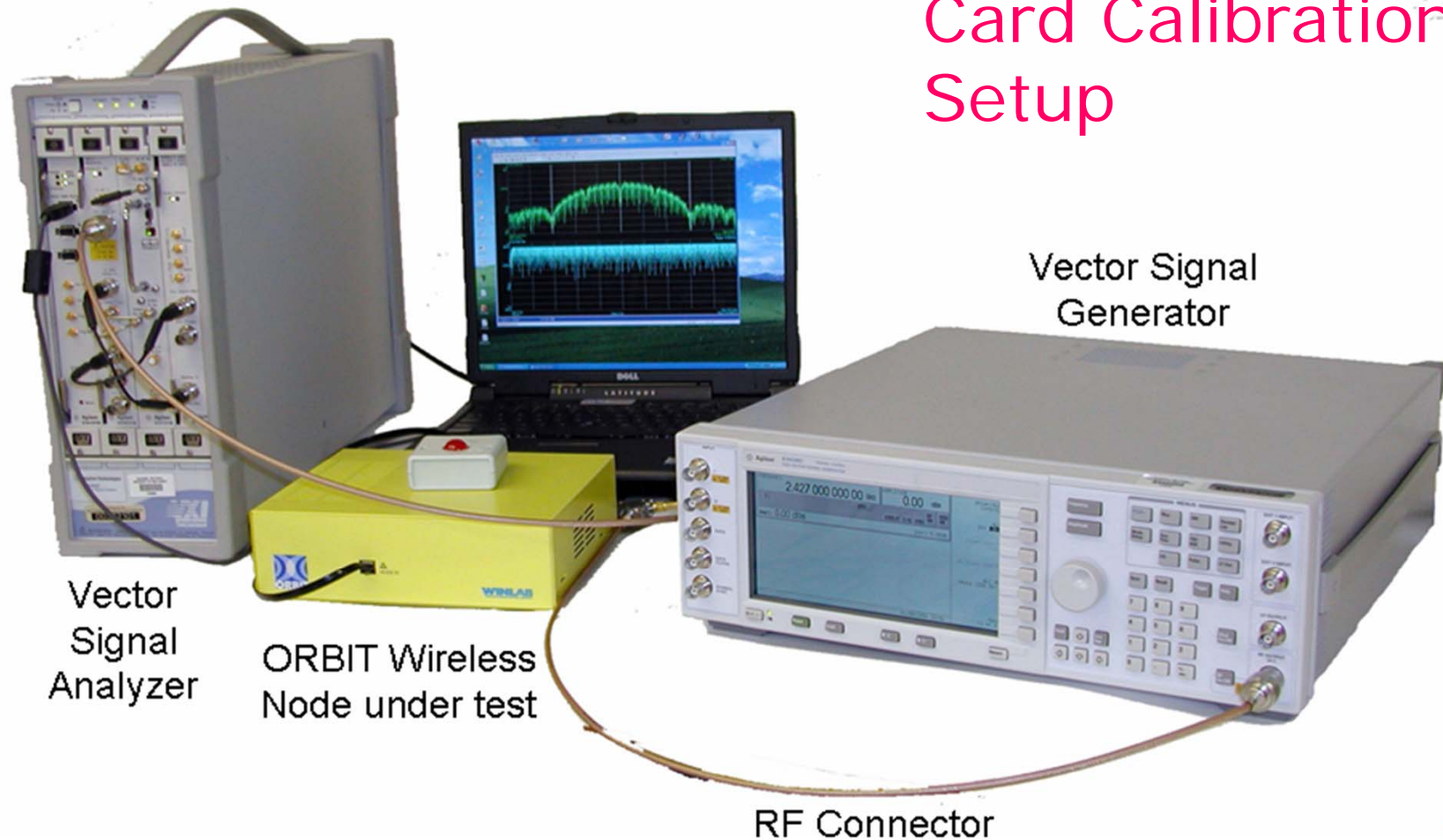
Transmitter calibration

Agilent 89600S Vector Signal Analyzer (VSA) used as the calibrated receiver

Transmitter calibration for different cards

Note that received power is not corrected for the 2dB cable loss

Receiver calibration

Agilent E4438C Vector Signal Generator (VSG) as the calibrated transmitter
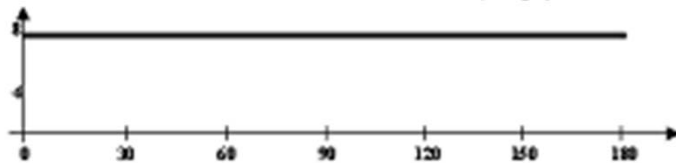

RSSI vs Transmit Power for different wireless cards
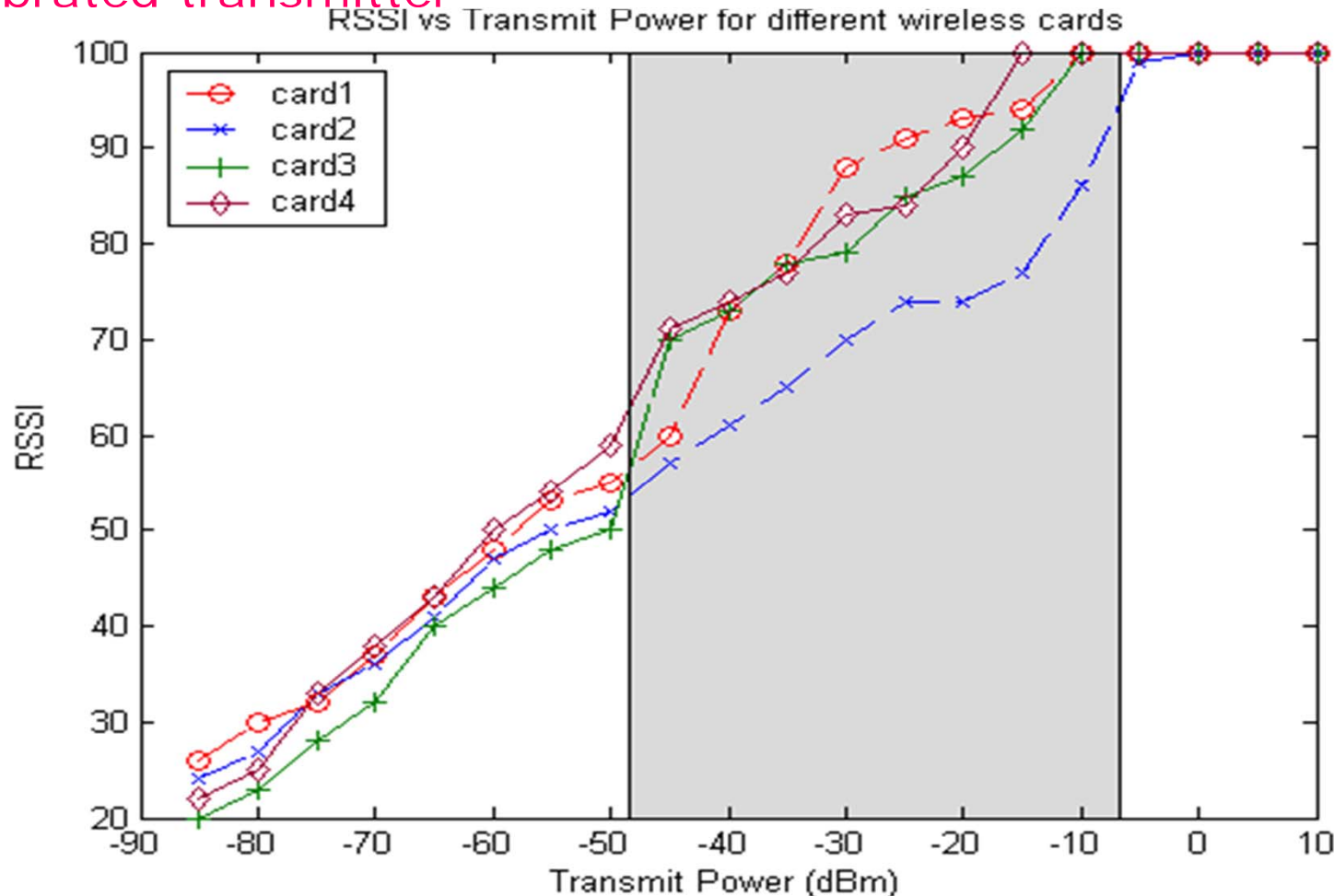
Note that the RSSI readings includes the 2 dB attenuation loss in the RF connector

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Temporal repeatability
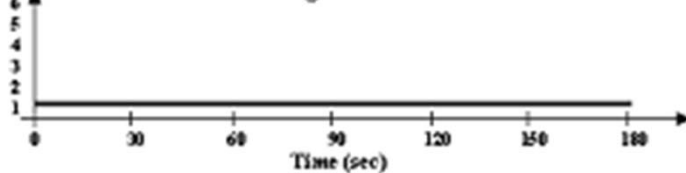
The Experiment

Experiment Topology
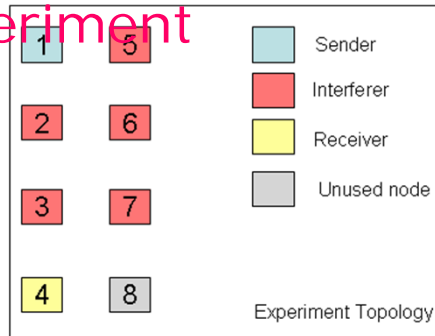
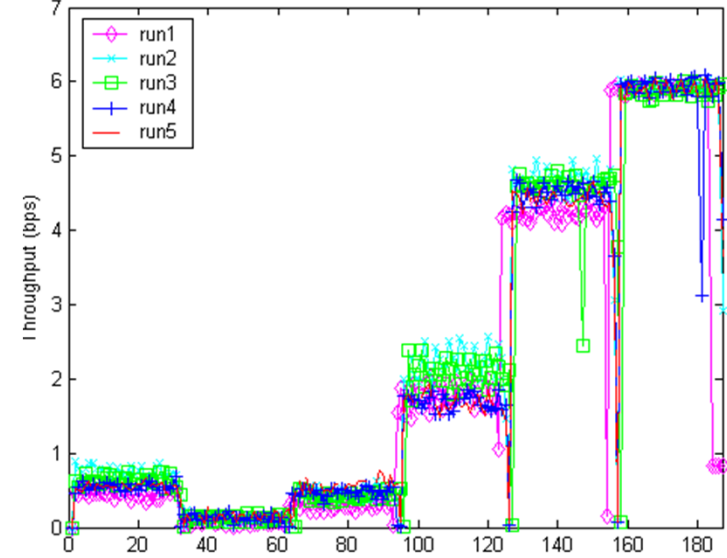Offered Load On All Senders (Mbps)

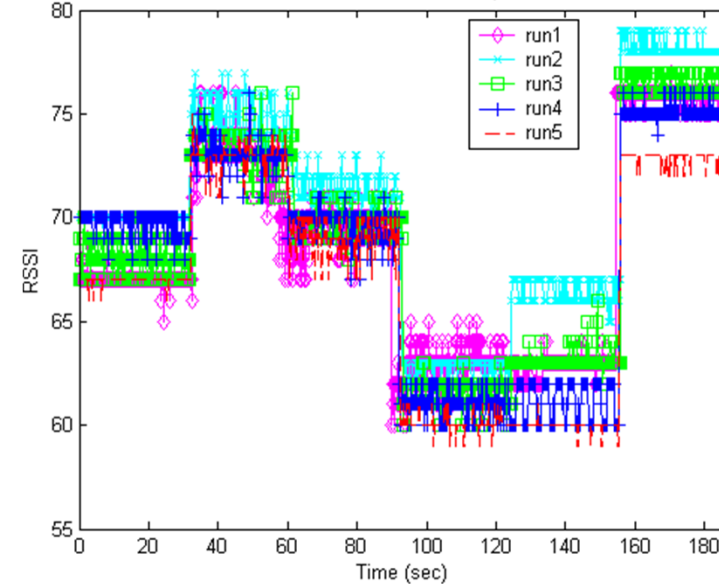Channel Assignment On Obstructed Link

Channel Assignment On Interferers

Time (sec)

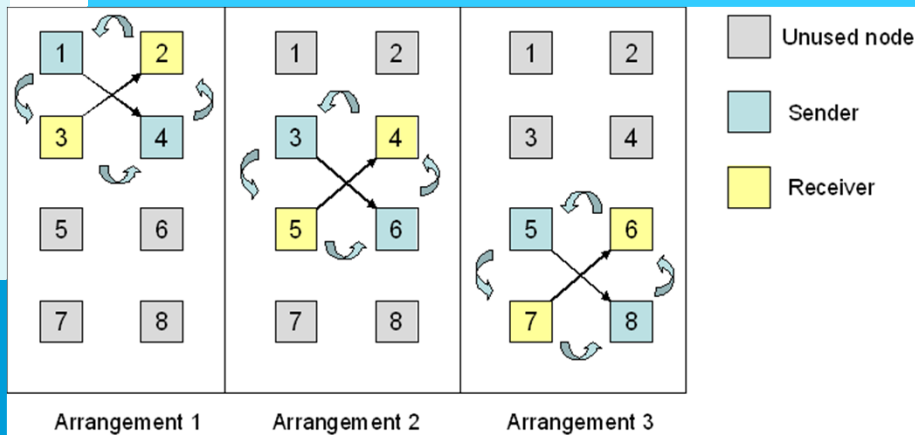Variation of throughput across different experimental runs

Variation of RSSI across different experimental runs

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Spatial repeatability

Blue sender sends to blue receiver

Yellow sender sends to yellow receiver

Experiment repeated on a different set of nodes with same
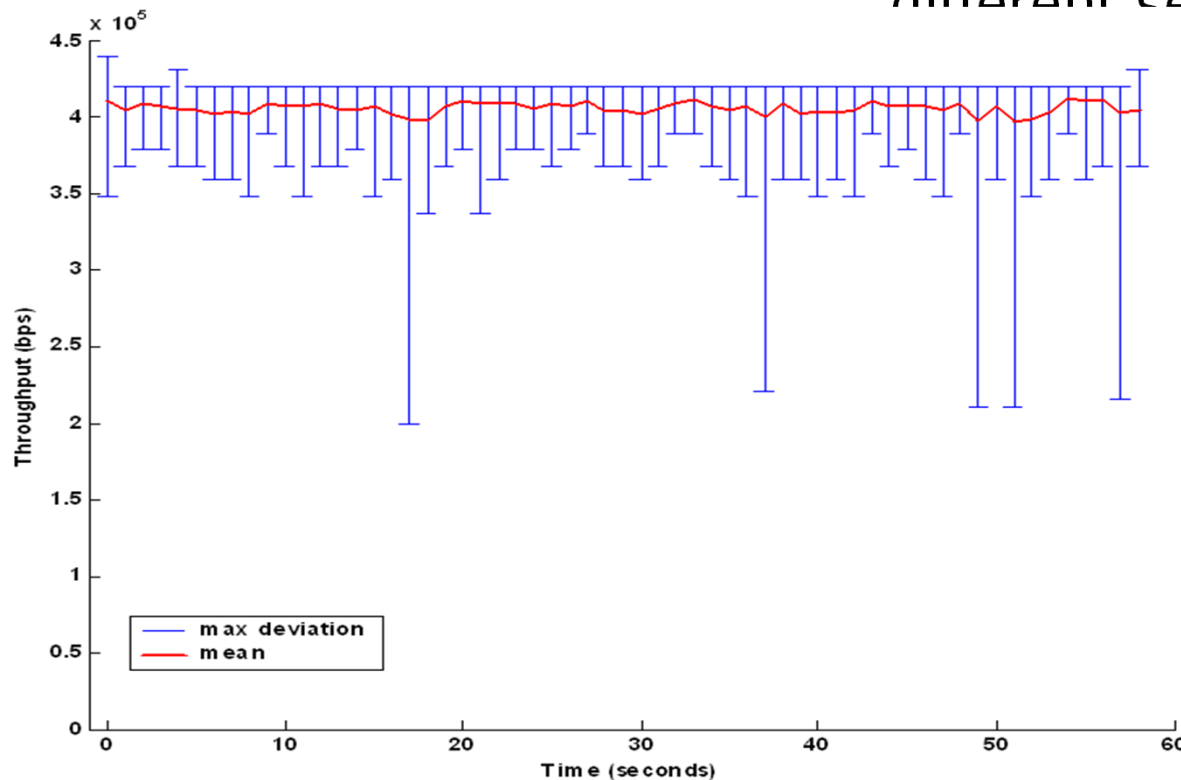
Spatial throughput variation
w.r.t mean
for experiment
duration averaged over
different experimental runs

Repeatability Conclusion

- Node calibration procedure necessary to address hardware dependencies
- Temporal variation is less than hardware variability
- Periodic re-calibration necessary
- Need to automate the on-site calibration procedure so that it can "monitor" the testbed "drift"

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Rate Control:
Performance of current implementations
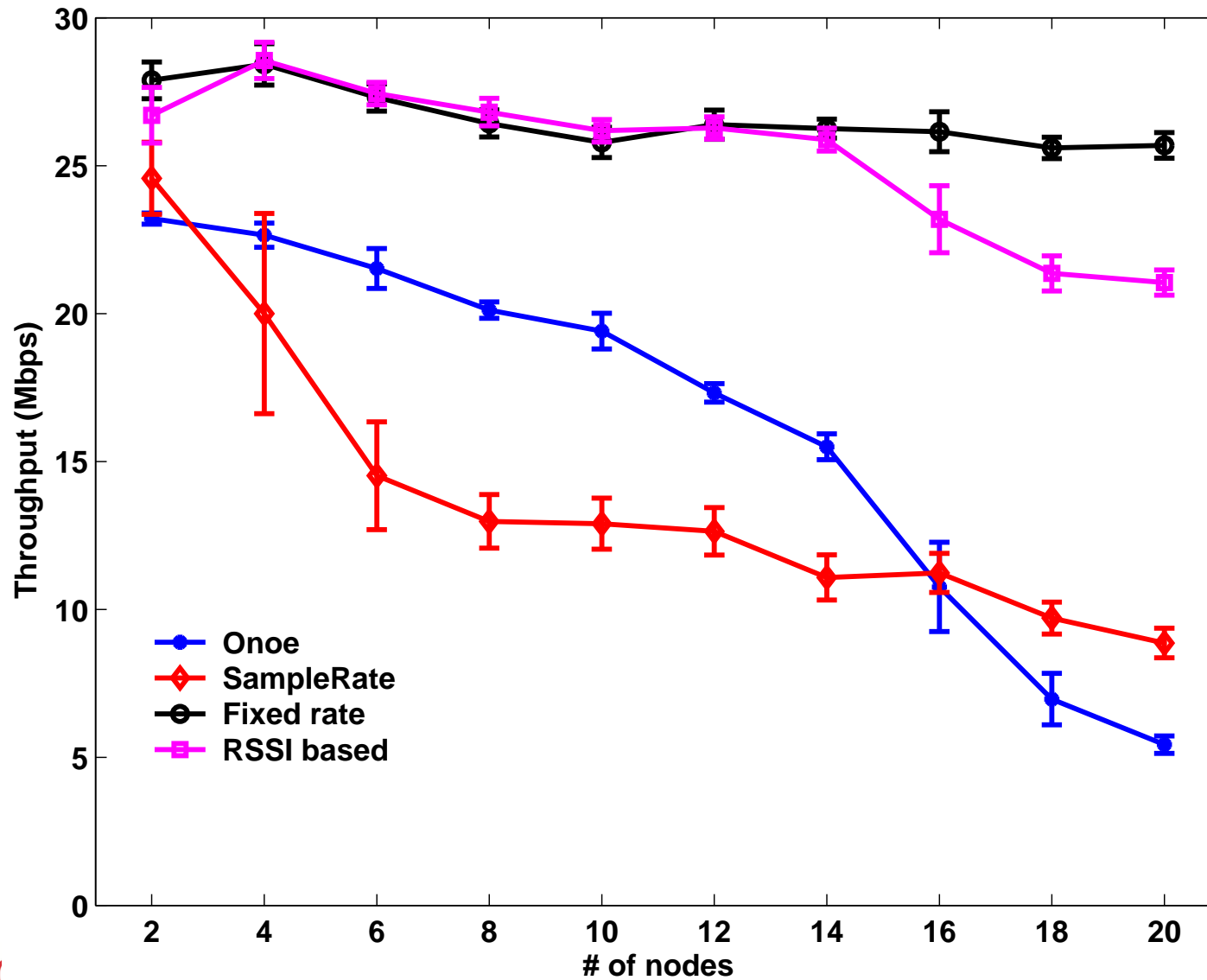
Resource Management: Multi-hop flows

Auto-rate, 1 channel, noise -16 to -5 dBm on Channel 48
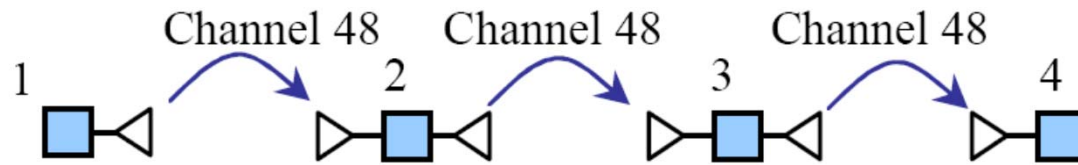
Auto-rate, 3 channels, noise -16 to -5 dBm on Channel 48
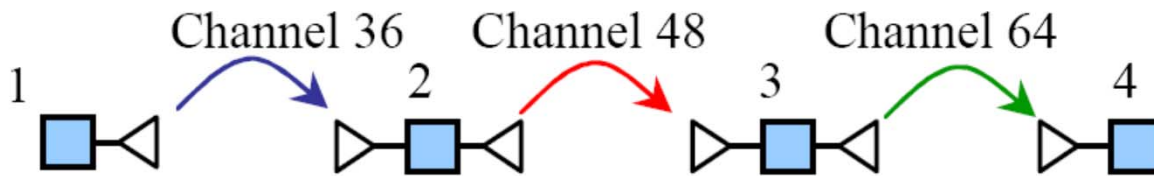
Can we do better??

Specific case: Noise -6dBm, but now with selectable bit rates

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~4x improvement
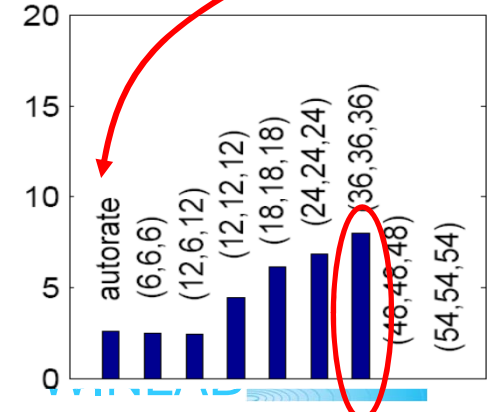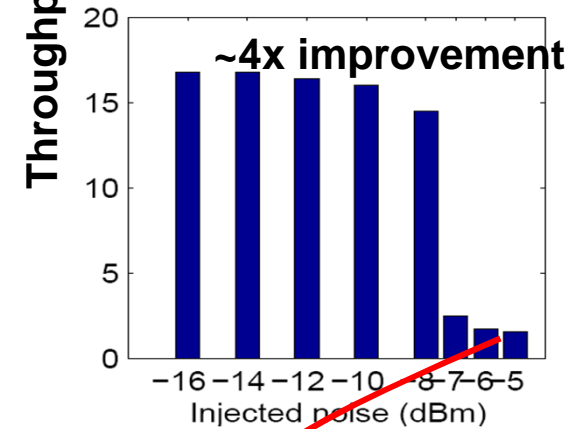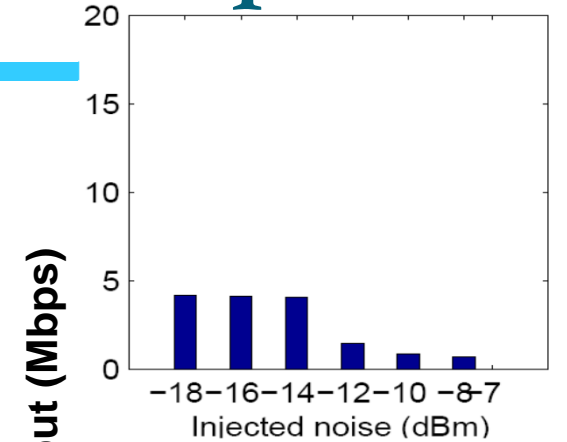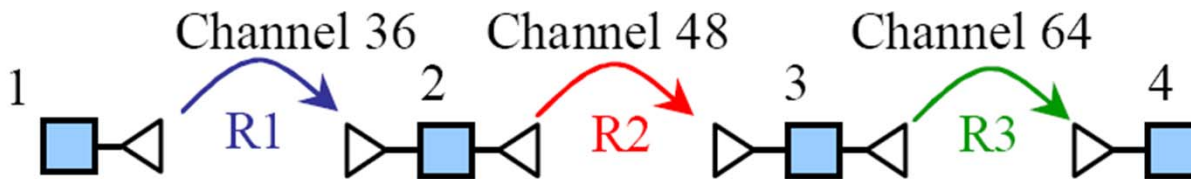
Mobility: Software Spatial Switching

□ A mobile's connection originates/terminates on a separate machine, called the <u>Virtual Mobile (VM)</u>.

□ Packets are tunneled to/from different grid nodes over time.

Virtual Mobile

→ Actual path.

▬ Tunnel.

◯ Grid node.

● Active Grid node.

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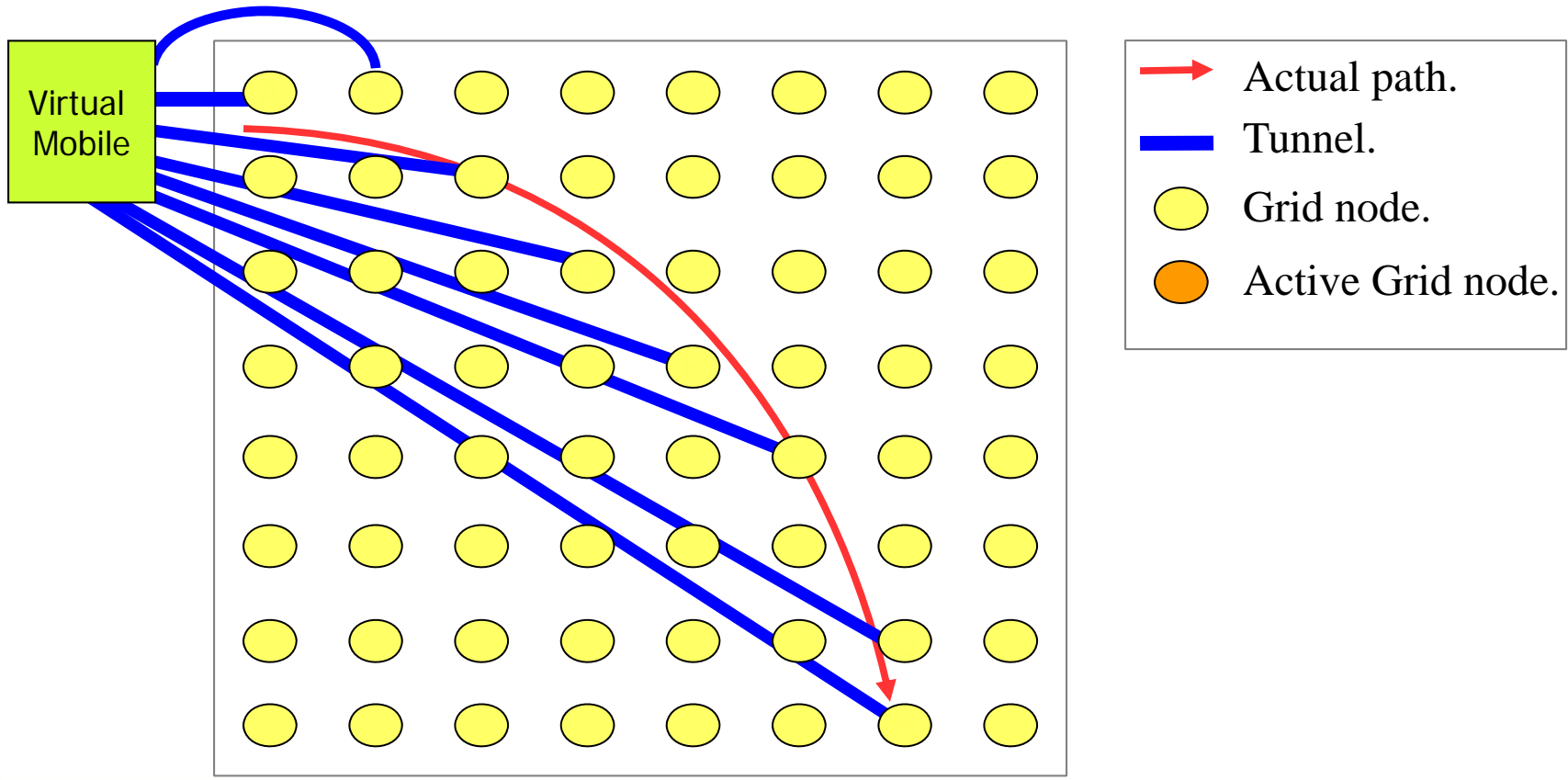
Usage Examples: Routing Protocols

Two hop topology
Varying packet size
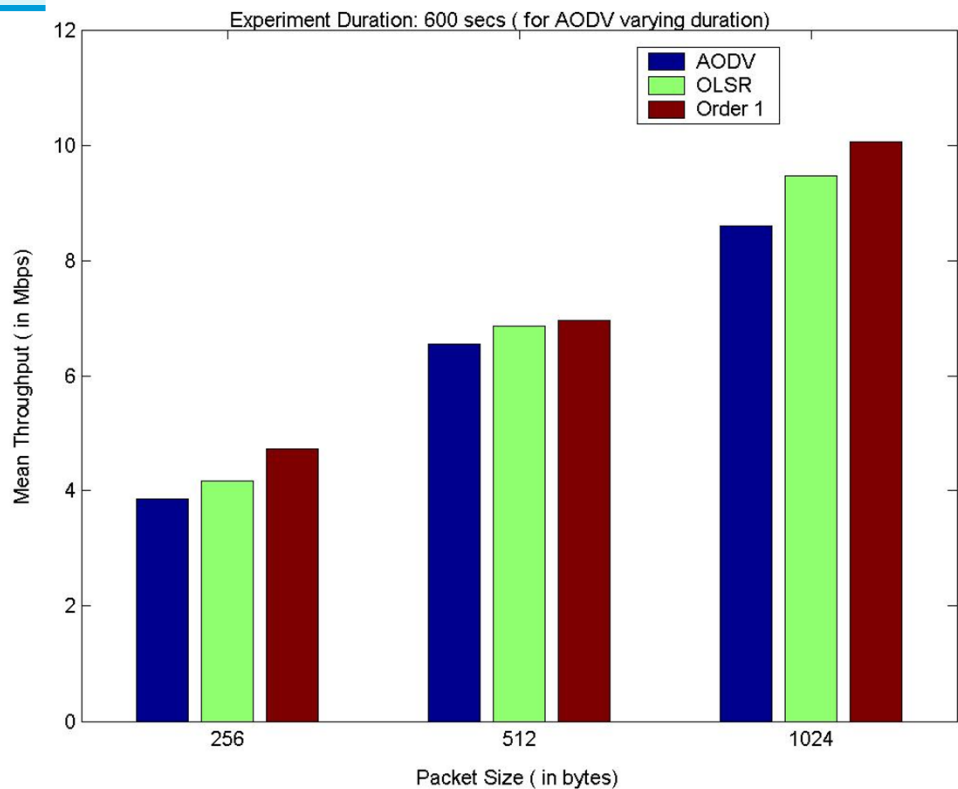
Multi-hop topology
Fixed packet size

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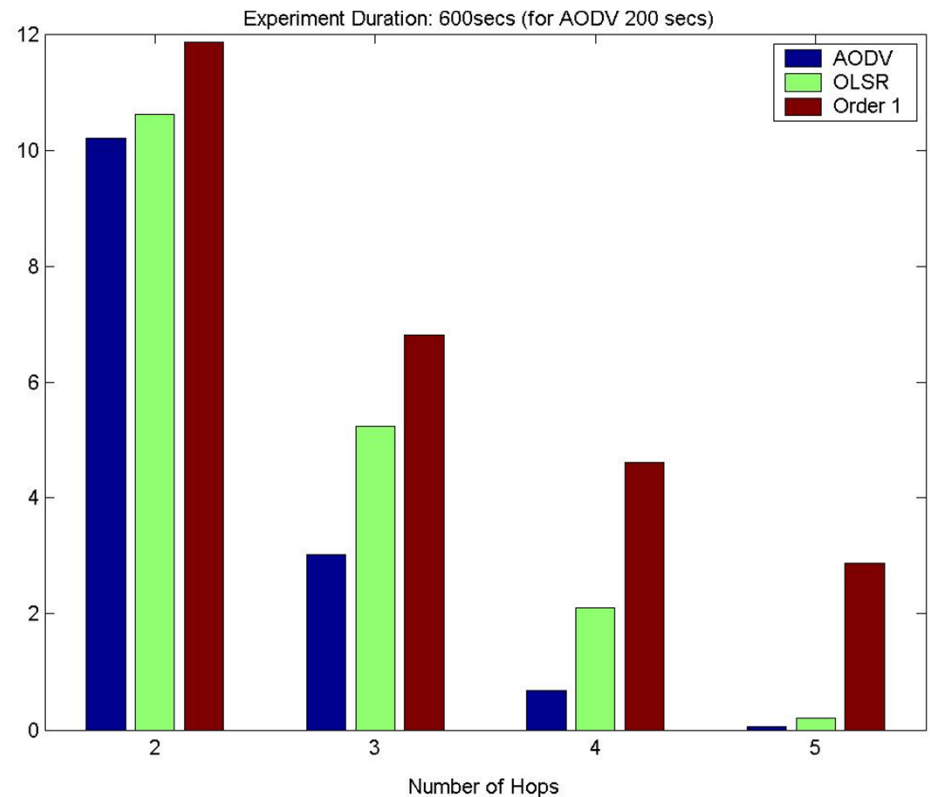
Wireless Security: Fingerprints in the Ether

- Wireless channels are "open" and hence more susceptible to eavesdropping, intrusion and spoofing...
- Interestingly, wireless channel properties ("RF signatures") can be exploited for authentication and to identify attackers
- Project on protocols and algorithms for security functions; also experimental validation

ORBIT Radio Grid

Network A

Noise Injection

Network B

Network E

Detection of Anomalous Traffic (Eve Spoofing Alice)

Eve Continues Transmitting

Eve Transmits

Alice Resumes Transmission

Alice Starts Transmitting

Detection Statistic η

Time in Seconds

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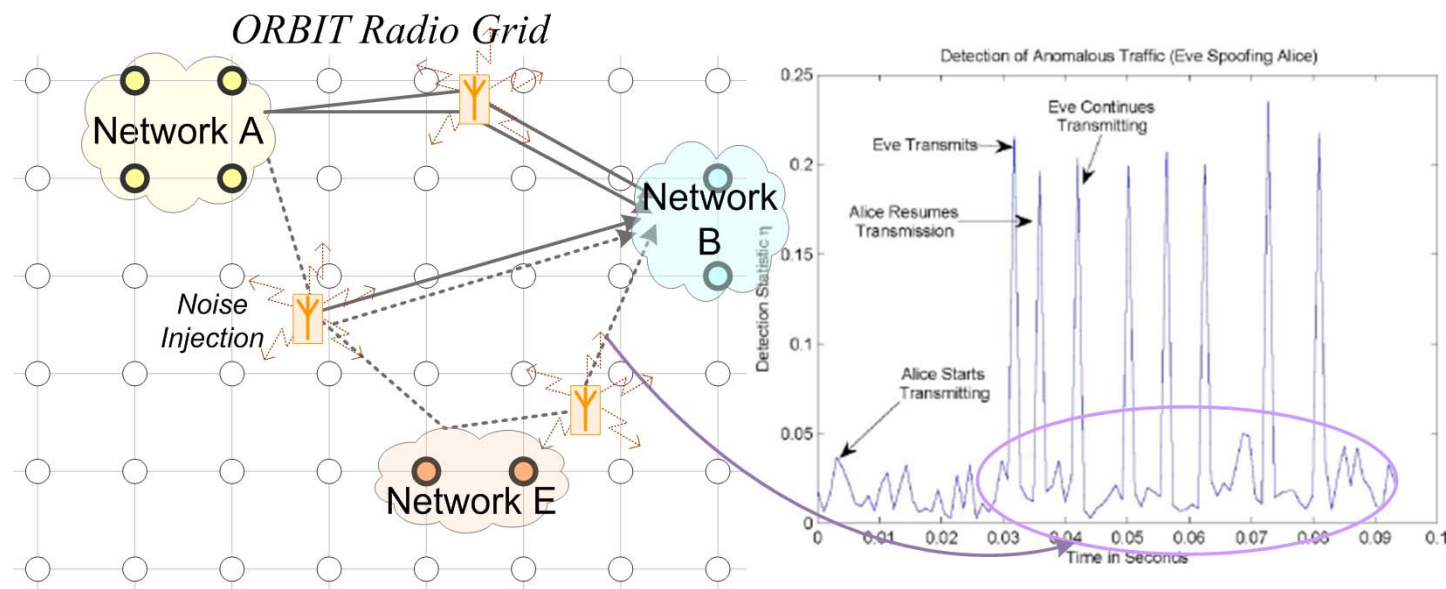
ORBIT Planet-Lab Proof-of-Concept Example

- Example video streaming experiment from wired server node on PL to wireless receiver node on ORBIT

Wired PlanetLab   **Wireless** Orbit
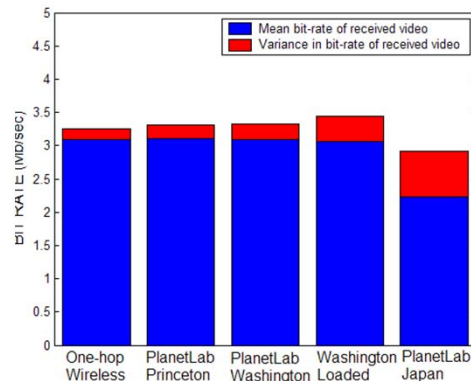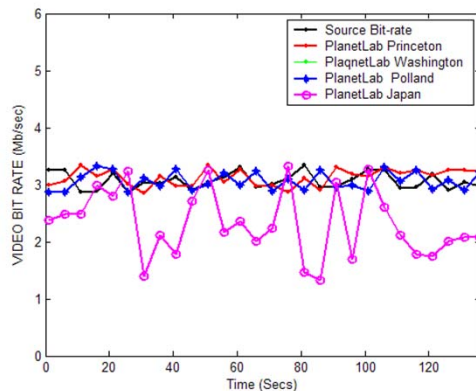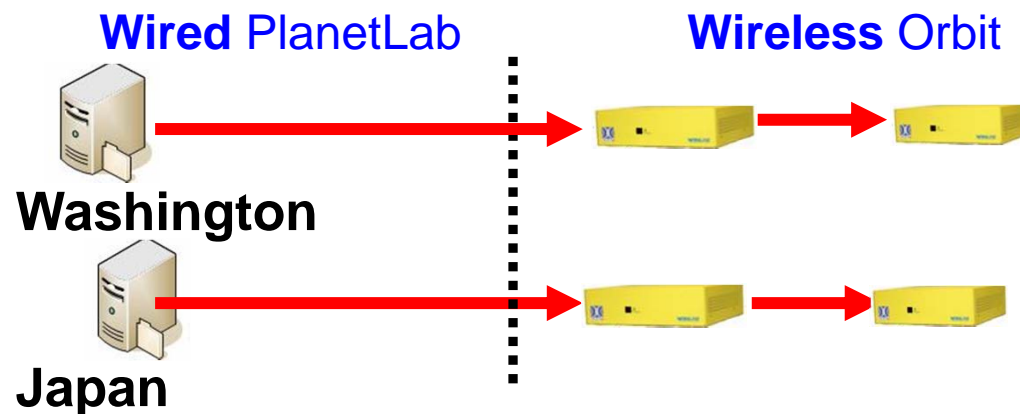
Washington

Japan

Experiment setting	Max Jitter (ms)	Max Delta (ms)	Mean Jitter (ms)
Wireless One hop	1.68	7.66	0.98
Pl − Princeton	1.69	7.69	0.98
Pl − Washington	1.88	8.76	1.05
Pl − Washington (Loaded)	35.76	415.8	3.62
Pl − Japan	52.18	779.02	7.38

Wireless Virtualization

- Support concurrent experiments to increase capacity

- Support both short-term and **long-term service experiments**

- Virtualization in wireless networks complicated by PHY/MAC interactions between nodes

- Several techniques being investigated:
  - Virtual MAC (VMAC)
  - Space division
  - Frequency division
  - Time division

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Wireless Virtualization (cont'd)

Partitioning a node in Time domain (TDMA)

Virtual Node 1 (VN$_1$) →

Virtual Node 2 (VN$_2$) →

Virtual Node 3 (VN$_3$) →

Time Slot 3 (TS$_3$)
Time Slot 2 (TS$_2$)
Time Slot 1 (TS$_1$)
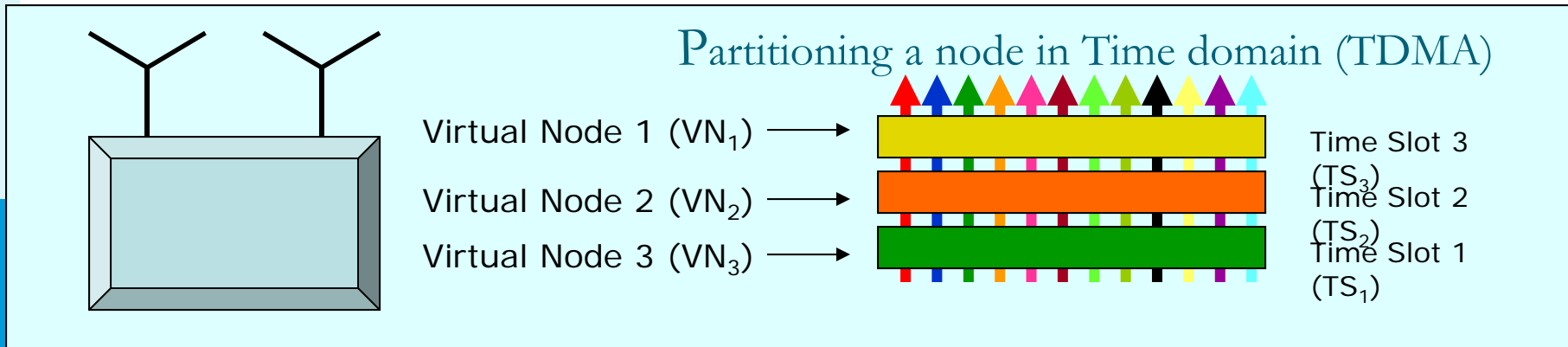
TDMA refers to switching Time-slots within a physical node to emulate multiple virtual nodes

Virtual Node 1 (VN$_1$)

Virtual Node 2 (VN$_2$)

Virtual Node 3 (VN$_3$)

Partitioning a node in Frequency domain (FDMA)
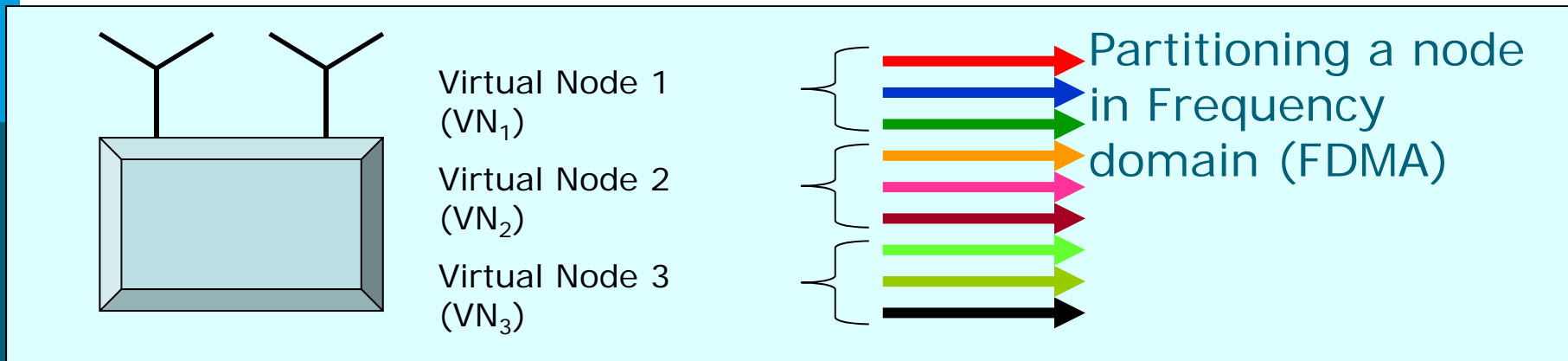
FDMA refers to switching channels within a physical node to emulate multiple virtual nodes

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Wireless Virtualization (cont'd)

Partitioning a node by Hopping in Frequency domain at different Time-slots (FH)

Virtual Node 1 (VN$_1$)

Virtual Node 2 (VN$_2$)

Virtual Node 3 (VN$_3$)

Time Slot 3 (TS$_3$)
Time Slot 2 (TS$_2$)
Time Slot 1 (TS$_1$)

Frequency Partition 1 (FP$_1$) • • • • Frequency Partition 4 (FP$_4$)
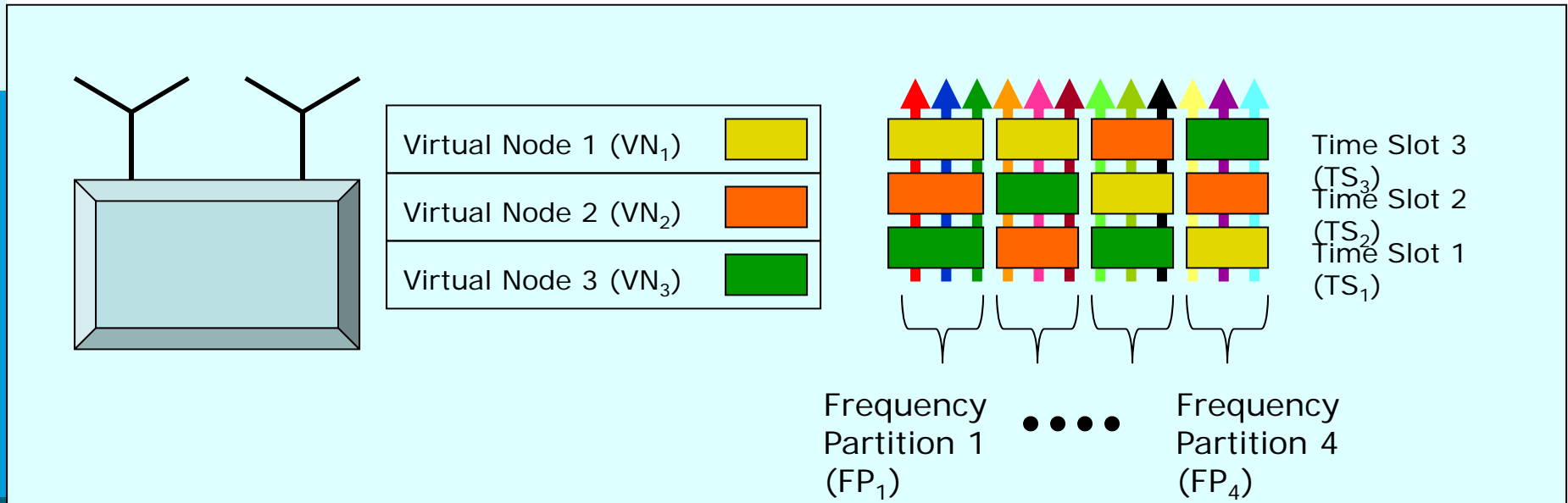
Frequency Hopping (FH) refers to partitioning of a node by allocating a unique <u>SEQUENCE</u> of Frequency and Time-slots to a virtual node

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Virtual MAC

Sliver 1   Sliver 2   Sliver 3   Sliver 4

Access Point | Access Point | Access Point | Access Point

Virtual Access Point 1   Virtual Access Point 2   Virtual Access Point 3   Virtual Access Point 4

Essid:1   Essid:2   Essid:3   Essid:4

Channel w   Channel x   Channel y   Channel z

Channel X

Essid:1   Essid:4

Essid:2   Essid:3

Exp. 1   Exp. 2   Exp. 3   Exp. 4

Exp. 1   Exp. 4

Exp. 2   Exp. 3

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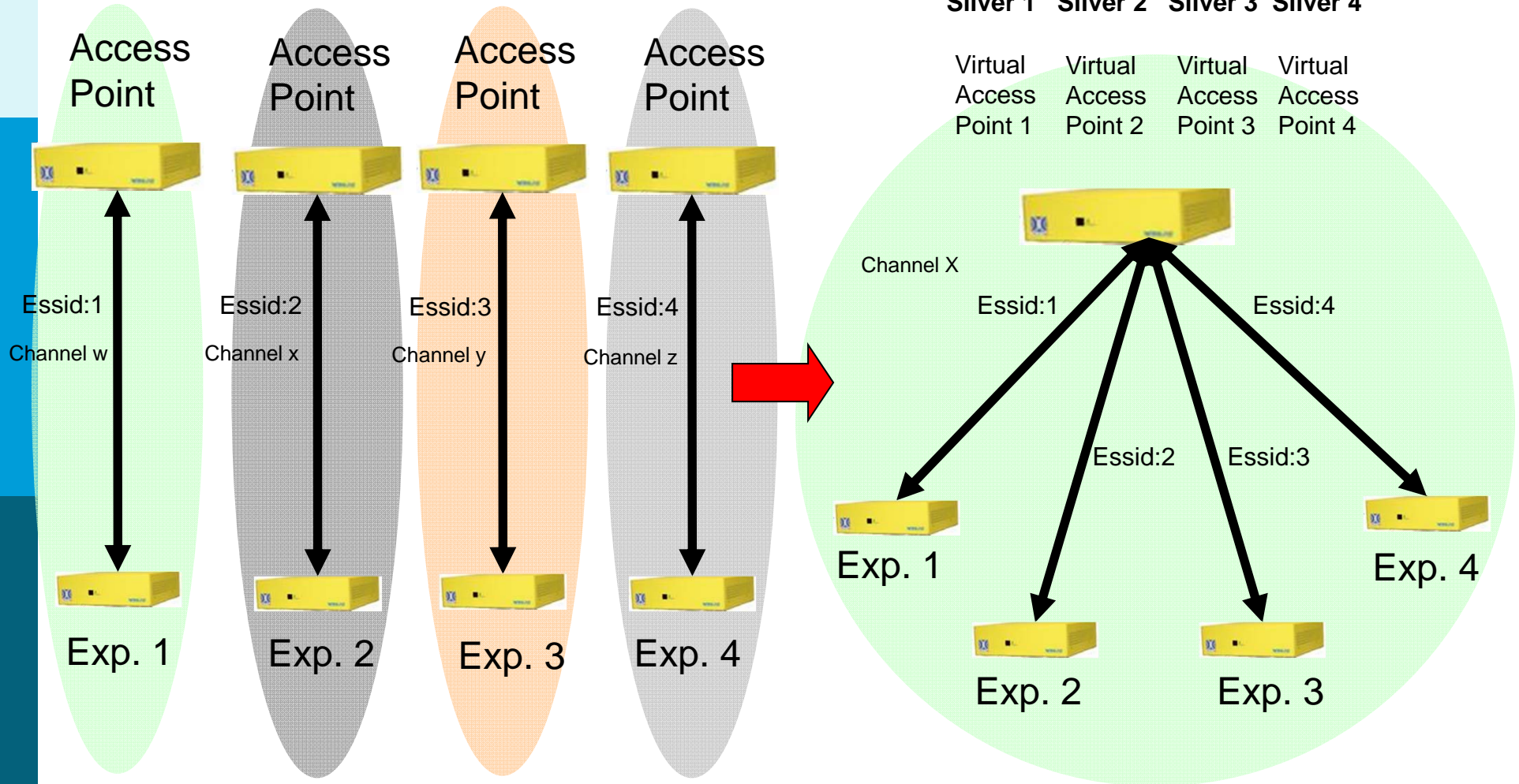
VAP Performance Comparison

- The VAP implementation adds a negligible overhead to the performance of a conventional AP.
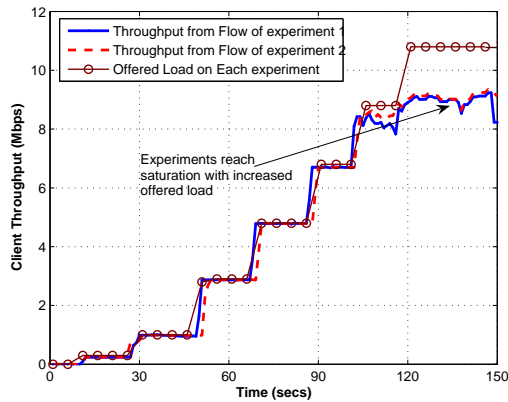- VAP based virtualization schemes would scale the available bandwidths for experiments as compared to no virtualization case.
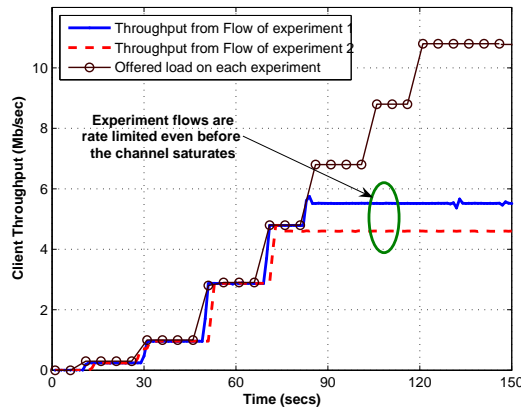

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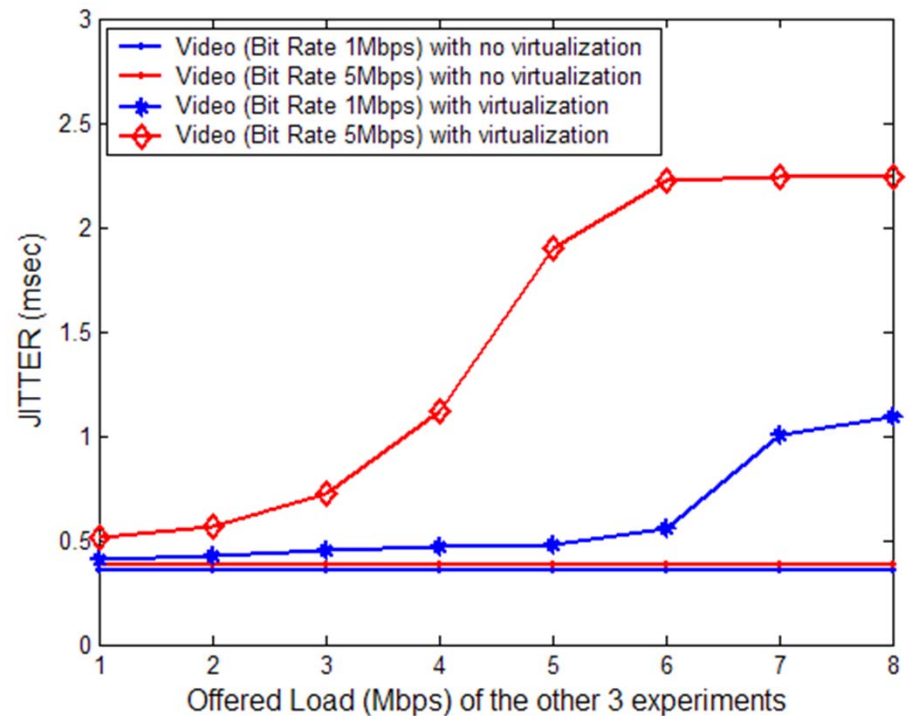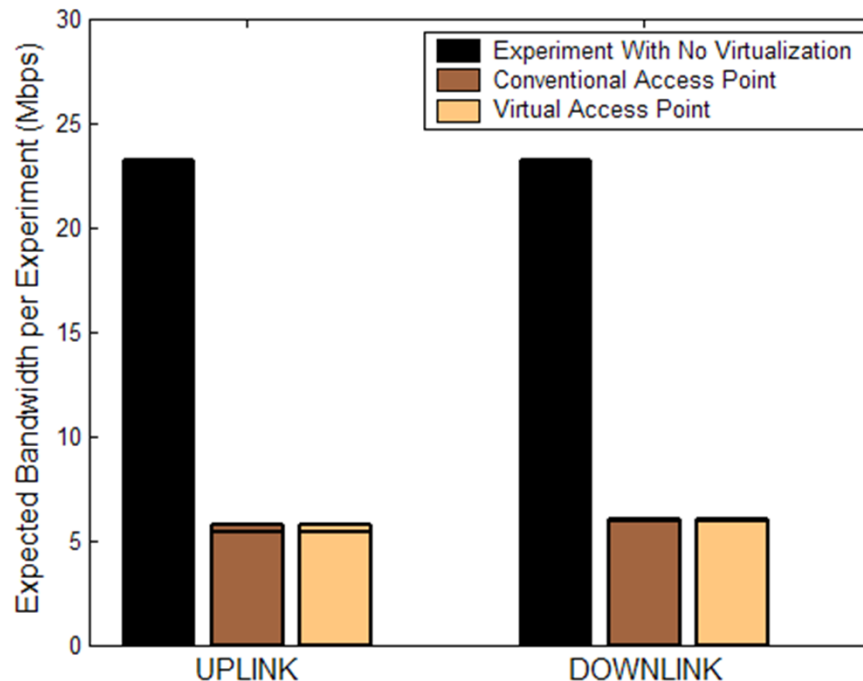
No Policy Manager: Throughput seen at the wireless client with lack of traffic shaping or policy management. The flows of Expt 1 and 2 drive the channel into saturation and effect the results of Expt 3 as visible from the degradation of the video quality.
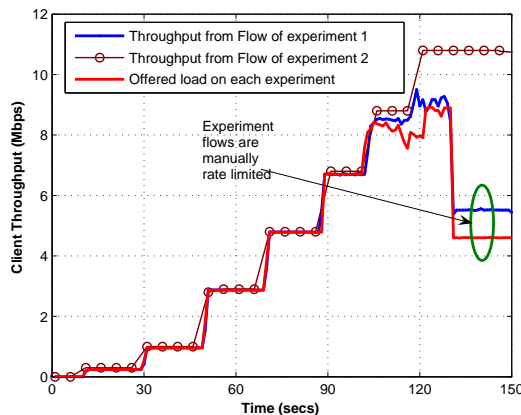

(a) Below saturation video at the start of the experiment

Pre-Policy: The policy manager decides the maximum throughput assigned to each experiment. The rate limitation of the experiments kicks in at the start.

(b) The data flows saturate the channel, thereby resulting in deterioration of the video quality


Dynamic Policy: In this approach, the policy manager kicks in dynamically at the sense of a possible saturation and limits the experiments to the assigned rate.

(c) Video performance after traffic shaping with manual intervention. Availability of sufficient bandwidth restores the video quality
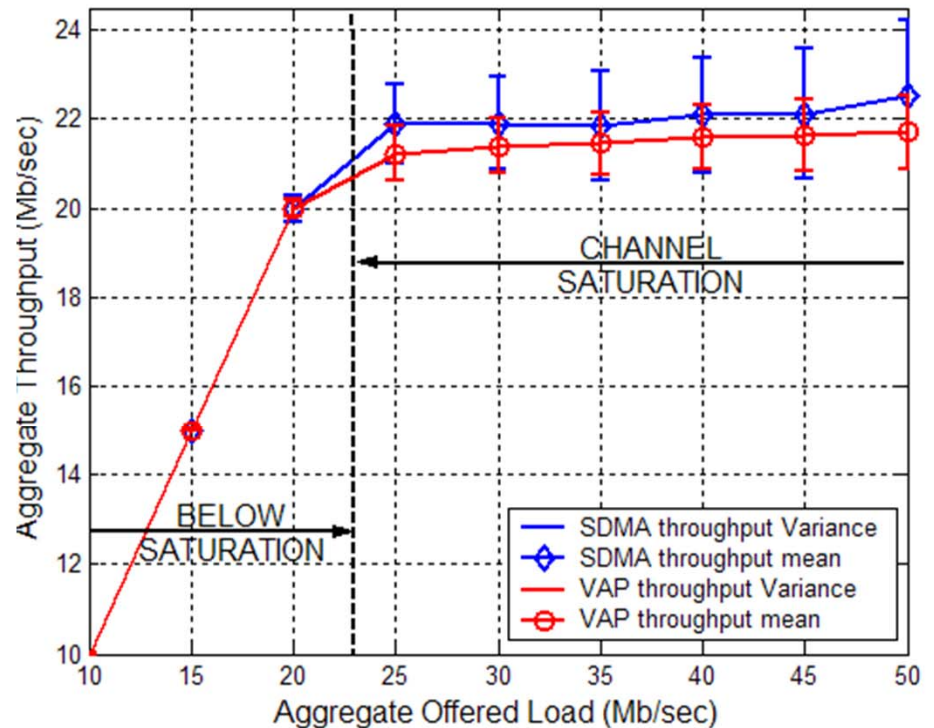
Space Division (SDMA) Virtualization

- Virtual console support (Xen with 4 instances)
- Full isolation on wired side (VLAN)
- New resource allocation/management service needed for proper isolation on wireless side

Console 1

Console 2

Slice 1   Slice 2

Slice 3   Slice 4

Console 3
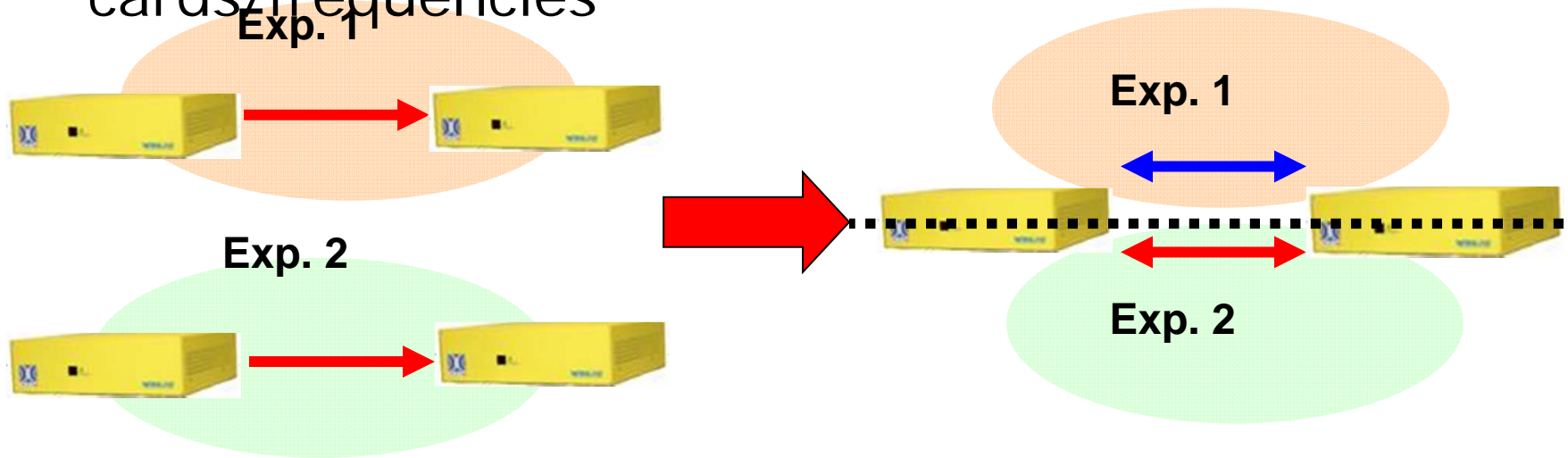
Console 4

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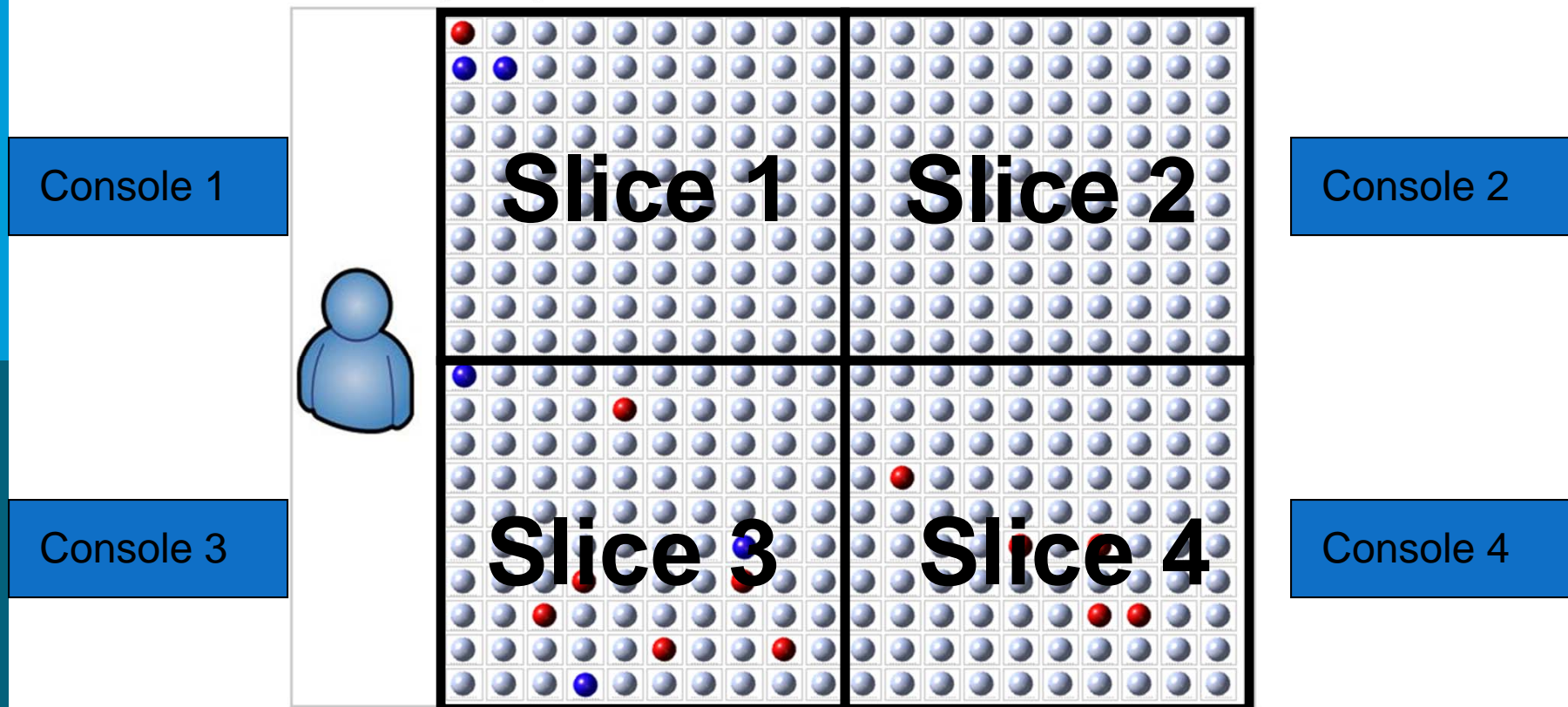
SDMA Performance Comparison

- SDMA based virtualization shows better performance than VAP as a result of 802.11 PHY layer capture effect.
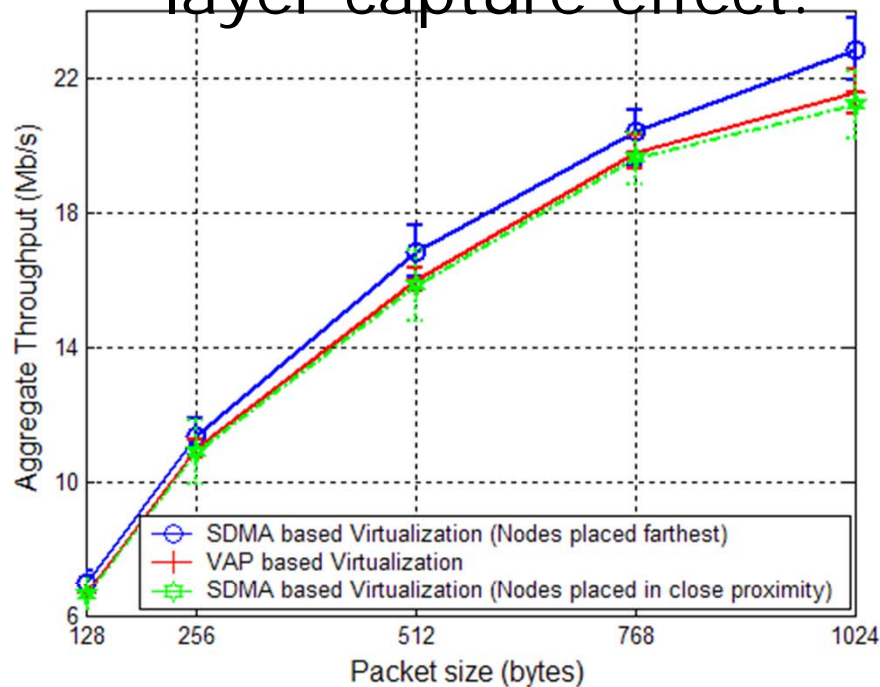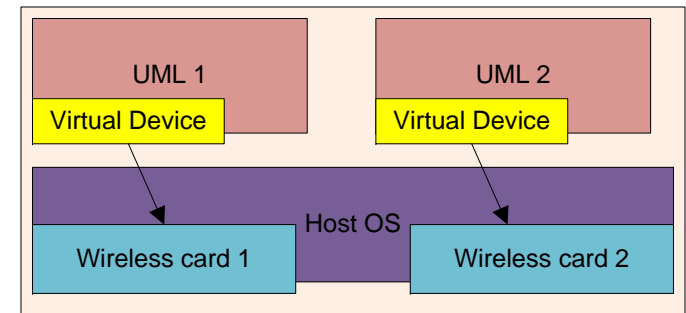
Frequency Division (FDMA) Virtualization

□ Two concurrent experiments can coexist using the same hardware via multiple radio cards/frequencies

• Evaluations based on UML (User Mode Linux) virtualization.
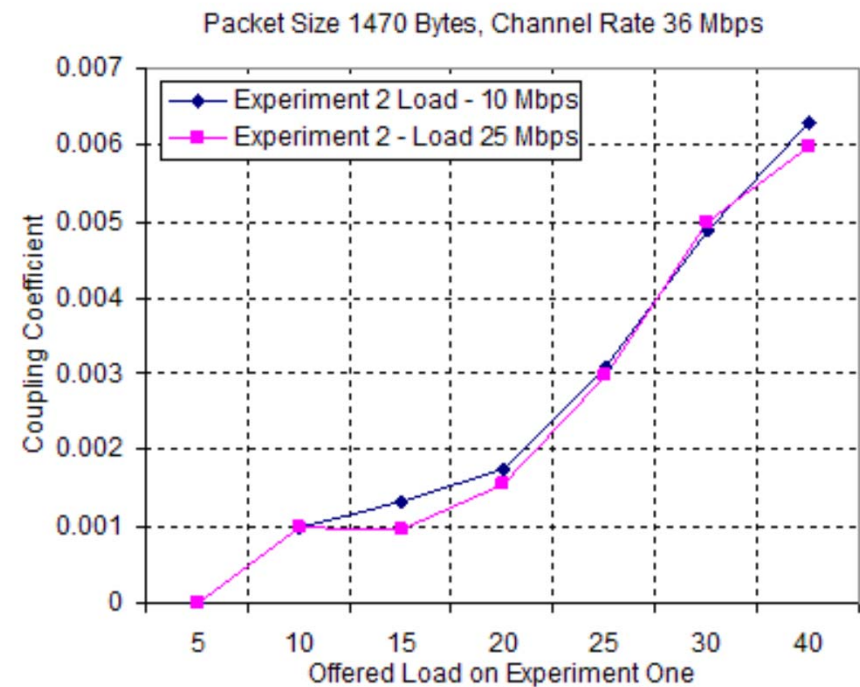
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FDMA Performance Comparison
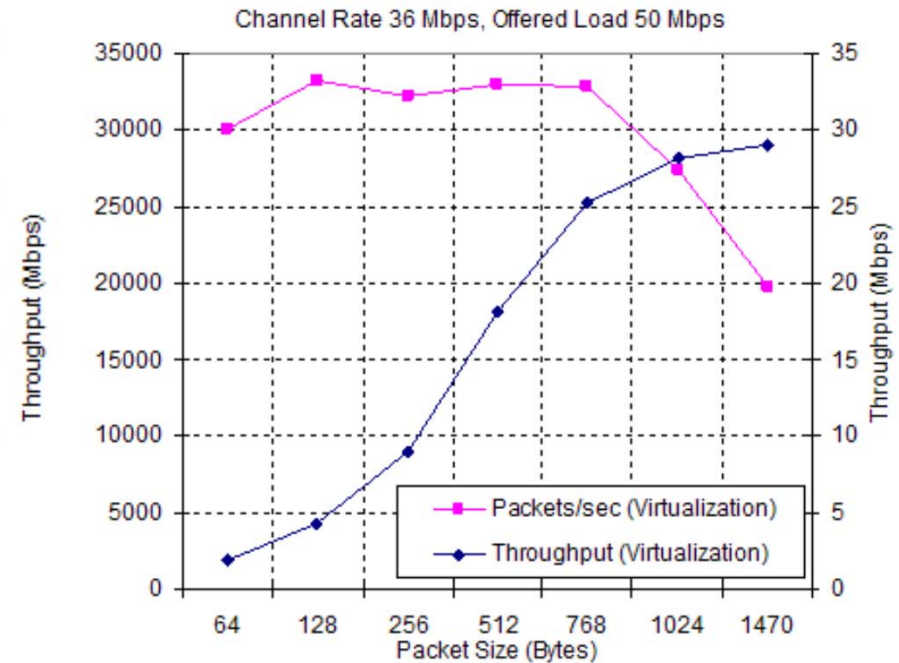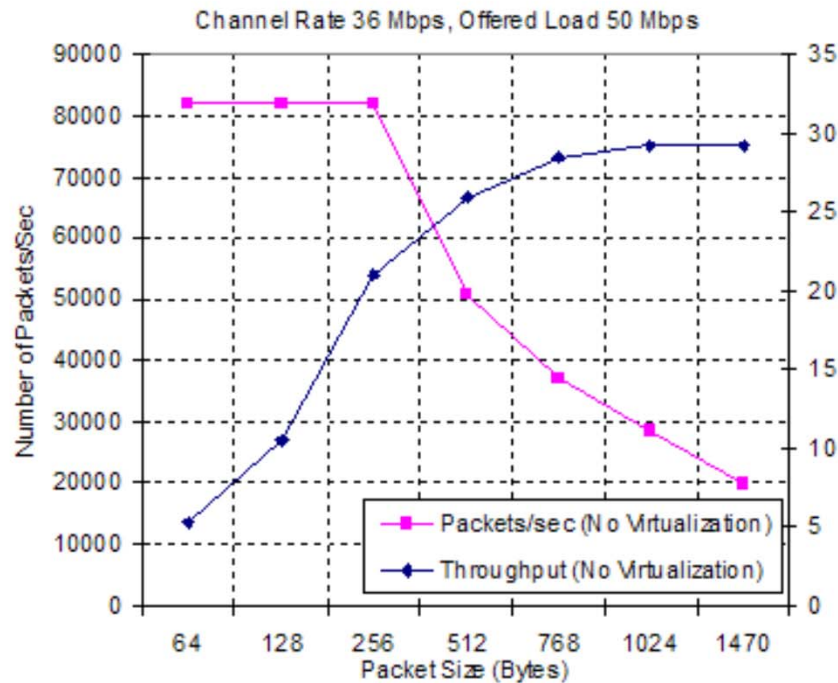
- **UDP Throughput** for virtualized network decreases rapidly with decrease in packet size.
- Without virtualization ~ 80,000 packets/sec sent out by wireless device.
- UML can successfully send up to 30000 packets/sec.

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FDMA Performance Comparison
Interference between Experiments sharing the same nodes

Packet Size 1470 Bytes, Channel Rate 36 Mbps

Packet Size 1470 Bytes, Channel Rate 36 Mbps
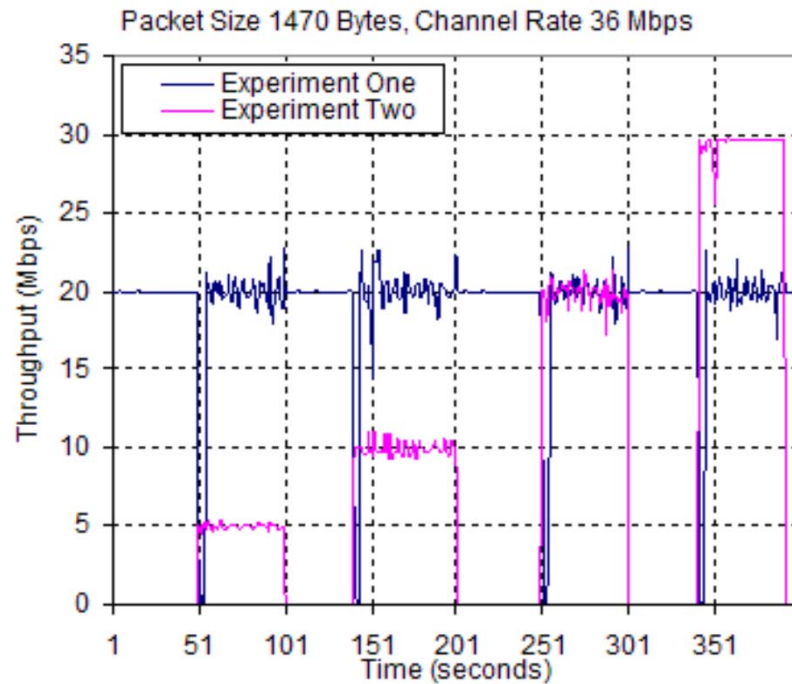
□ After an instantaneous dip, the throughput on 1st UML settles around its original value, but its time variance increases.

□ The coupling coefficient increases almost linearly with the increase in offered load on UML 1 and is not affected by the load on 2nd experiment.

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Wireless Virtual Network Problem

- Given a virtual network graph $G_v(V_v, E_v, C_v)$ and a physical network $G_p(V_p, E_p, R_p)$ where
  - V → Vertices
  - E → Edge set
  - C → Constraints
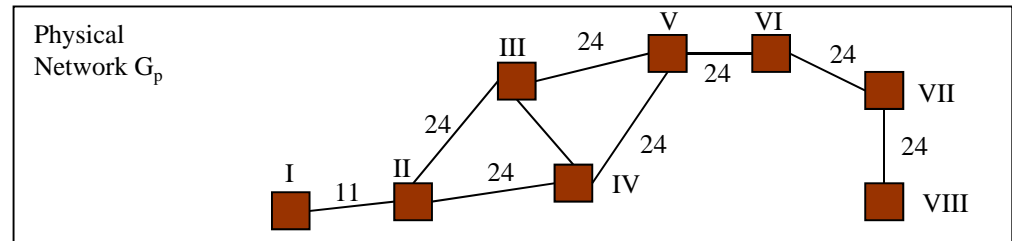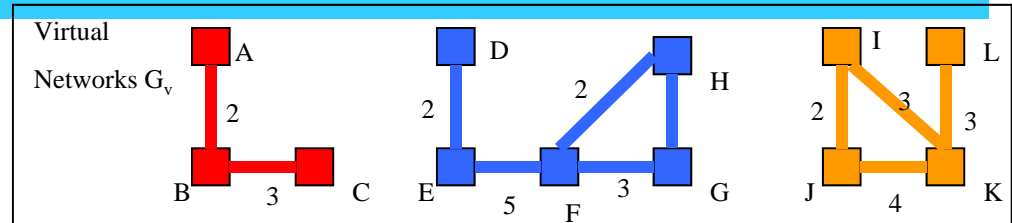 - R → Resources

- The mapping problem is defined as

$$M : G_v \rightarrow (V_p^{'}, E_p^{'}, R_p^{'})$$

- Where,

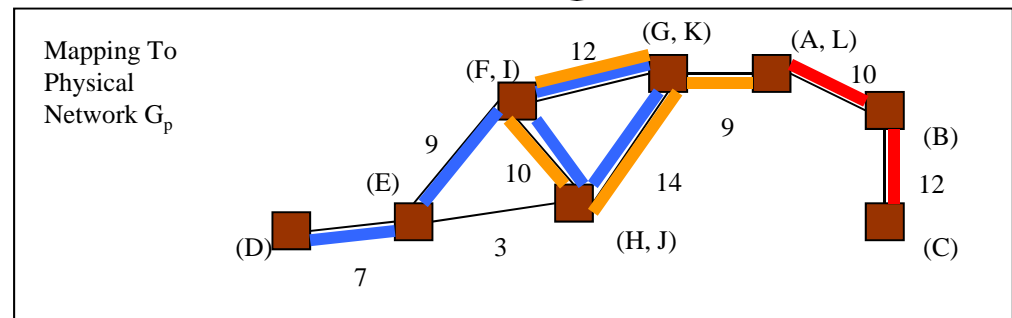$$V_p^{'} \subset V_p , E_p^{'} \subset E_p$$

  - and all constraints are satisfied

Resource assignment in wireless networks can be more difficult due to interference between nearby links

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Wireless Virtual Network Problem (cont.)

Node #	Residual time VN1	Residual time VN2 1st mapping	Residual time VN2 2nd mapping
A	0.8	0.6	0.8
B	0.6	0.2	0.4
C	0.6	0.2	0.4
D	0.8	0.6	0.4
E	1.0	1.0	0.8

VN Assignment Heuristics

- Min residual time across network

- Balanced residual time across nodes

- Minimize total cost (assigned time) across all nodes
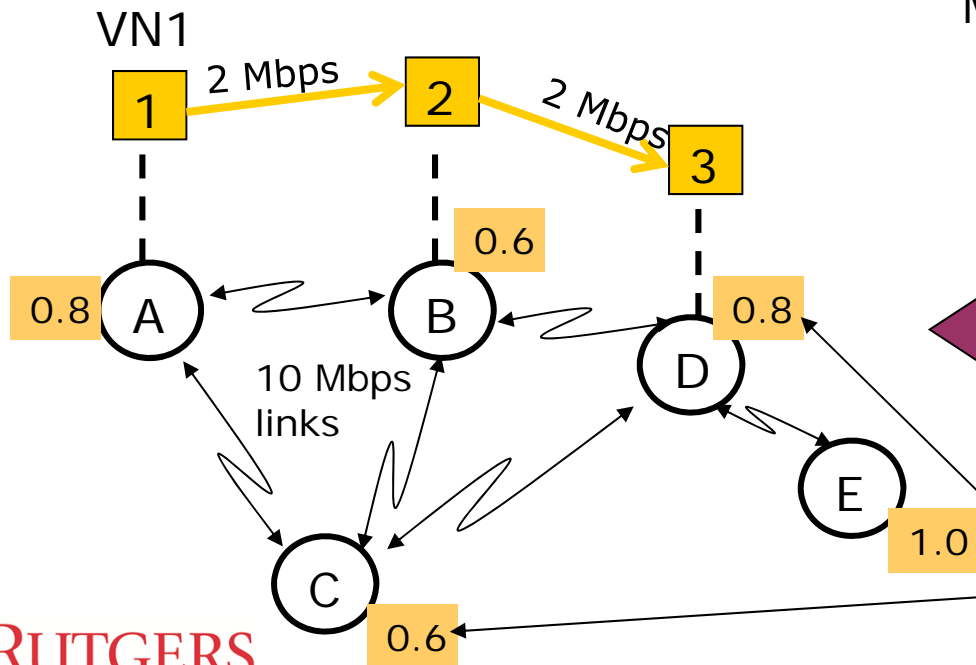
More balanced assignment

VN2 mapping:

1st option: 4->A, 5->B, 6->C

2nd option: 4->E, 5->D, 6->B

VN1

2 Mbps

2 Mbps

0.6

0.8

0.8

10 Mbps links

0.6

1.0

2 Mbps

2 Mbps

VN2

Residual Channel time

ORBIT: Vehicular Experiment Support
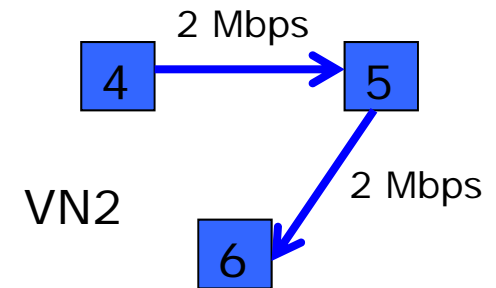
- Trunk mounted standard ORBIT radio node with two 802.11a/b/g WLAN interfaces
- Power inverter supporting up to 300W load, converting 12VDC-to-110VAC
- 802.11a/b/g antennas that can be mounted inside or outside of the vehicle

- Pharos i360 GPS unit

- ElmScan5 USB Scan Tool for real-time vehicle data reading through OBD-II interface

- Dash mounted Samsung Q1 UMPC to be used as the experiment control console

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Modeling

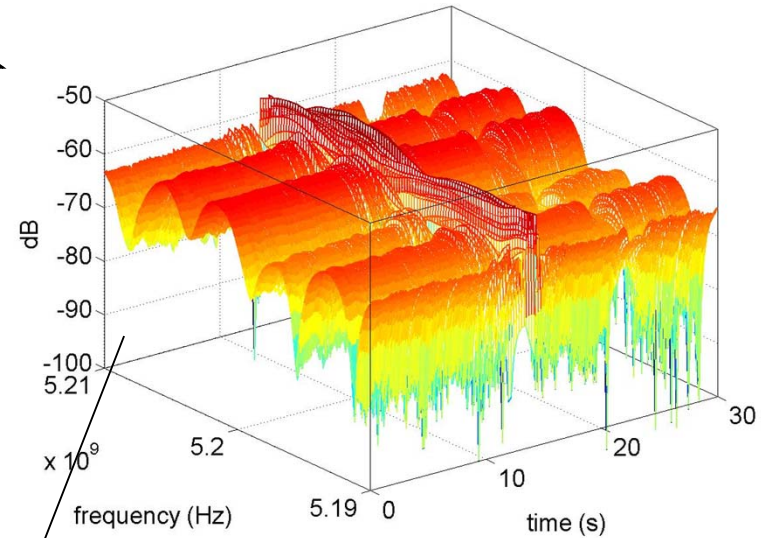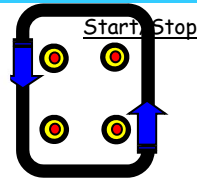self storage containers

4.4m

pylons mark the car route
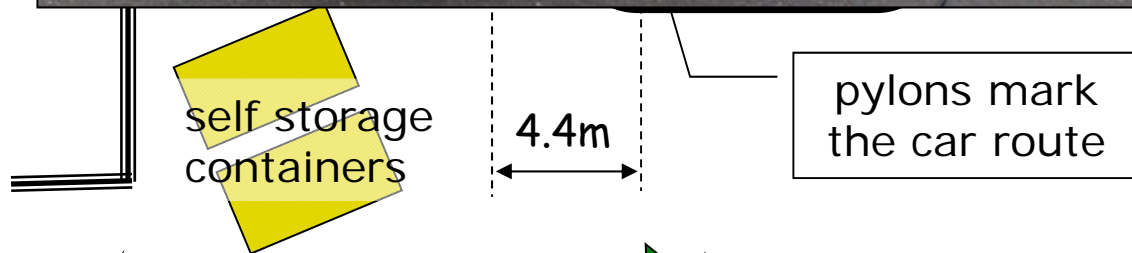
Near-simultaneous measurements:

Vector Network analyzer sweeps 20MHz 33 times per second

Pair of 802.11 nodes is used to capture RSSI for 1000 beacon packets

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Modeling
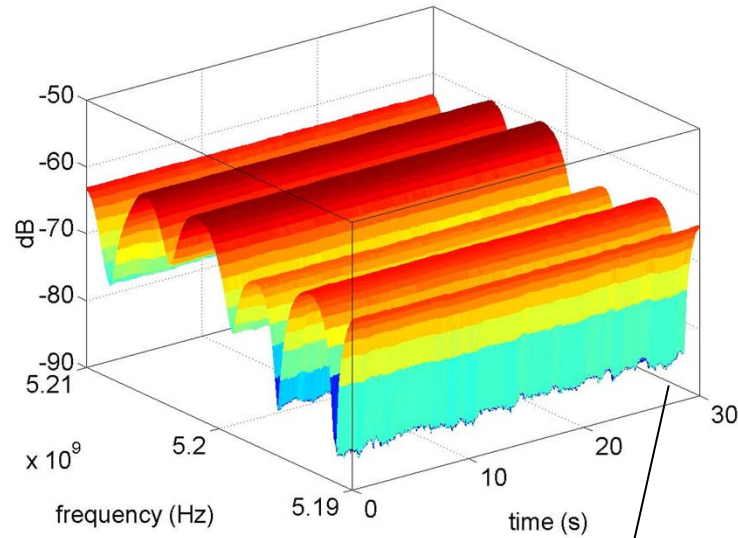
Time invariant channel: fixed multipath (selectivity)

Time varying channel: transfer function magnitude

Time varying channel: channel power

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MAC: New requirements

90% PDR line
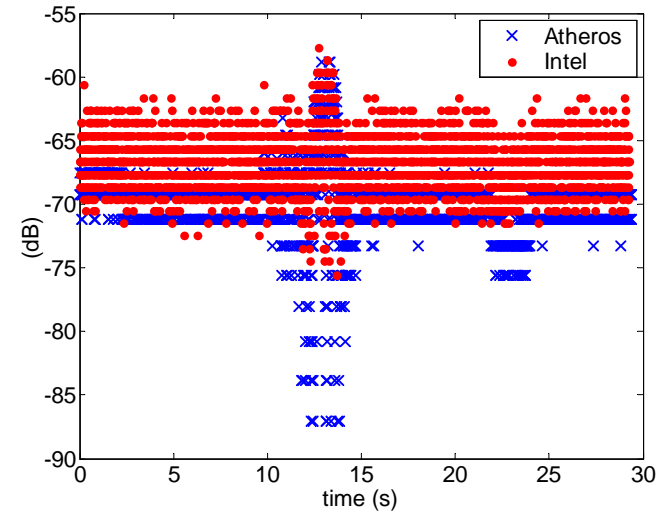
Packet delivery rate (PDR) @10pps
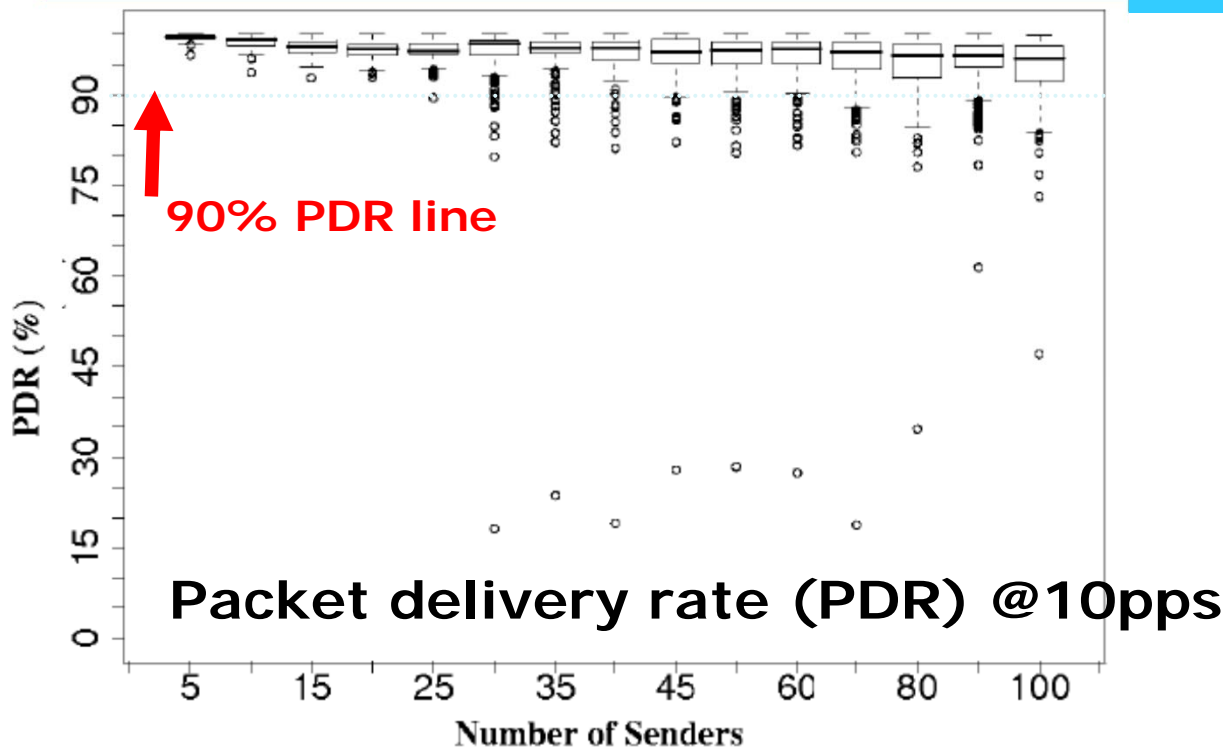
Boxplot Summary

- ← Max. value
- ← Upper Quartile
- ← Median
- ← Lower Quartile
- ← Min. value
- ← Outlier

PDR statistics across receivers

Min.	Max.	Mean	Std. Dev.
84%	100%	94.4 – 97.6%	2.4 – 5%

Significant PDR variation across RX (upto 16%)

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WiMAX Virtualization

□ Design Goals:

- Multiple independent virtual networks (VNs), each with specified % of BS capacity
    - □ Inter-slice fairness & isolation
- For GENI experiments, each VN should be qualitatively equivalent to a dedicated BS
- Each VN (slice) should support multiple clients
    - □ Intra-slice fairness
    - □ Multiple traffic types

Physical 802.16e BS

20 % Slice1

10 % Slice2

30 % Slice3

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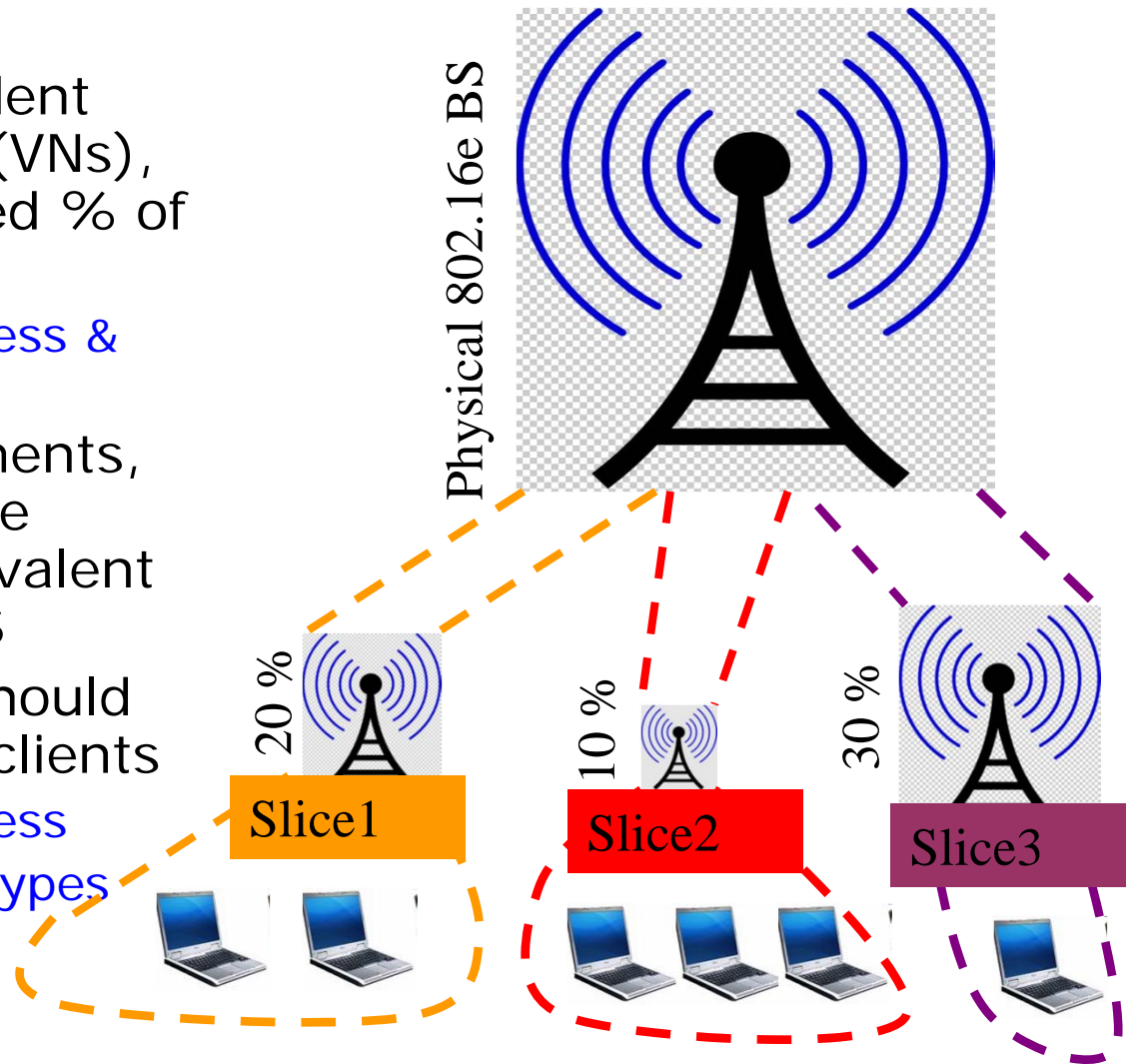
Virtual WiMAX Implementation
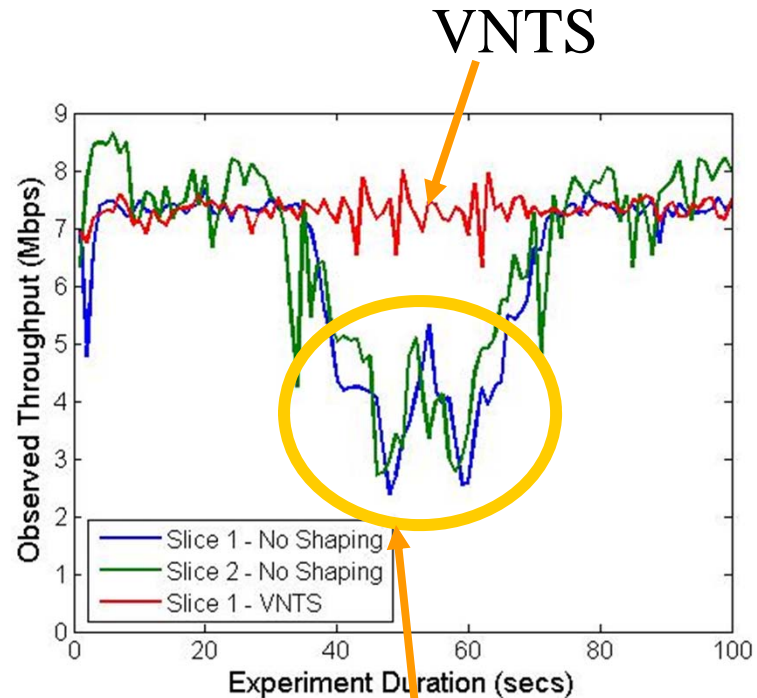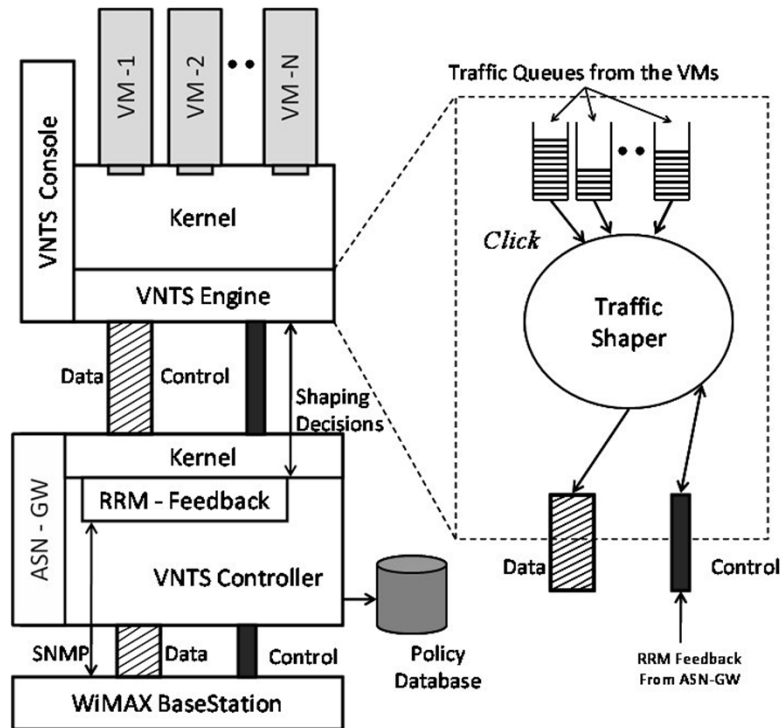
- VN traffic shaping (VNTS) on external GENI controller
- Maintains fairness & isolation between slices
- Uses SNMP status feedback (MCS, rate,..) from BS

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OF Meso-scale Deployments: Rutgers

ION Connectivity Example

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ION Performance

Experimental Package: Storage and Mobility Aware Routing Metric in CNF

Maintain long and short term routing costs

- Short term (S): instantaneous view of the cost to reach a destination
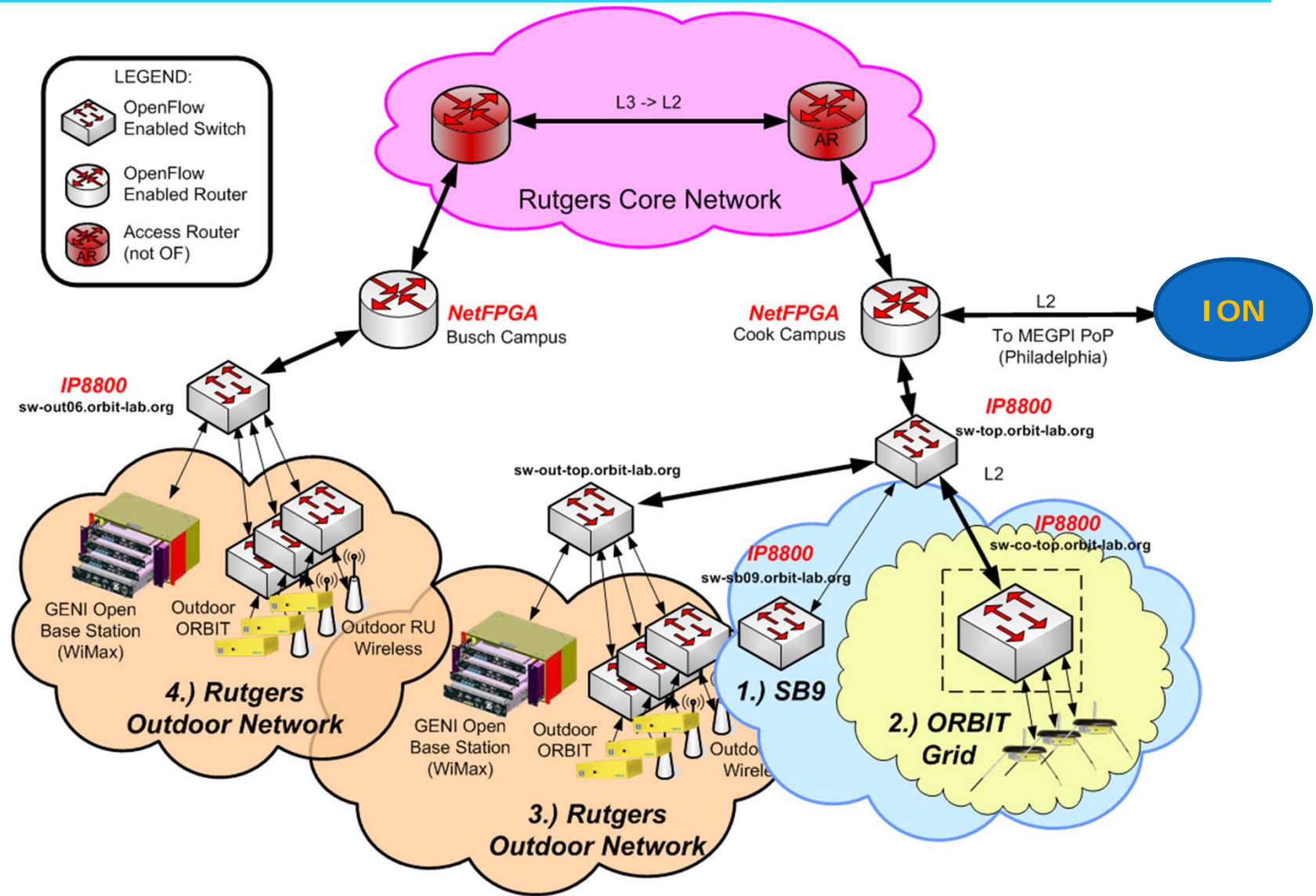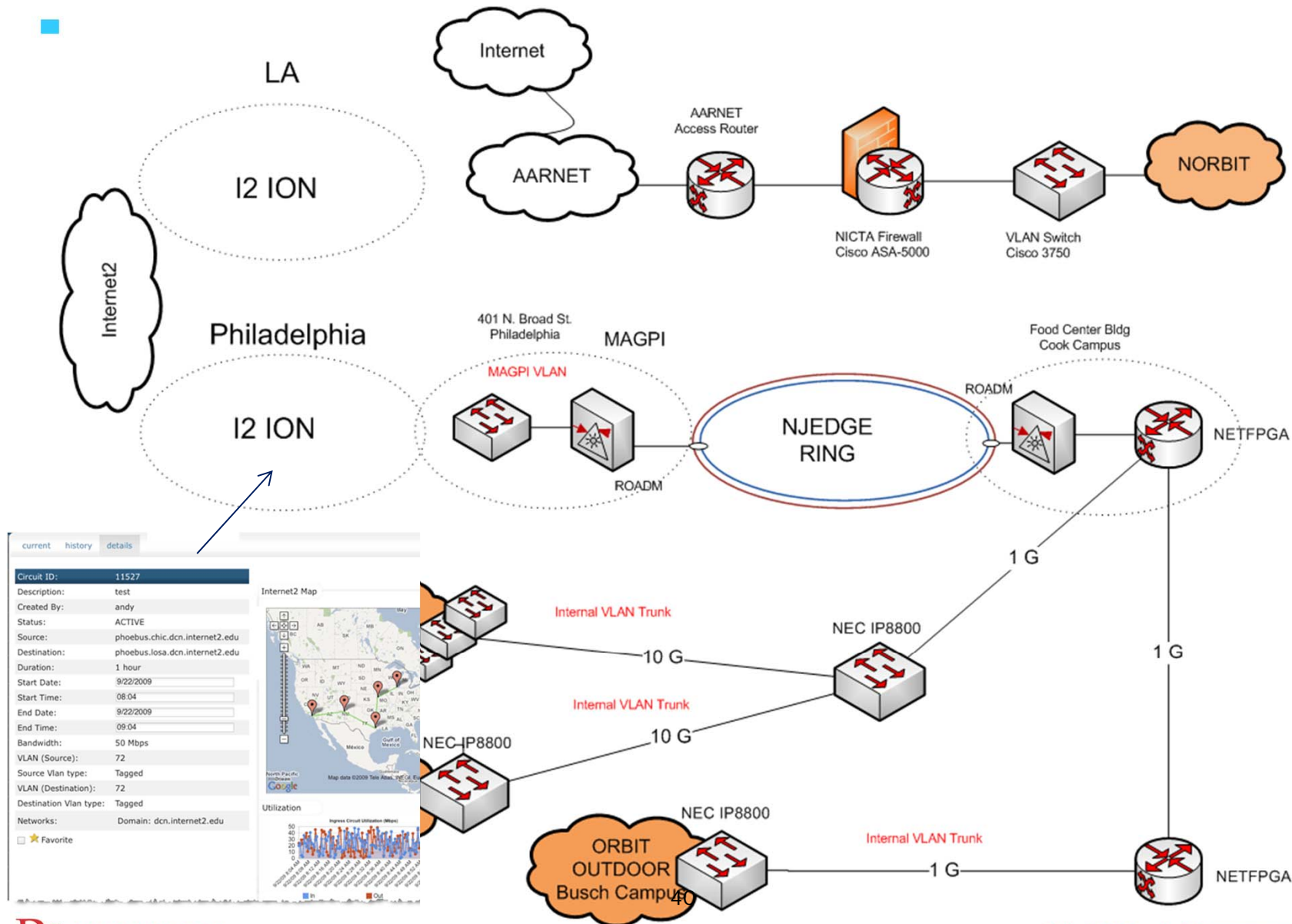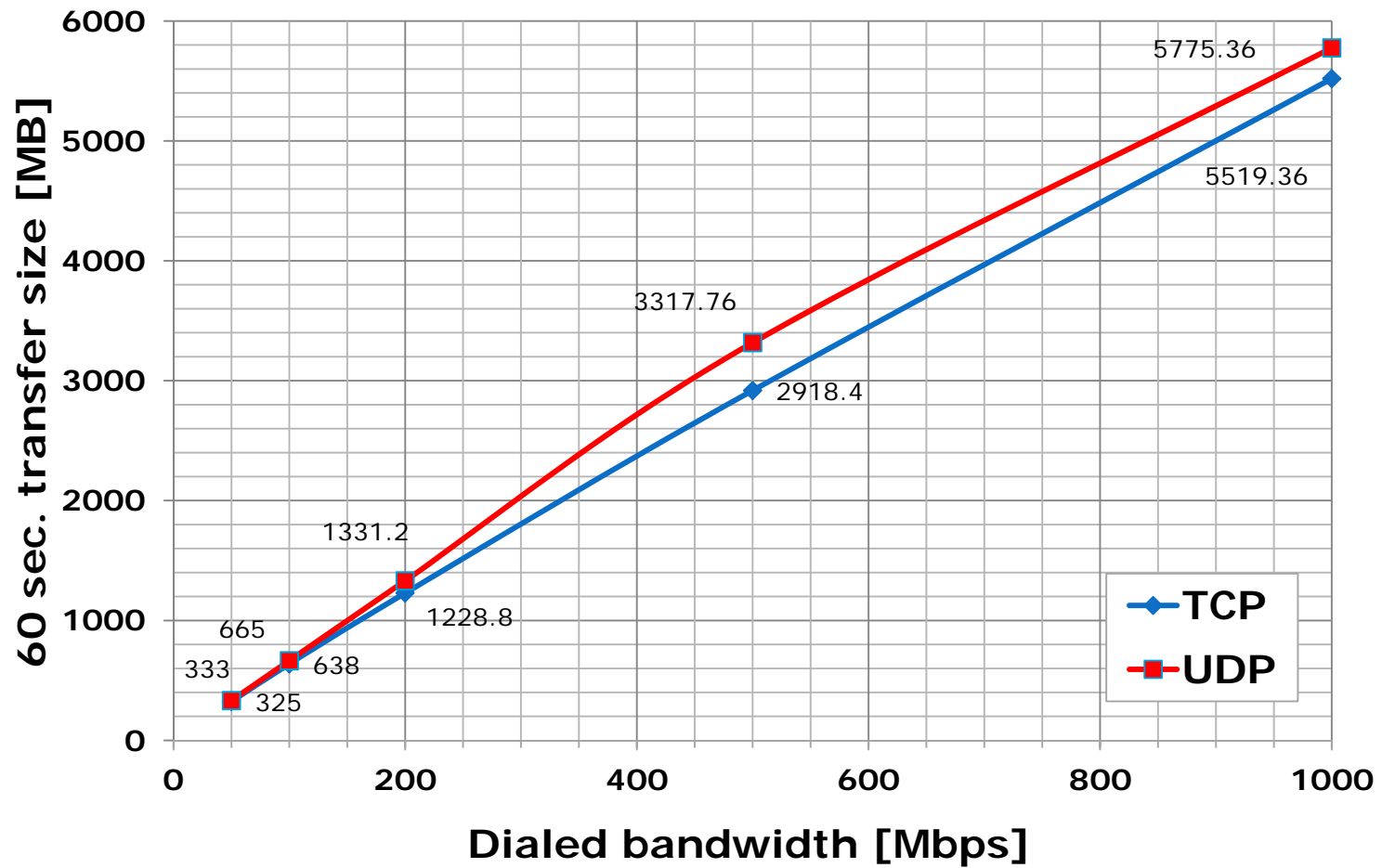- Long term (L): Historical perspective of the cost to reach the same destination along the same route.
- Collect and "remember" multiple such routes

Maintain view of current available storage at routers

- Indicates queue build up and therefore contention at the MAC layer, broken links and congestion

Costs and storage values are essentially providing link conditions averaged over route update period.

COST
- Expected Transmission Time based upon MAC layer data rate, queuing delay, congestion
- Expected Transmission count reflects number of transmissions necessary for successful data reception
- Load, energy, traffic balancing

Long term cost >> short term cost
FORWARD ONLY IF DOWNSTREAM PATH HAS AMPLE SPACE

Long term cost ≅ short term cost
STABLE PATH

Long term cost << short term cost
STORE

Long term cost / Short term cost

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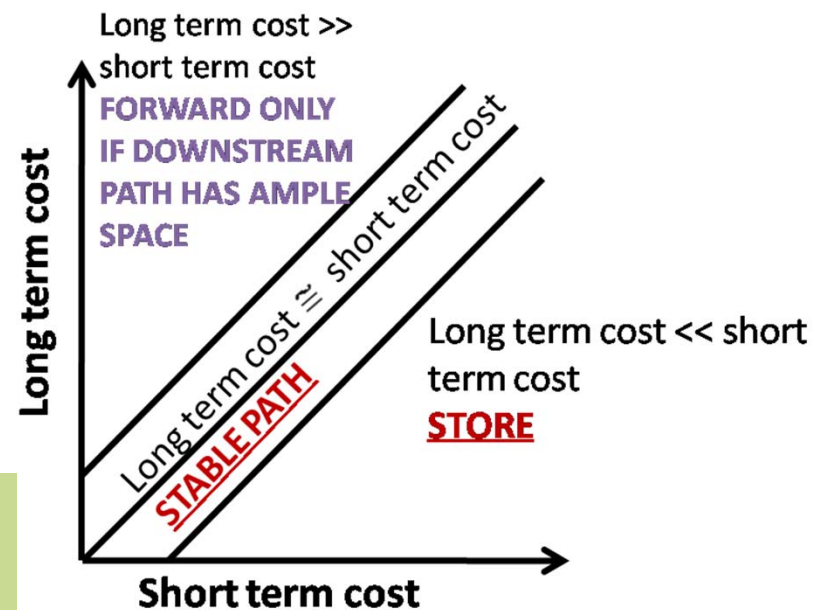
Experimental Package: CNF ORBIT Implementation
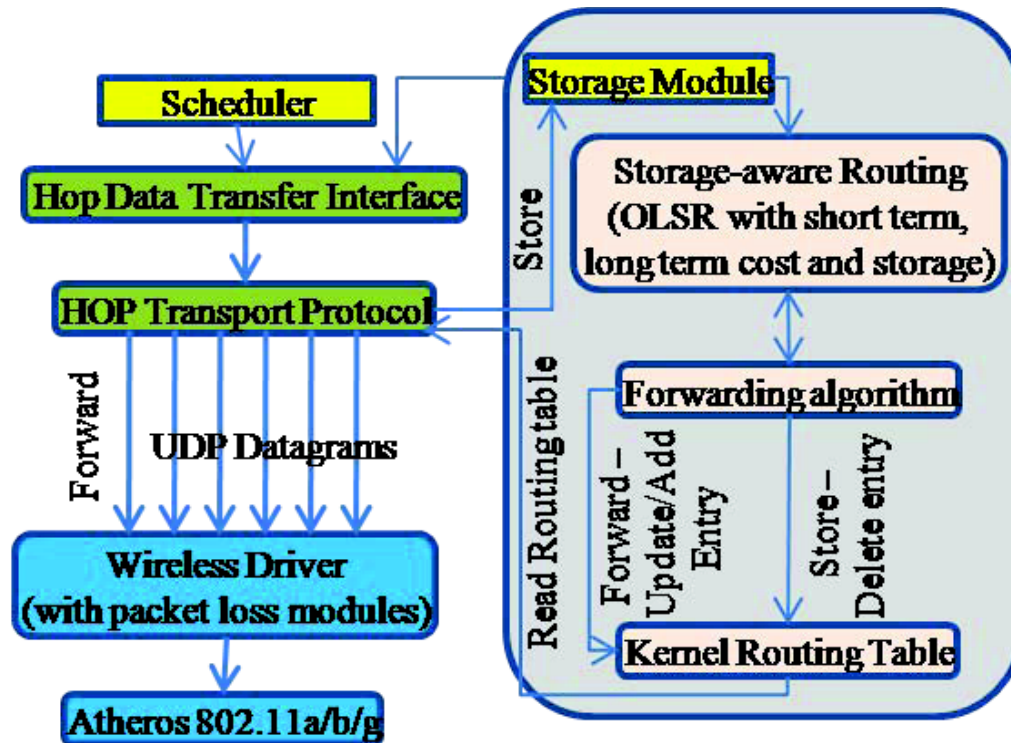
Software Architecture
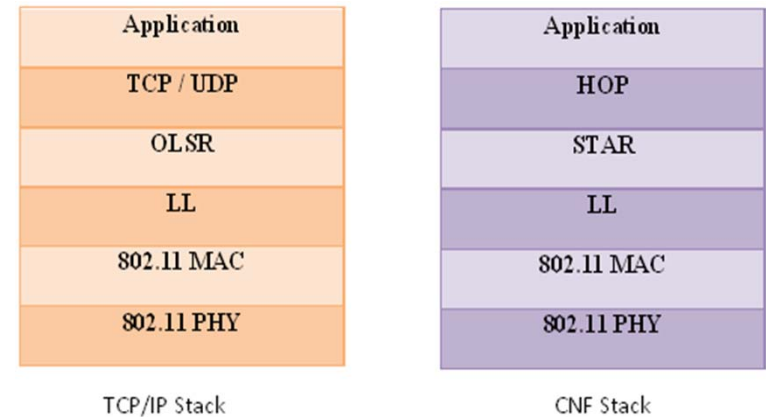
Comparison protocolStacks

Experimental Package: CNF Performance Results from ORBIT Experiments

- Poisson arrival process
- File size 500KB
- 3 simultaneous flows
- 100 file transfers
- Average throughput
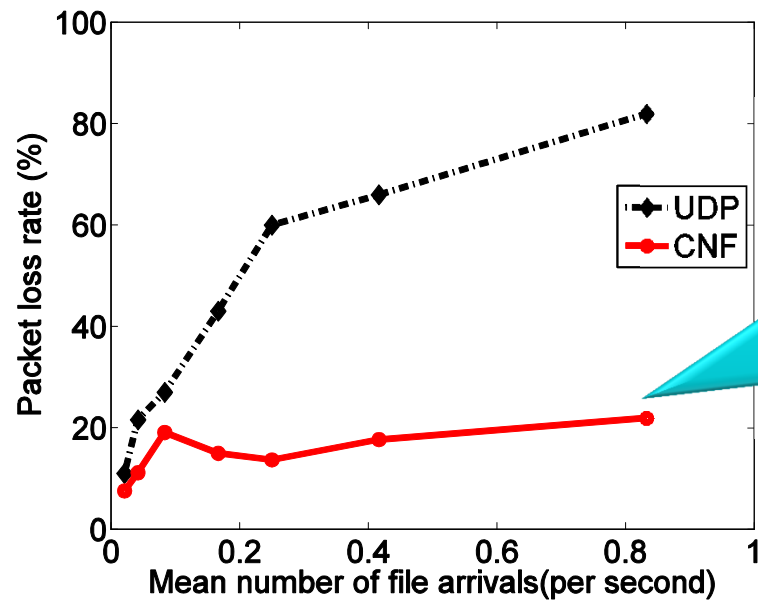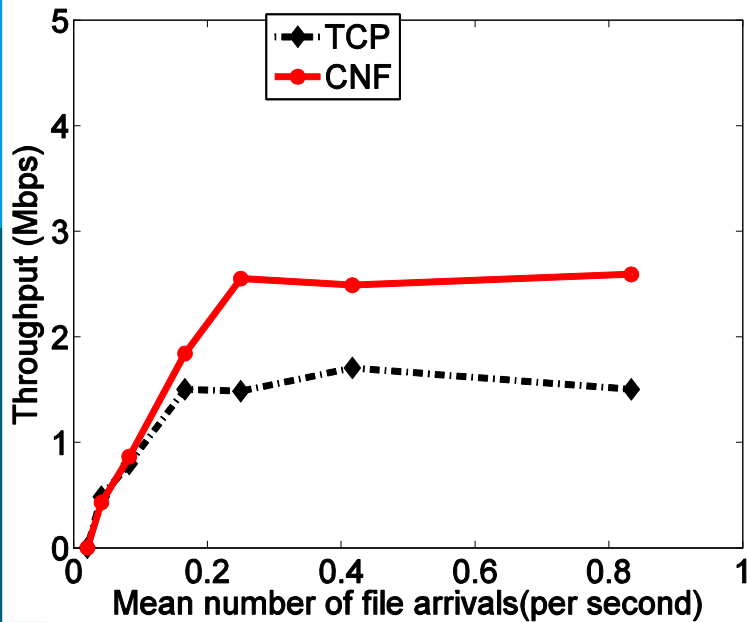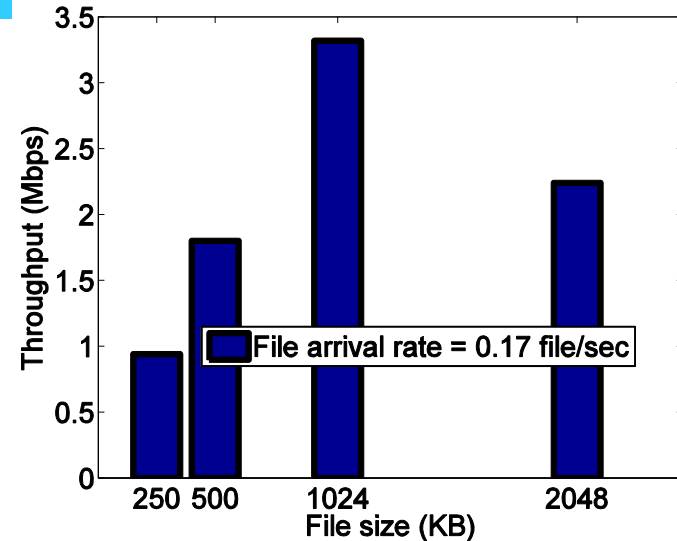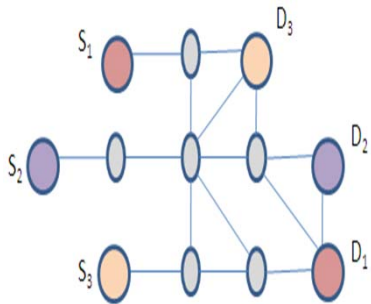
CNF implicitly does flow control, avoiding packet drops

Experimental Package: GeoMAC for Reliable V2V Messaging
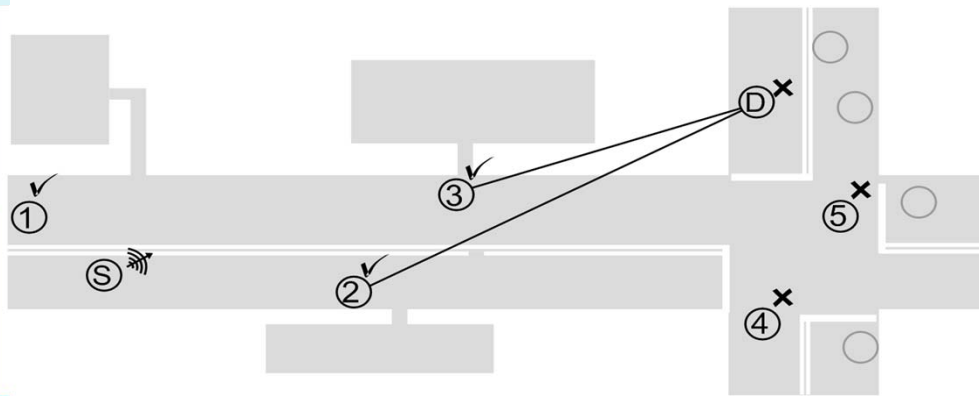
- ❑ Unreliable wireless channel: severe fading due to shadowing due to static and mobile obstructions
- ❑ GeoMac opportunistically uses neighboring vehicles to forward messages.
- ❑ Forwarders selected based on geographic heuristics
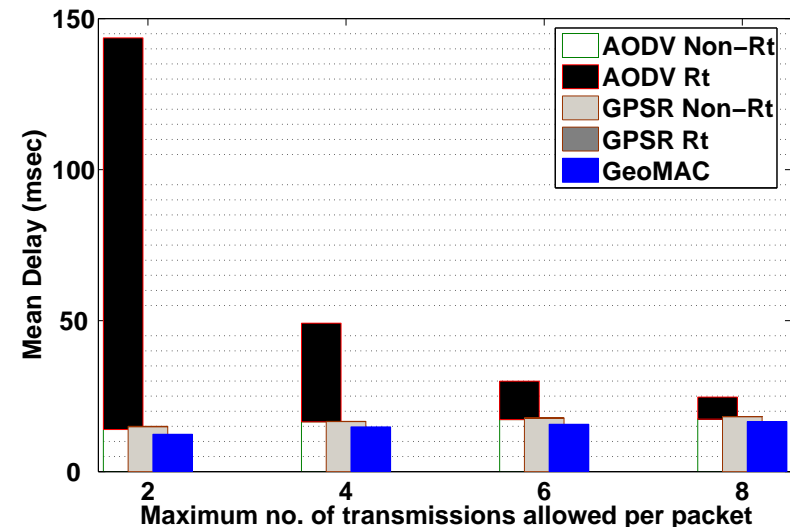
❑ GeoMac achieves lower delay and more reliable transmissions than ad hoc routing protocols

Experimental Package: ParkNet

Rangefinder + GPS
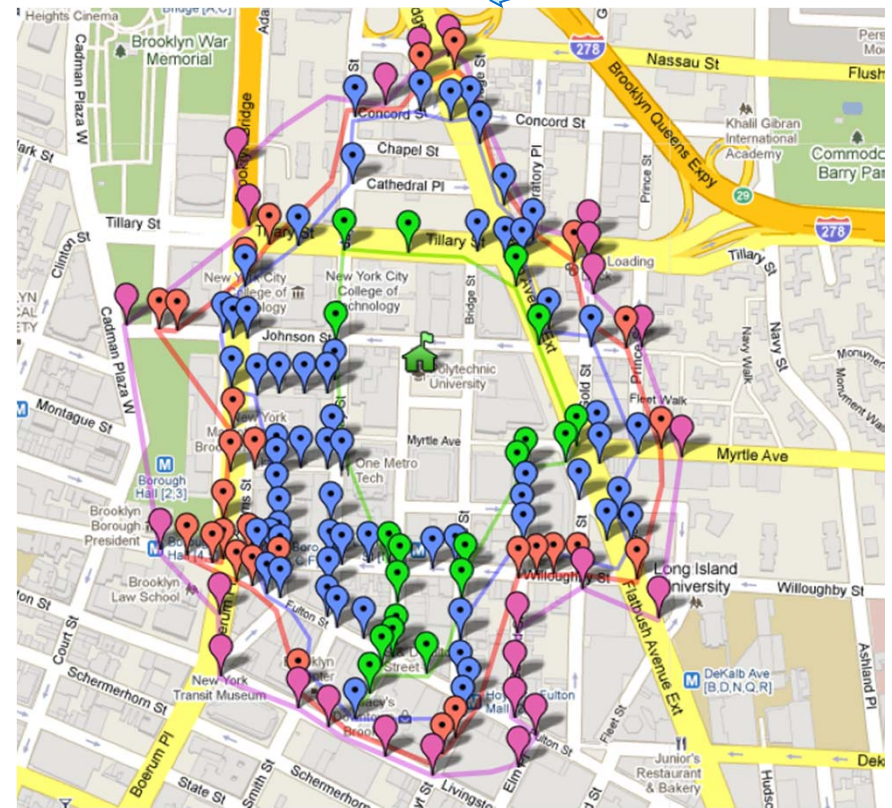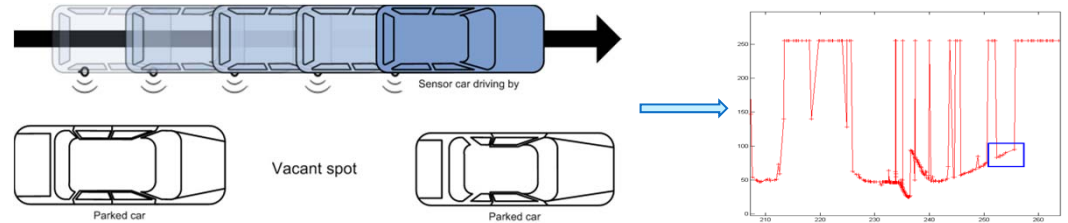
Experimentation with delay-tolerant data collection protocols on Wimax networks utilizing:
- Tools for executing and orchestrating experiments across a set of mobile nodes
- Monitoring & instrumentation plane to obtain and manage large amounts of measurements (data)

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Experimental Package: ParkNet (cont.)

Experiment Description

CN

AM

RC Apps
OML

RC OML Server

EN

Rutgers Aggregate

GENI Backbone

Brooklyn Poly Aggregate

Control Network (CN)

Experimental Network (EN)

PubSub Server

AM

RC OML Base Station Control App

WiMAX

RC OML Sensor Apps

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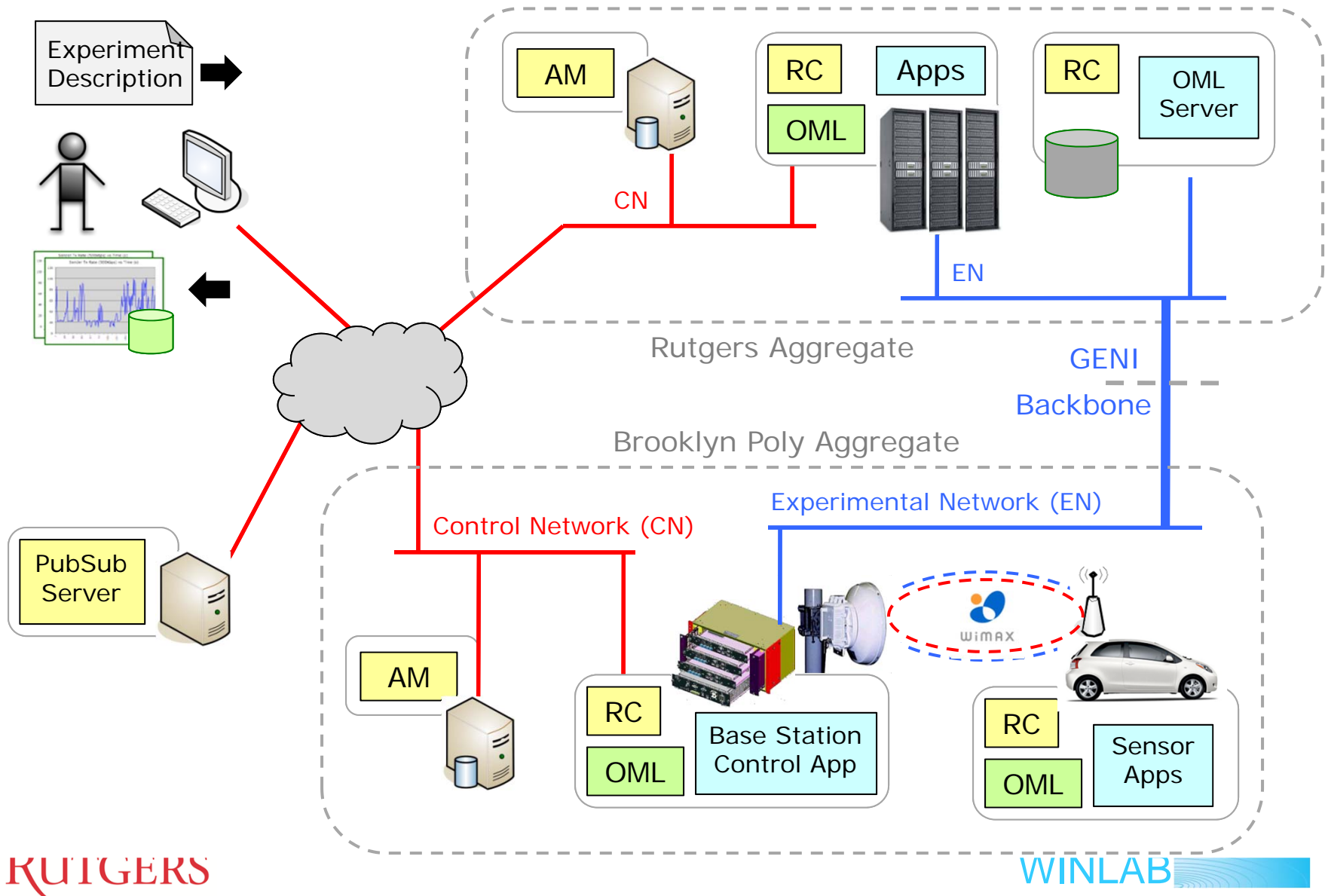
Experimental Package: Cooperation

Packet recovery over heterogeneous networks

- Wireless devices are connected to the principal network (GENI WiMAX) to receive multicast or broadcast data such as live video feeds.

- A wireless device may lose some of the data sent over the principal network.

- Physically co-located devices form an assistant network over WiFi to recover the lost data cooperatively from their peers.

Courtesy: Fraida Fund and Thanasis Korakis

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Experimental Package: Network Coding

Network Coding Architecture

	Baseline	HARQ	HARQ-ARQ	NC-Best
64 QAM 1/2 at 13 dBm	5.33	1.97	1.02	5.98
64 QAM 2/3 at 17 dBm	5.26	2.86	1.33	5.99
64 QAM 3/4 at 18 dBm	5.13	3.18	1.32	5.99
64 QAM 5/6 at 20 dBm	4.11	3.66	3.93	5.87
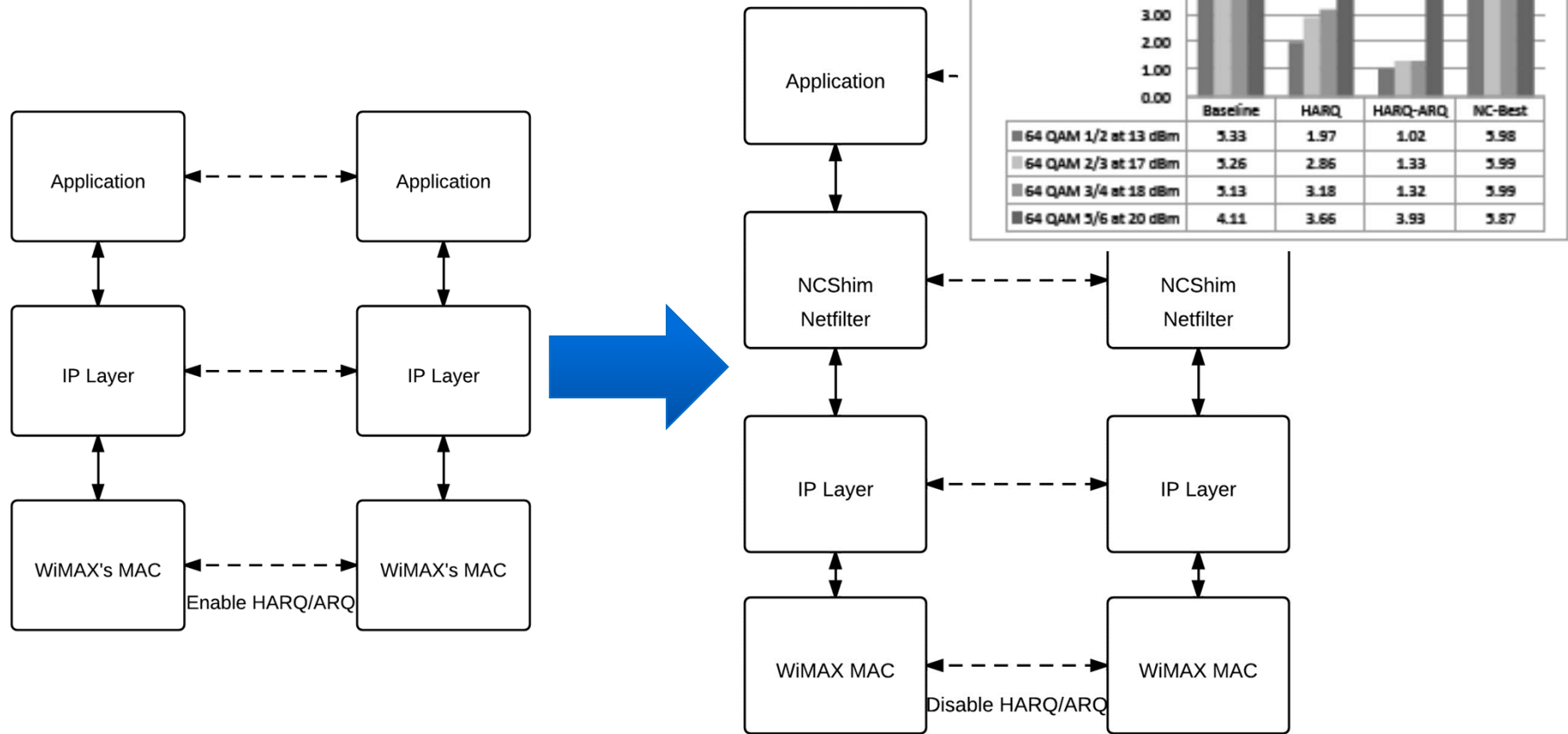
Courtesy: S. Teerapittayanon, K. Fouli, M. Medard, M.-J. Montpetit, X. Shi

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Experimental Package:
Multi-radio Coexistence Problem in Dense Environments
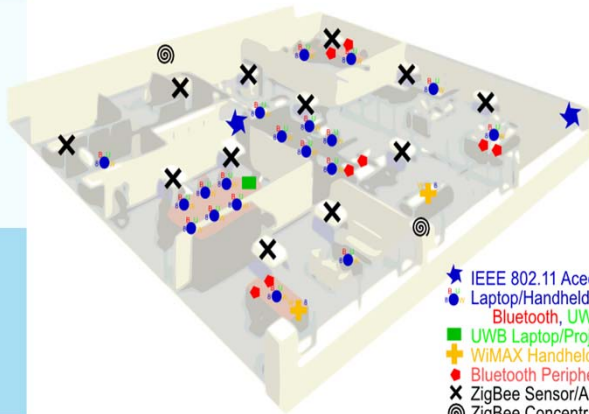
Legend:
★ IEEE 802.11 Aceess Point
● Laptop/Handheld Computer w/ 802.11, Bluetooth, UWB, and WiMAX radios
■ UWB Laptop/Projector
✚ WiMAX Handheld w/ 802.11 radio
● Bluetooth Peripheral
✕ ZigBee Sensor/Actuator
◎ ZigBee Concentrator

"Typical" Enterprise and Small Office and Home Office (SOHO) environments

❑Existing networks with heterogeneous radios were not designed for coexistence.
❑Ad-on and extrinsic solutions are important research challenges.
- ▪Cross technology coordination
- ▪Interference awareness
- ▪Reactive and dynamic adaptation.

1. 5 pairs of Zigbee nodes
2. 8 Wi-Fi Nodes
   - 4 WWW users
   - 2 VOIP users
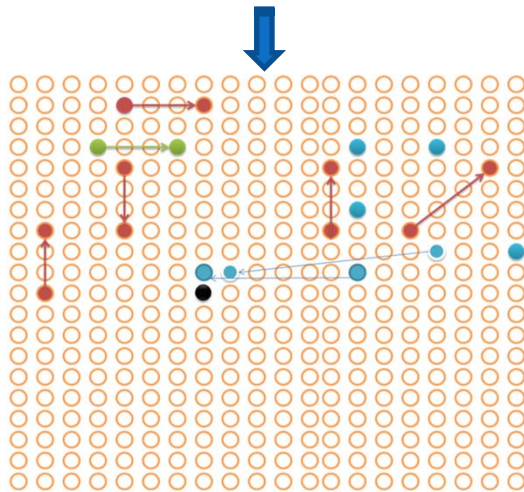   - 2 Video users
3. 2 Pairs of Bluetooth VOIP users

Legend:
● Zigbee Nodes
● Bluetooth VOIP Nodes
● Access Point
● WiFi WWW Nodes
● WiFi VOIP Nodes
● WiFi Video Nodes
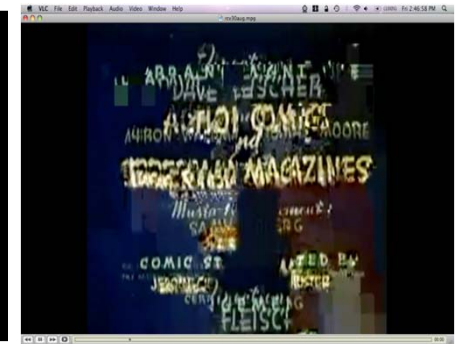
❑Visible Video distortion
❑VoIP over Wi-fi has 2x packet drops, 15% drop in average bit rate

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GENI Wireless Going Forward:
Even Deeper Programmability
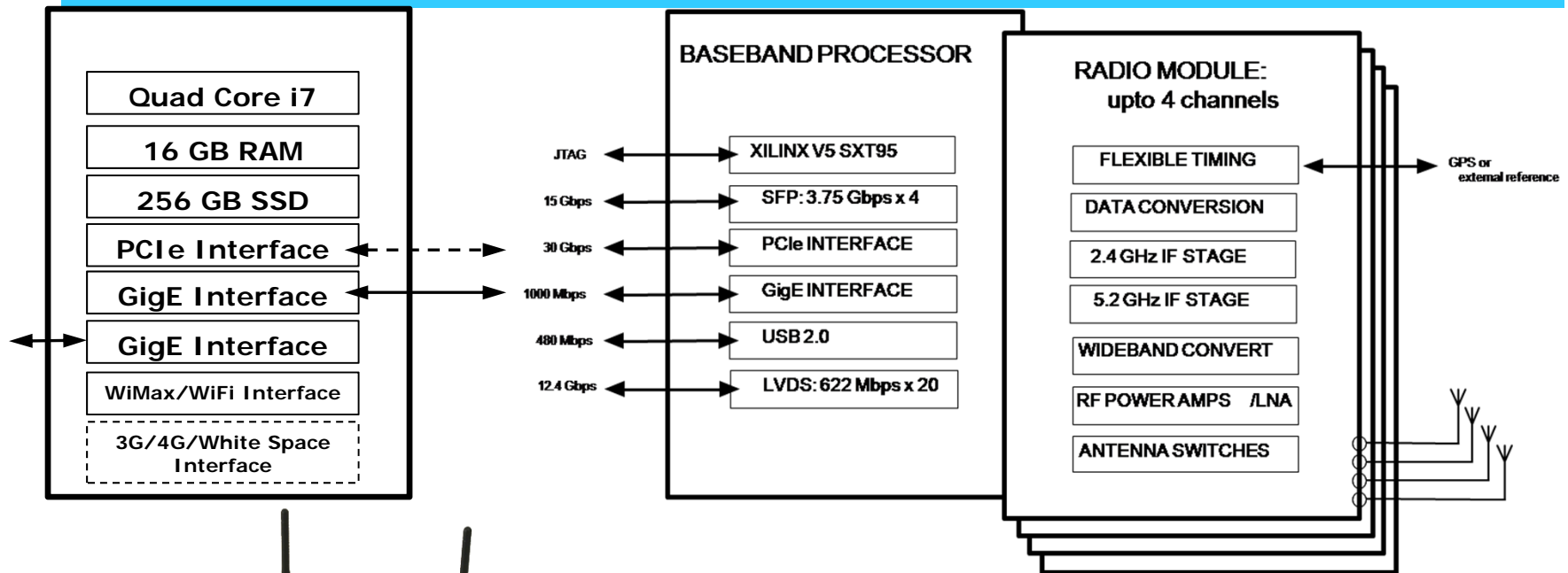
- Up to four full duplex RF modules
- Tuning range : 100-7500 MHz
- Range of COTS baseband FPGA platforms (Vertex 6 LX50/SX95)
- Standard interfaces: 1000 BaseT, (SFP) USB (8x PCIExpress)
- 25 MHz baseband
- 12-bit ADC sampling rate of 64 MSps on I/Q
- 12-bit DAC update rate of 200MSps

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Prototyping and Evaluation: Execution Summary

Phase 1	Phase 2	Phase 3

Prototype

Standalone Modules → Integrated MF Protocol Stack and Services → Deployable s/w pkg., box

Evaluation

Simulation and Emulation → Smaller Scale Testbed → Distributed Testbed E.g. 'Live' on GENI

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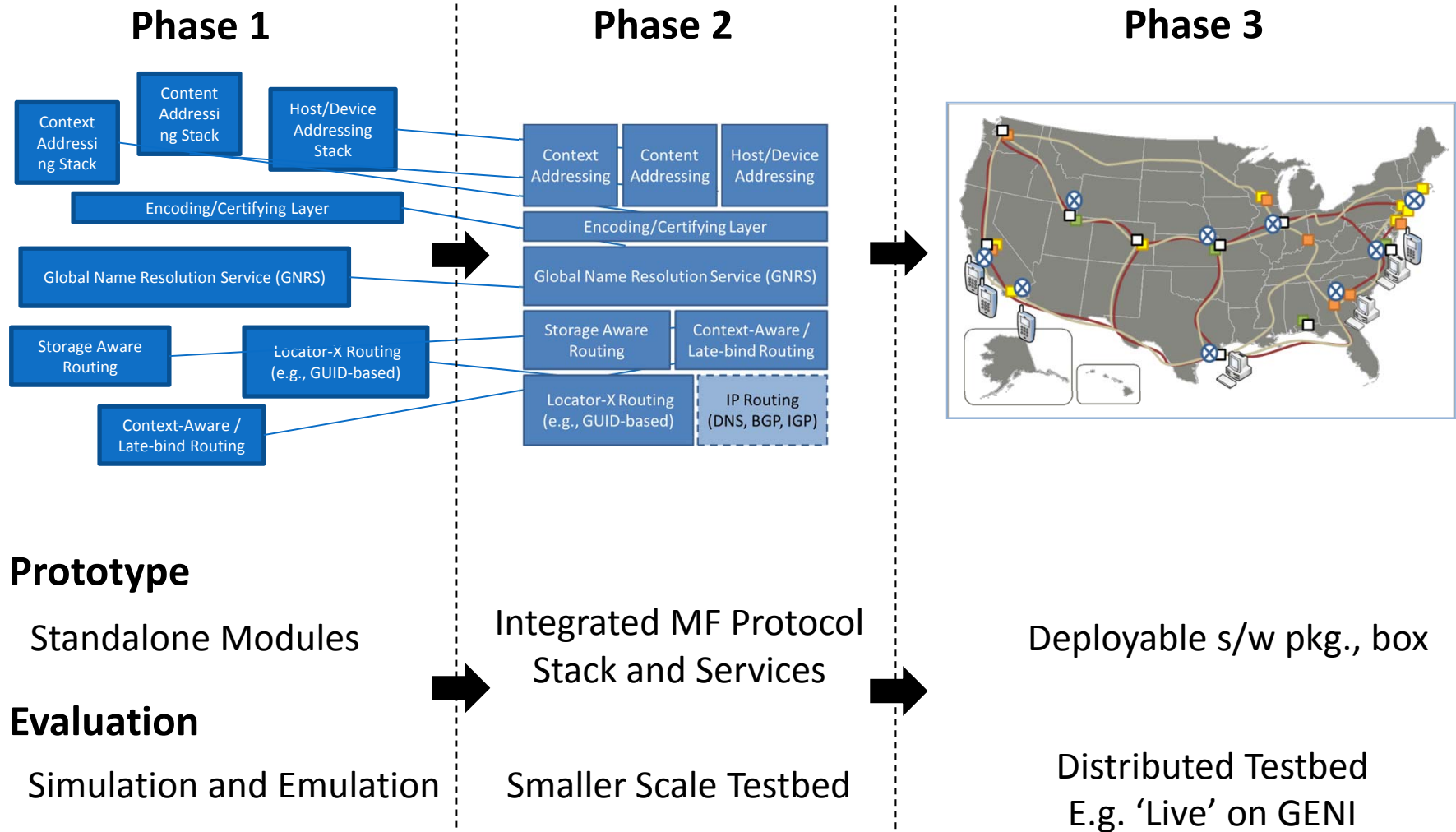
MobilityFirst Prototyping: Click-based Router Implementation
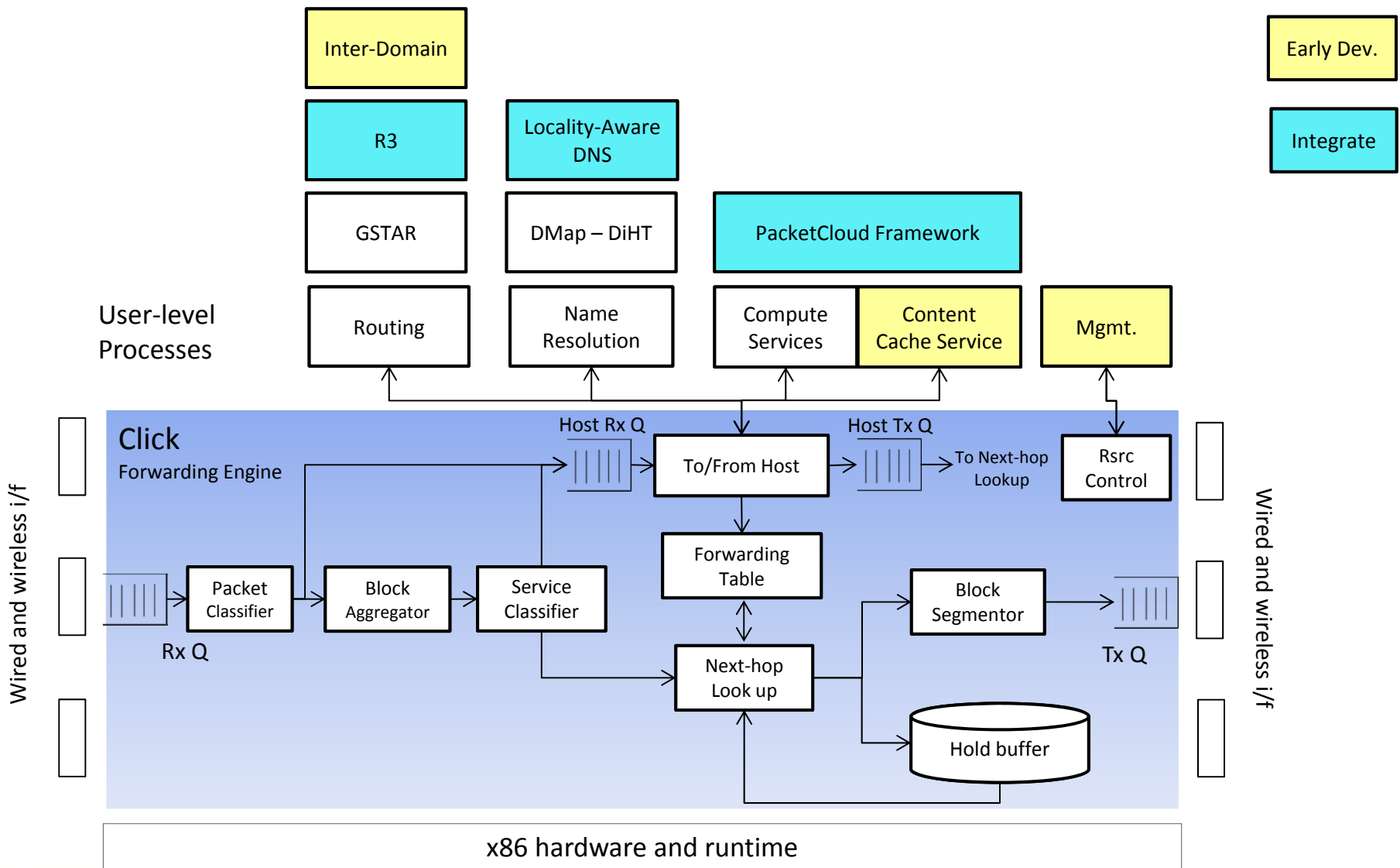
Experimental Package: MobilityFirst (cont.)

Android and Linux Prototype

'Socket' API:
open()
send()
get()
recv()
attach()
close()

Network Layer

User policies →

| App-1 | App-2 | App-3 |

Context API

Network API

Context Services

E2E Transport

GUID Services

Sensors

Security

Storage-Aware Routing

Interface Manager

'Hop' Link Transport

| WiFi | WiMAX | Ethernet |
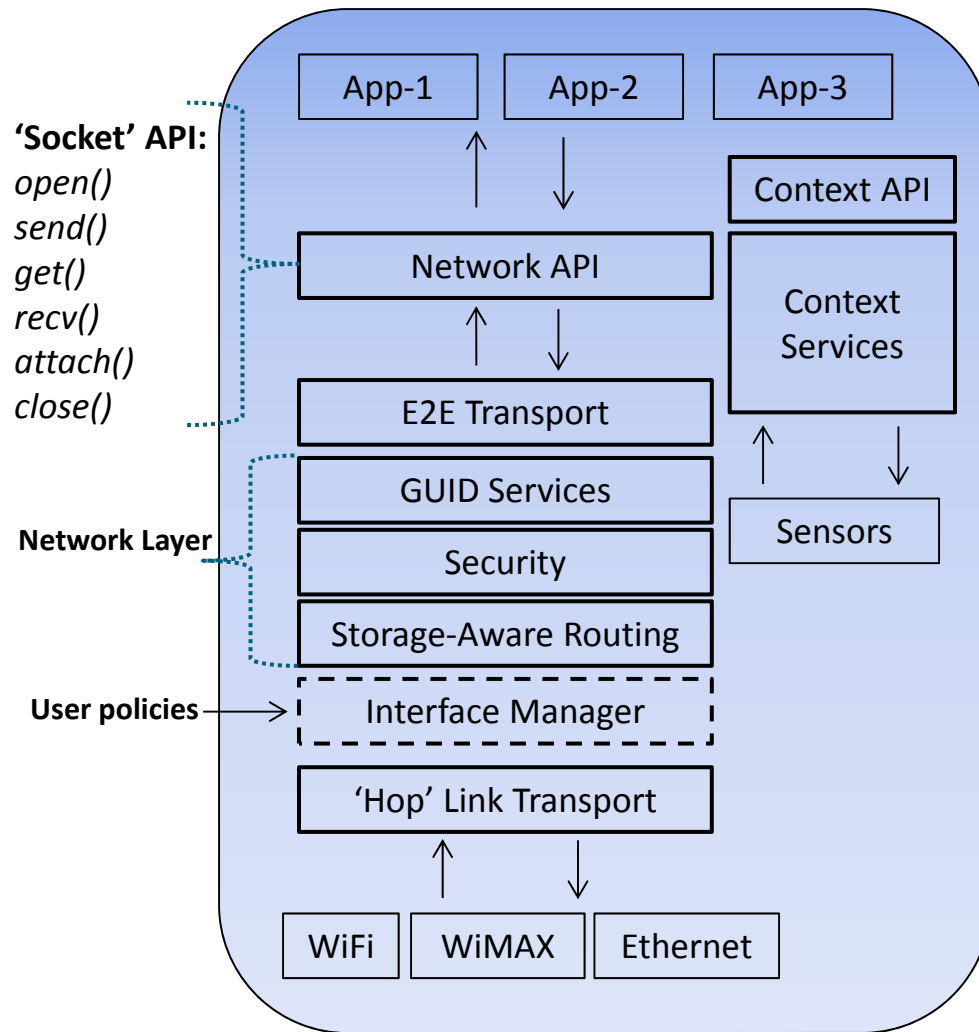
Linux PC/laptop with WiMAX & WiFi

Android device with WiMAX & WiFi

Device: HTC Evo 4G, Android v2.3
(rooted), NDK (C++)

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MobilityFirst GENI Deployment

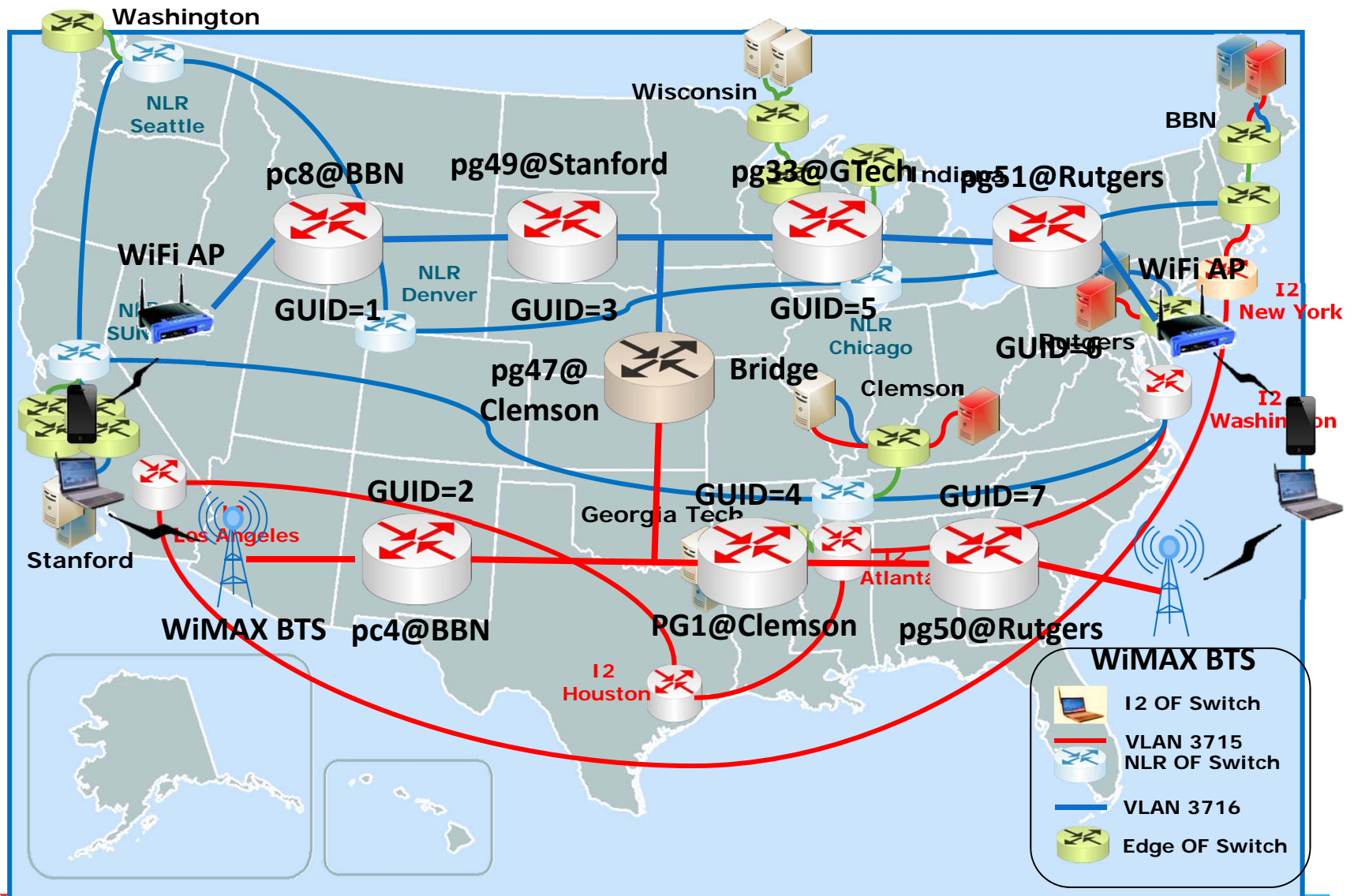# Need for Ontology

Port

Antenna Port   *Switch Port*   *IP Port*
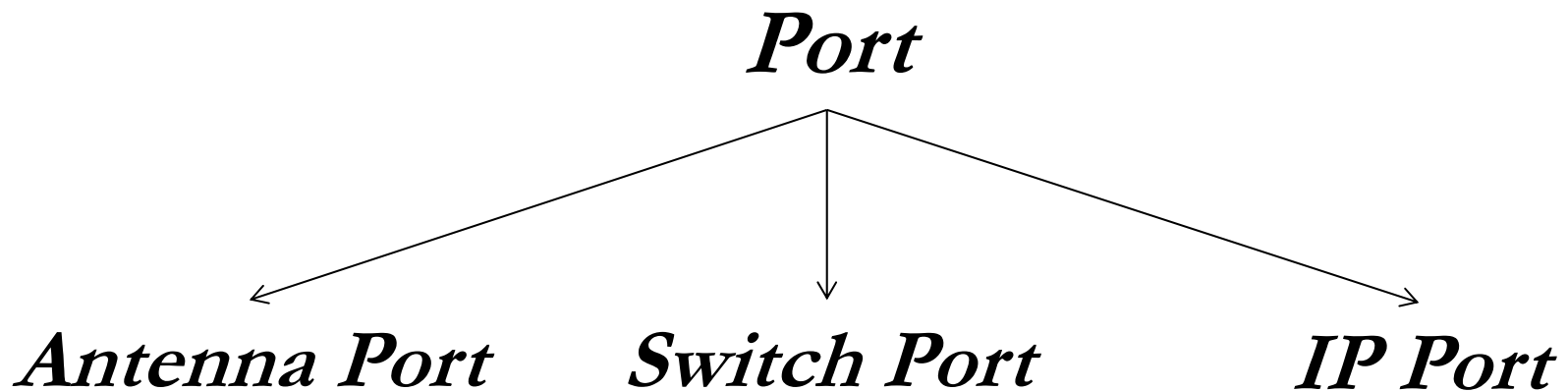
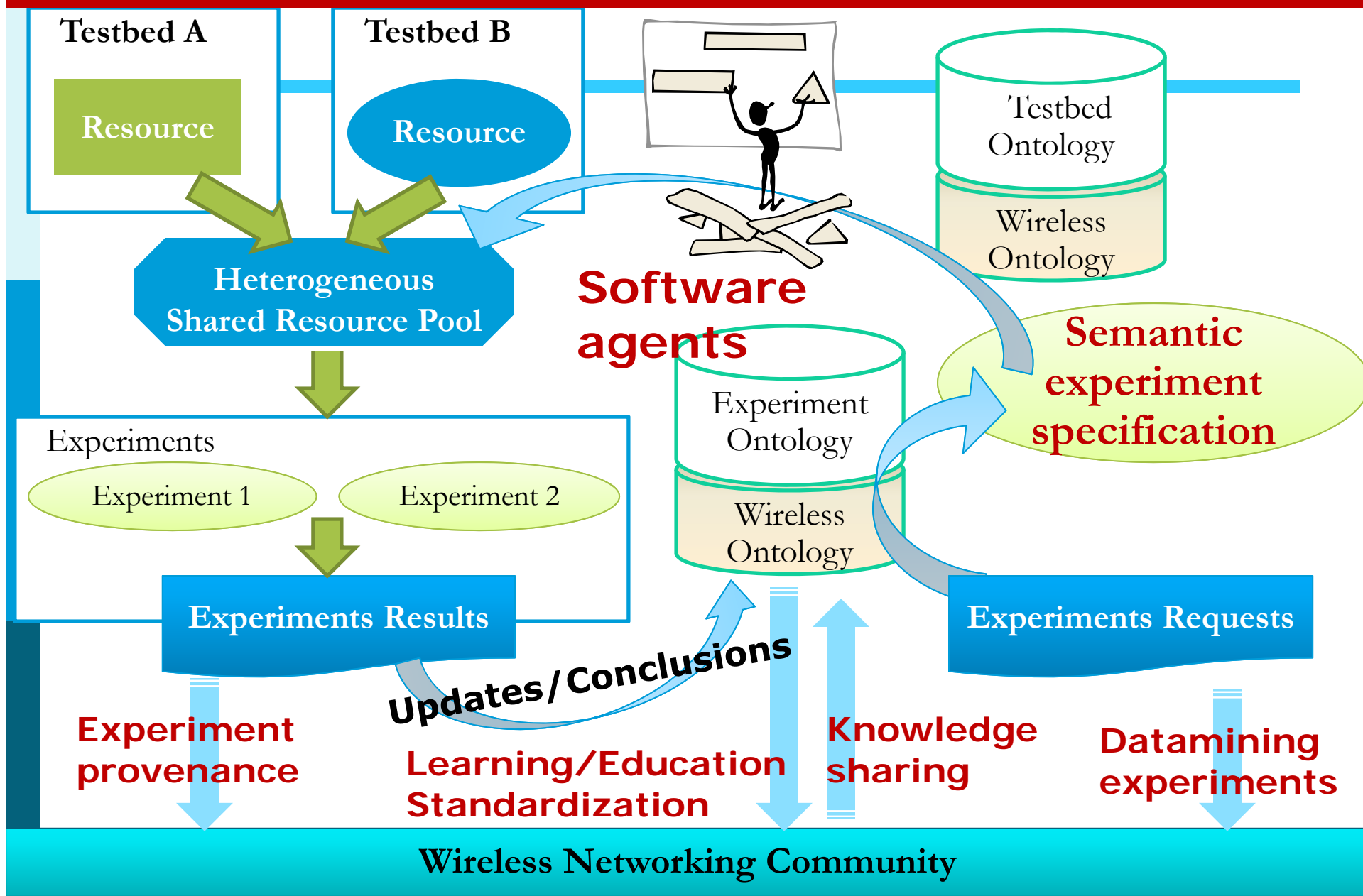String describing physical antenna port on a wireless device ("main"," aux", "primary", "secondary", "port 1", "port 2", etc.

Integer: describing physical port on a switch (1, 2, 3, 4, 5, ...)
or
String: SNMP set/get OID

"**port** is an application-specific or process-specific software construct serving as a communications endpoint in a computer's host operating system", 16-bit integer

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weTASOR: Community built ontology for wireless experimentation

Testbed A

Resource

Testbed B

Resource

Heterogeneous Shared Resource Pool

Software agents

Testbed Ontology

Wireless Ontology

Semantic experiment specification

Experiments

Experiment 1   Experiment 2

Experiment Ontology

Wireless Ontology

Experiments Results

Experiments Requests

Updates/Conclusions

Experiment provenance

Learning/Education Standardization

Knowledge sharing

Datamining experiments

Wireless Networking Community

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More Information

www.geni.net

www.orbit-lab.org

wimax.orbit-lab.org

witestlab.poly.edu

groups.geni.net/geni/wiki/WiMAXInteg

www.mytestbed.net

mobilityfirst.winlab.rutgers.edu

crkit.orbit-lab.org

www.planet-lab.net

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