Quail Ridge Wireless Mesh (QuRiNet) and Related Research

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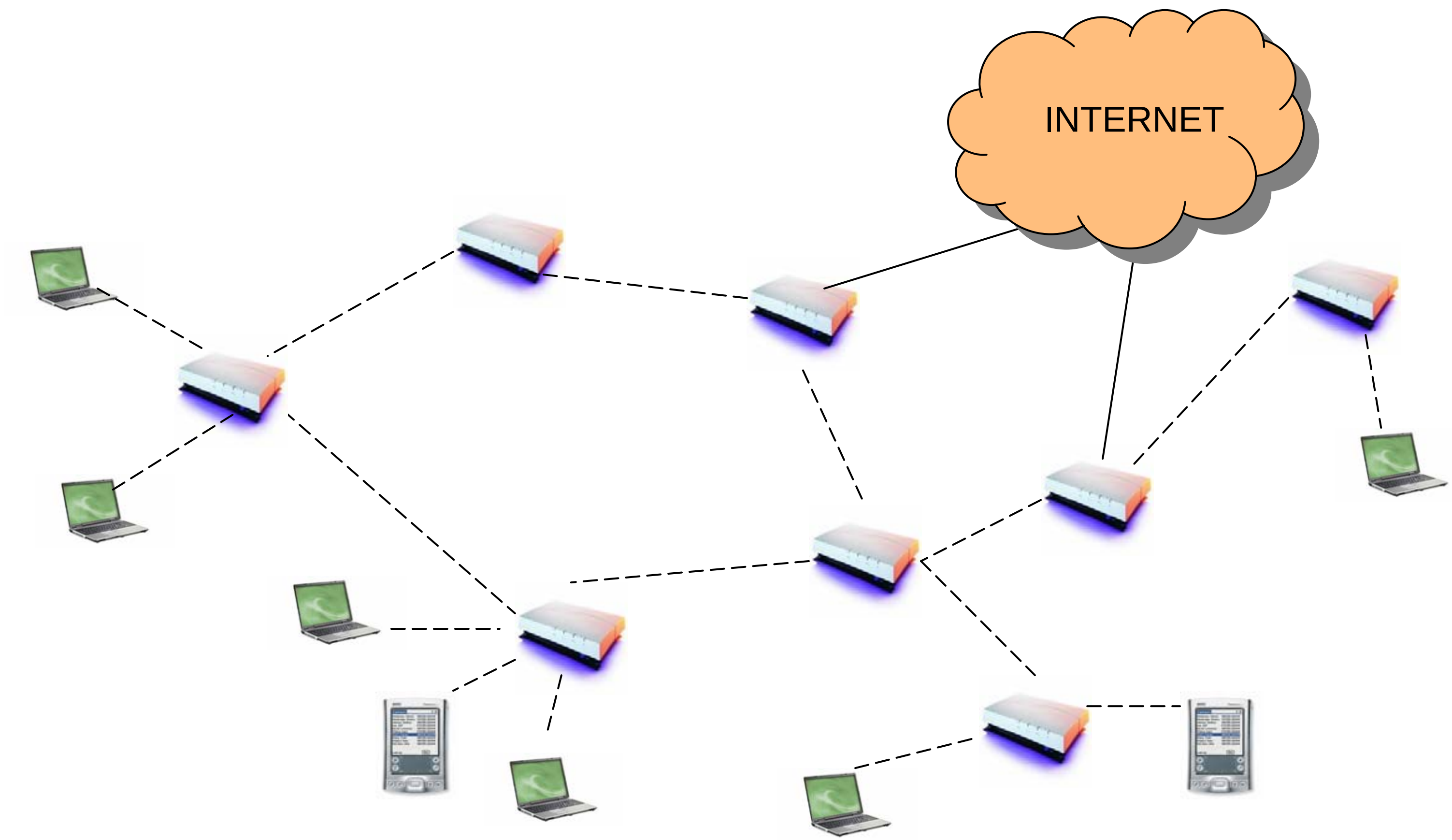
Wireless Mesh Networks (WMNs)

- WMNs consist of *wireless routers*, which provide the wireless backbone, and *access points for mobile clients*
- Nodes of WMNs are mostly static, although the clients may be mobile
- Communication is usually through multiple hops in the wireless medium
- WMNs are being increasingly deployed across enterprises, universities and even cities

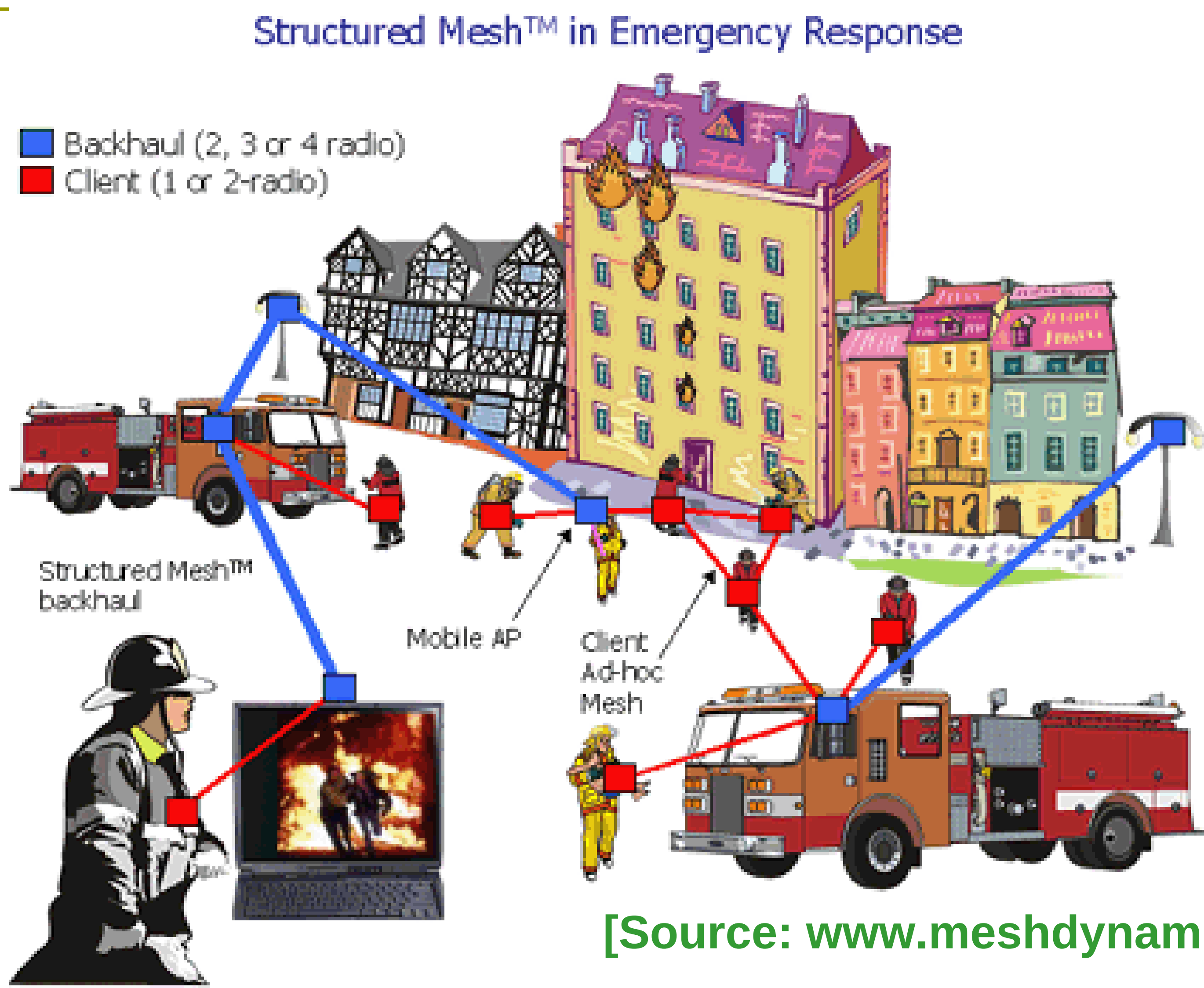
Wireless Mesh Architecture



Applications

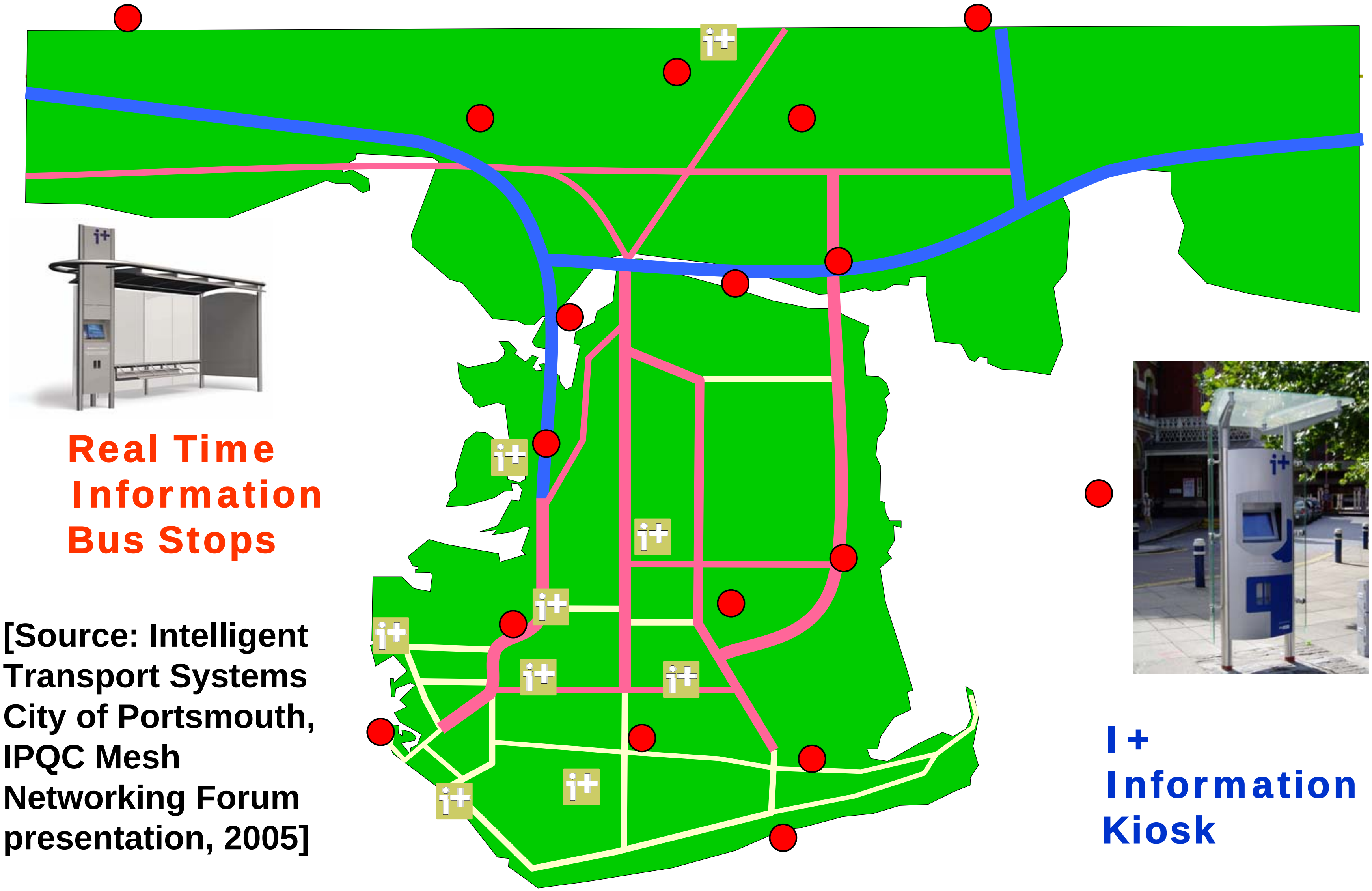
- Community Networks
- Enterprise Networks
- Home Networks
- Local Area Networks for Hotels, Malls, Parks, Trains, etc.
- Metropolitan Area Networks
- Ad hoc deployment of LAN
  - Public Safety, Rescue & Recovery Operation

Public Safety



[Source: www.meshdynamics.com]

Intelligent Transportation System



Real Time Information Bus Stops

I+ Information Kiosk

[Source: Intelligent Transport Systems City of Portsmouth, IPQC Mesh Networking Forum presentation, 2005]

Why Wireless Mesh?

- Low up-front costs
- Ease of incremental deployment
- Ease of maintenance
- Provide NLOS coverage
- Advantages of Wireless APs (over MANETs)
  - Wireless AP backbone provides connectivity and robustness which is not always achieved with selfish and roaming users in ad-hoc networks
  - Take load off of end-users
  - Stationary APs provide consistent coverage

In this presentation…

- Overview of QuRiNet: Quail Ridge Wireless Mesh Network
- Lessons Learnt
- Leveraging research efforts:
  - QoS Provisioning in WMNs
  - WiMO
  - Scalable Enterprise Networks
- Future Plans

Quail Ridge

- A natural reserve maintained by the University of California Natural Reserve System (NRS)
- 2,000 acres of wilderness adjacent to Lake Berryessa near Davis
- Hilly terrain with heavy forest growth
- Used by ecological researchers for studying flora and fauna on the region

Quail Ridge Reserve

Why a WMN in a natural reserve ?

- Quail Ridge is used by ecological researchers for wildlife and botanical research
- Various audio/video data to be collected, along with weather information and other statistics
- Hilly terrain, forest growth make repeated trips a tedious task for researchers
- Data collection in a non-intrusive manner is not feasible
- Lack of power supply and wired infrastructure in the region
- Weather ranges from very hot to very cold, making on-site research difficult

By deploying a WMN …

- We made remote data collection an easier task for the researchers
- Also provide a communication infrastructure for on-site research
- Established an excellent test bed for future research on WMNs
- The interference-free test-bed facilitate protocol design, diagnostics, and tuning
  - This benefit cannot be provided by urban mesh networks, where it will be difficult to isolate interferences from external sources

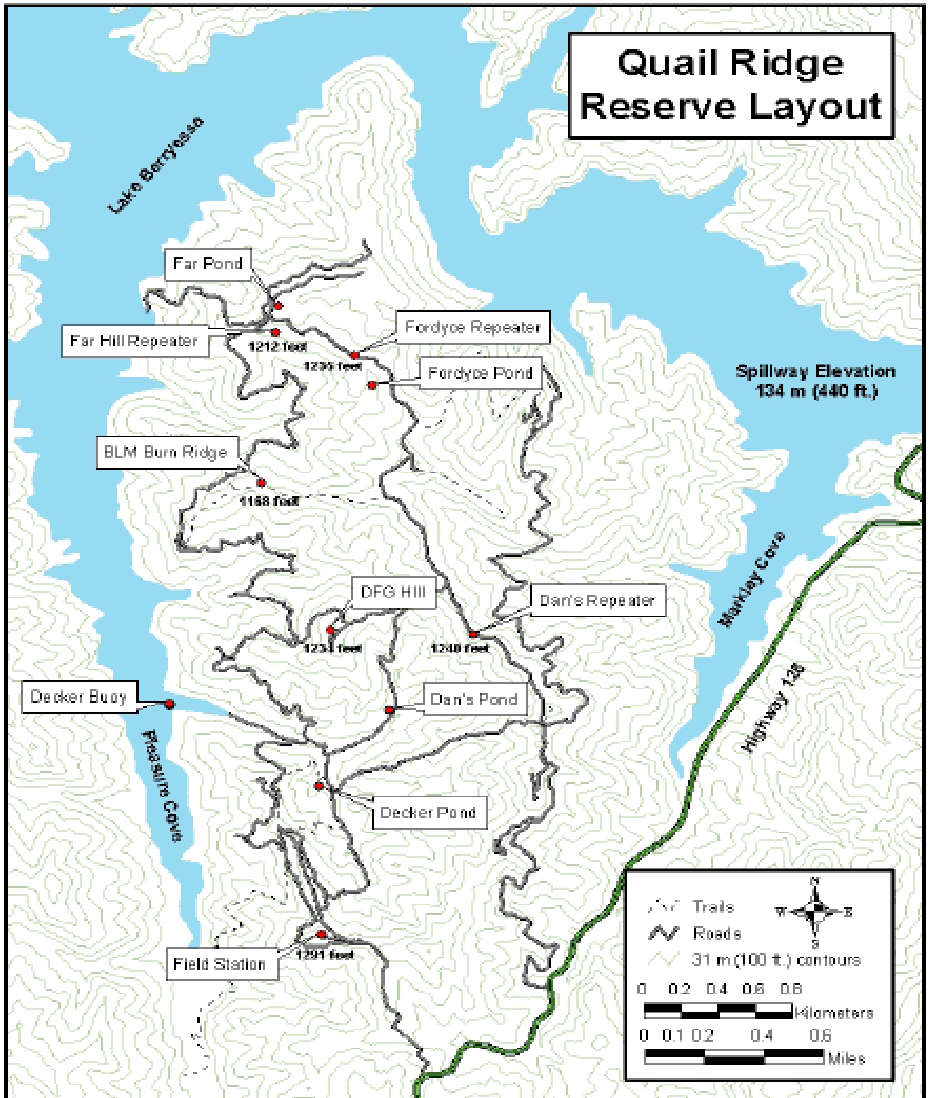
Unique Features of QuRiNet

- Deployed in a wild life reserve in face of various topological and technological challenges
- Currently operational and helping researchers and one graduate course in ecology.
- Area is free of any interference and other electronic noise
- Runs completely on solar-power due to lack of power supply in the region

Network Architecture

- Currently consists of 10 operational nodes, with 30 being the final objective
- Each node utilizes dual-radios and multiple orthogonal IEEE 802.11g channels
- Each node utilizes directional and omni-directional antennas for connecting to the wireless backbone and to provide local Wi-Fi access
- Three layers:
  - Backbone (directional antenna)
  - Midlayer (omnidirectional)
  - Sensor Network: functionality-specific networks at various locations

QuRiNet Site Layout



Nuts & bolts of QuRiNet

- Soekris net4826 boards serve as access points
- 266 MHz 586 processor with 128 MB SDRAM main memory and 64 MB flash memory
- Support dual mini-PCI Type III sockets
- Ubiquiti Networks SuperRange2 802.11 b/g 400mW Atheros cards are used as wireless radios for the network
- High power cards were chosen keeping in mind the large distances and hilly terrain

Nuts & bolts of QuRiNet (contd.)

- Using a custom built Linux distribution with madwifi-ng driver for wireless cards (provides higher level of programmability)
- Directional and omni-directional antennas attached to each node
- Solar-power equipment deployed at each site for power supply

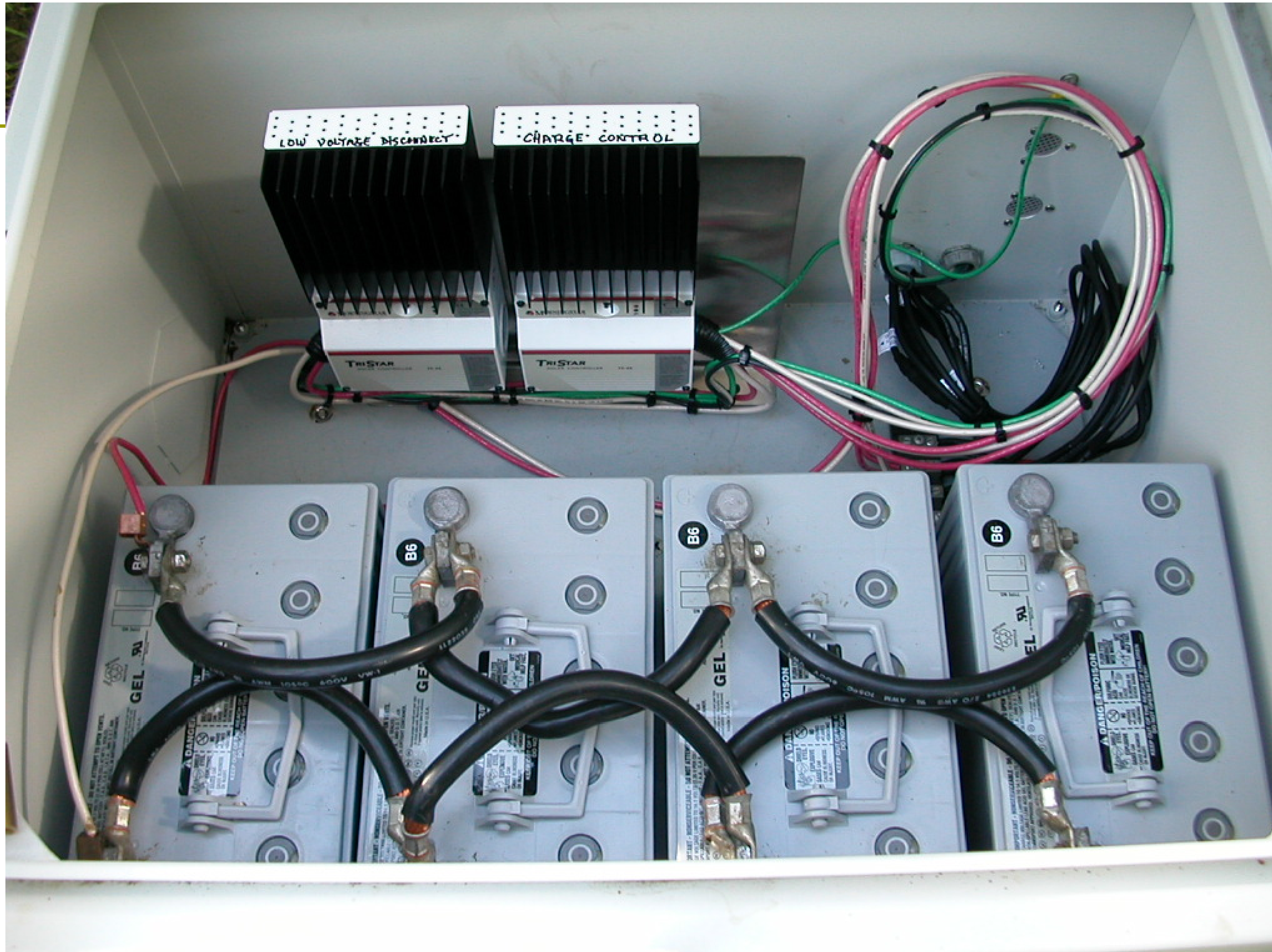
Performance Data from QuRiNet

	Destination				
Source	fldstn	dfghill1	dfghill2	danrptr	farhill
fldstn	-	14.41	14.48	5.35	15.26
dfghill1	17.21	-	23.30	14.07	17.50
dfghill2	20.14	23.18	-	14.39	17.61
danrptr	1.53	7.34	7.12	-	-
farhill	15.13	14.84	15.53	-	-

End-to-end Throughput matrix (Mbps)

	Destination				
Source	fldstn	dfghill1	dfghill2	danrptr	farhill
fldstn	-	93.74	86.62	227.04	82.70
dfghill1	89.53	-	32.90	224.86	74.07
dfghill2	89.79	30.34	-	245.94	91.64
danrptr	955.42	193.94	147.63	-	-
farhill	84.51	80.54	109.13	-	-

End-to-end Average RTT matrix (ms)


LOW VOLTAGE DISCONNECT
CHARGE CONTROL
TRISTAR
TRISTAR

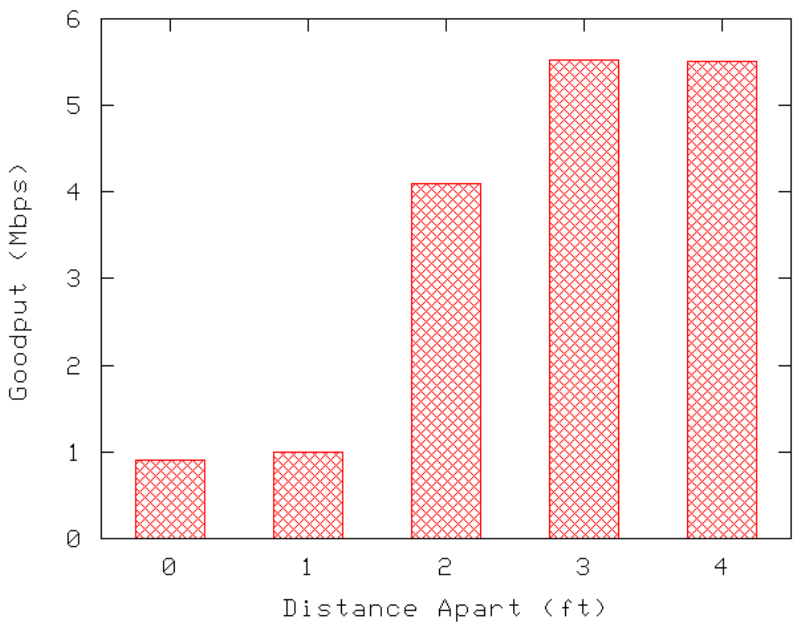

Lessons Learnt

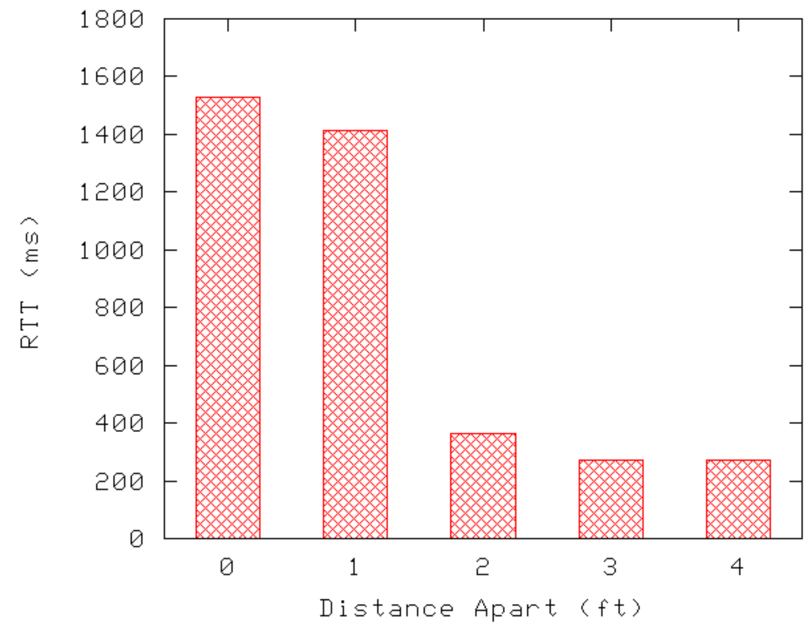
- Deployment constraints
  - Location, line of sight, events
  - Bureaucratic hassles
- Interferences among orthogonal channels because of antenna placement
- Device driver issues
- Transmission power issues
- Maintenance issues
- Robustness and reliability
- Measurements, Monitoring, and Management
- Remote access and network data collection

Analyzing Interference among Orthogonal Channels

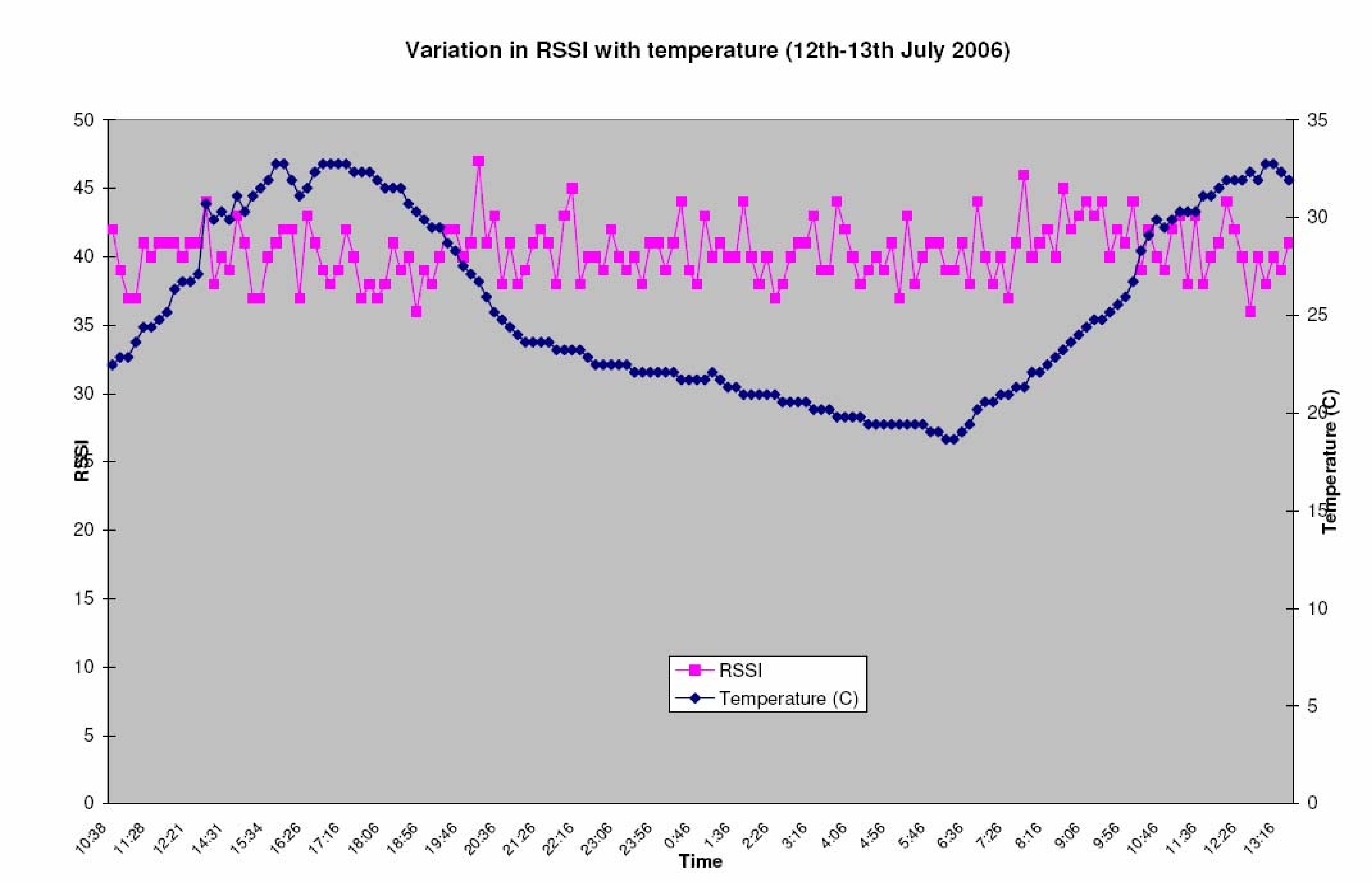
- 4 Access Points in a linear topology
- Multi-radio, Multi-Channel, Multi-Hop Tests
- 5 dBi gain antennas elevated 4 ft and separated 4 ft
- 100 ft between APs

Impact of Antenna Proximity

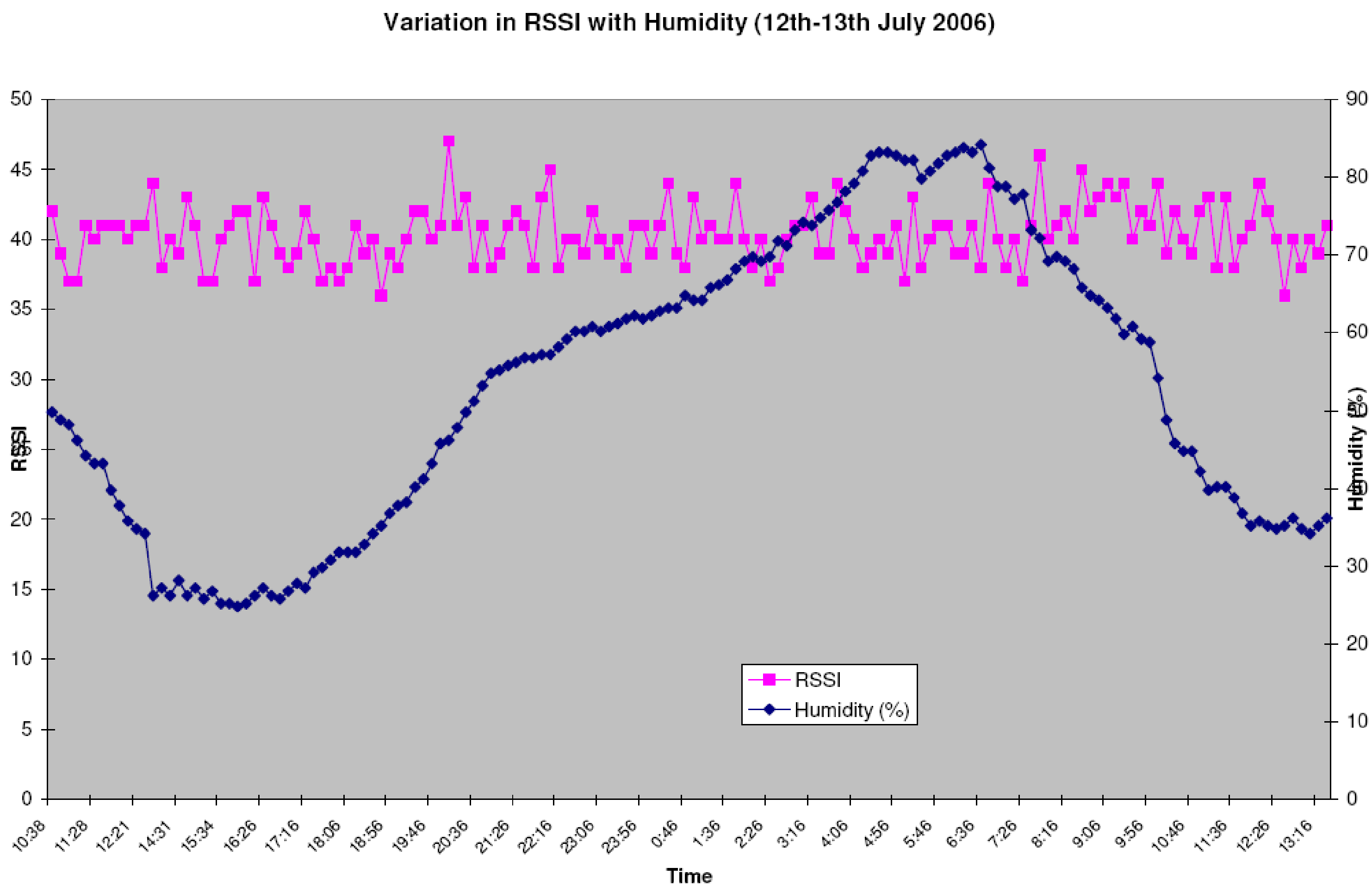




Performance Data from QuRiNet -1



Performance Data from QuRiNet- 2



Research leveraging QuRiNet Testbed

- Capacity Enhancement
  - Multi-radio and multi-channel configurations
- QoS provisioning in WMNs
  - Adaptible Per-Hop Differentiation (APHD)
  - TDMA-based channel and link scheduling
- WiMO: Wireless management Overlay

Capacity Enhancement

- Protocol enhancement would provide marginal improvements – shouldn't ignore them though
- Capacity limitation – fundamental
  - Spatial interference
  - Spectrum availability
- Spatial interference: could be handled through effective use of space
  - Directional antenna
  - MIMO
- Spectrum availability: enhance channel utilizations
  - Multiple channels
  - Multiple radios

MAC for Multichannel Multihop Multiradio Wireless networks

- Static Channel Allocation
  - Need multiple interfaces per node
  - Non-overlapped channel allocation
  - Static scheduling of packets or flows
  - No channel switching
- Dynamic Channel Allocation
  - Single radio (or two radios, the second one forming a control framework)
  - Multiple radio with multi-channel scheduling
  - Fast channel switching

Current progress

- Model development:
  - Create MCG (multi-channel conflict graph)
  - Channel allocation
  - Link allocation in time slots
- Formulize the problem into a linear programming problem
- Develop both dynamic and static algorithms
- Evaluate and compare the performance for both algorithms
- Evaluate the effect of topologies, varying number of radios and channels

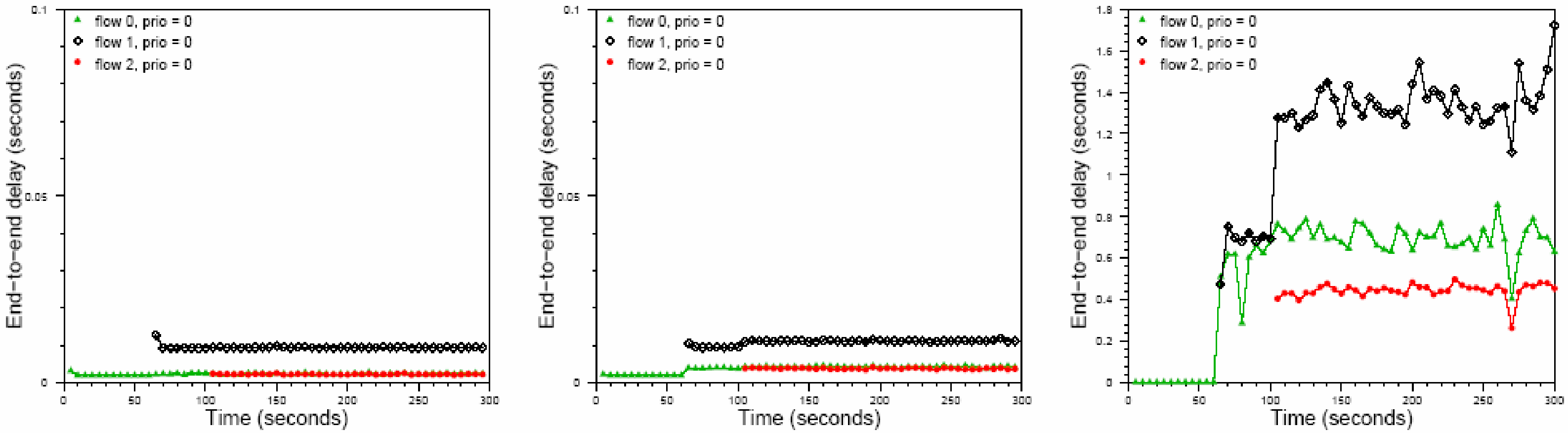
QoS Support in Wireless Mesh

- For random access MAC
  - Admission control
  - Scheduling flows
    - Hop-delay budget
- For scheduled MAC
  - Link activation schedule
  - Flow-schedule

APHD (Adaptive Per Hop Differentiation)

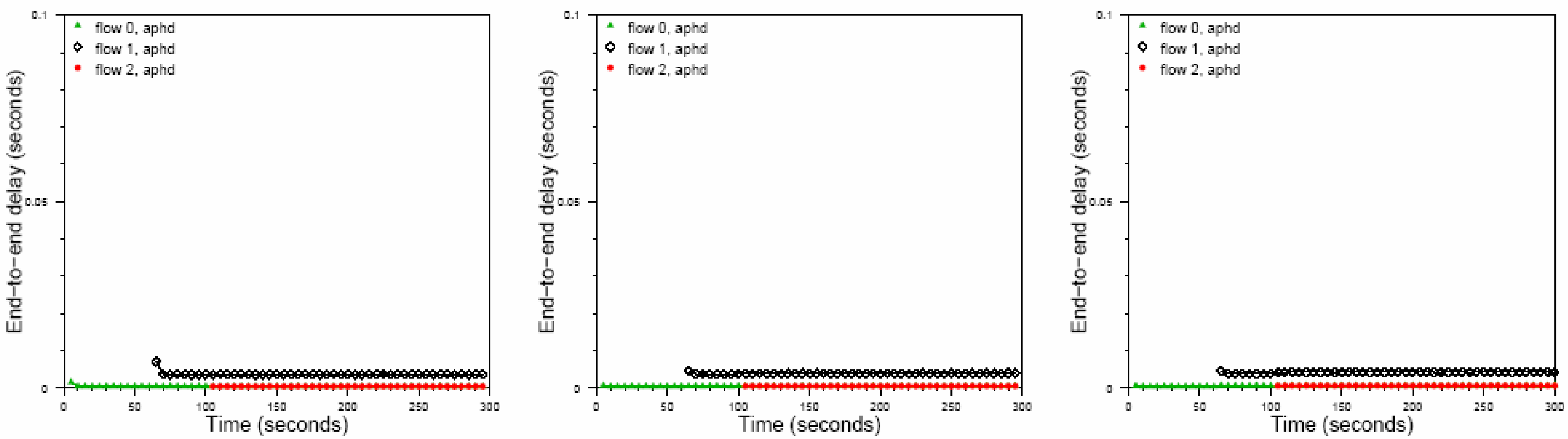
- APHD extends IEEE 802.11e EDCA QoS capability into multihop networking environments
- APHD provides excellent end-to-end delay assurance, while achieving much better network utilization, compared pure EDCA scheme
- Extending IEEE 802.11e for multihop networks
  - APHD focuses on per hop priority adaptation to achieve end-to-end requirement
- Inter-layer design approach
  - Information is shared among multiple layers
  - Actions take place at multiple layers to do one task
- Localized and distributed
  - Decision making is on per packet and per node basis
- Efficient network utilization
  - Only raise packet's priority level when needed

Sample Results I: delays



(a) source rate: 10 vs 10 vs 10 pkts/sec (b) source rate: 50 vs 50 vs 50 pkts/sec (c) source rate: 100 vs 100 vs 100 pkts/sec

Fig. 4. EDCA: end-to-end delay (different route length)



(a) source rate: 10 vs 10 vs 10 pkts/sec (b) source rate: 50 vs 50 vs 50 pkts/sec (c) source rate: 100 vs 100 vs 100 pkts/sec

Fig. 6. APHD: end-to-end delay (different route length)

Sample Results II: throughputs

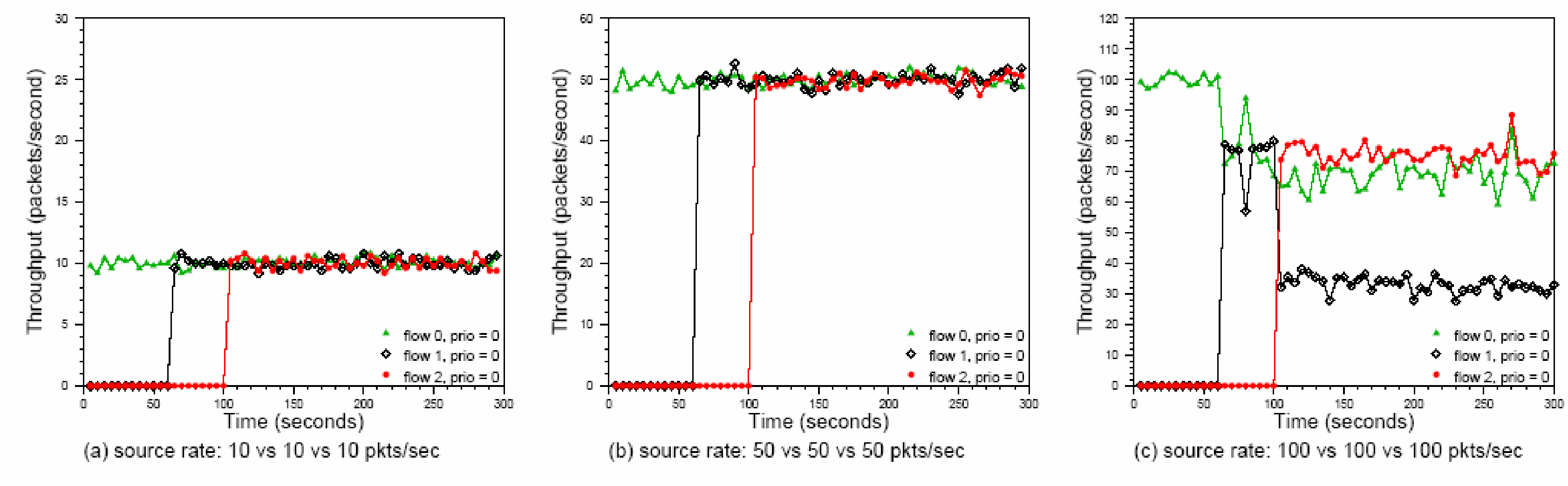


Fig. 5. EDCA: end-to-end throughput (different route length)

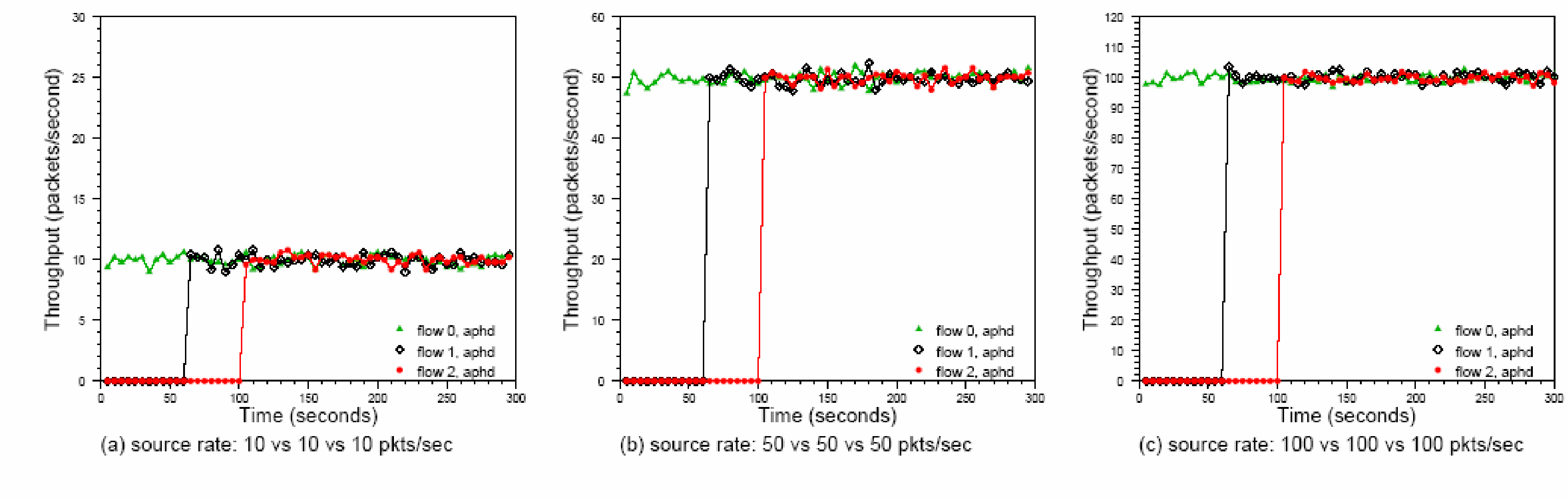


Fig. 7. APHD: end-to-end throughput (different route length)

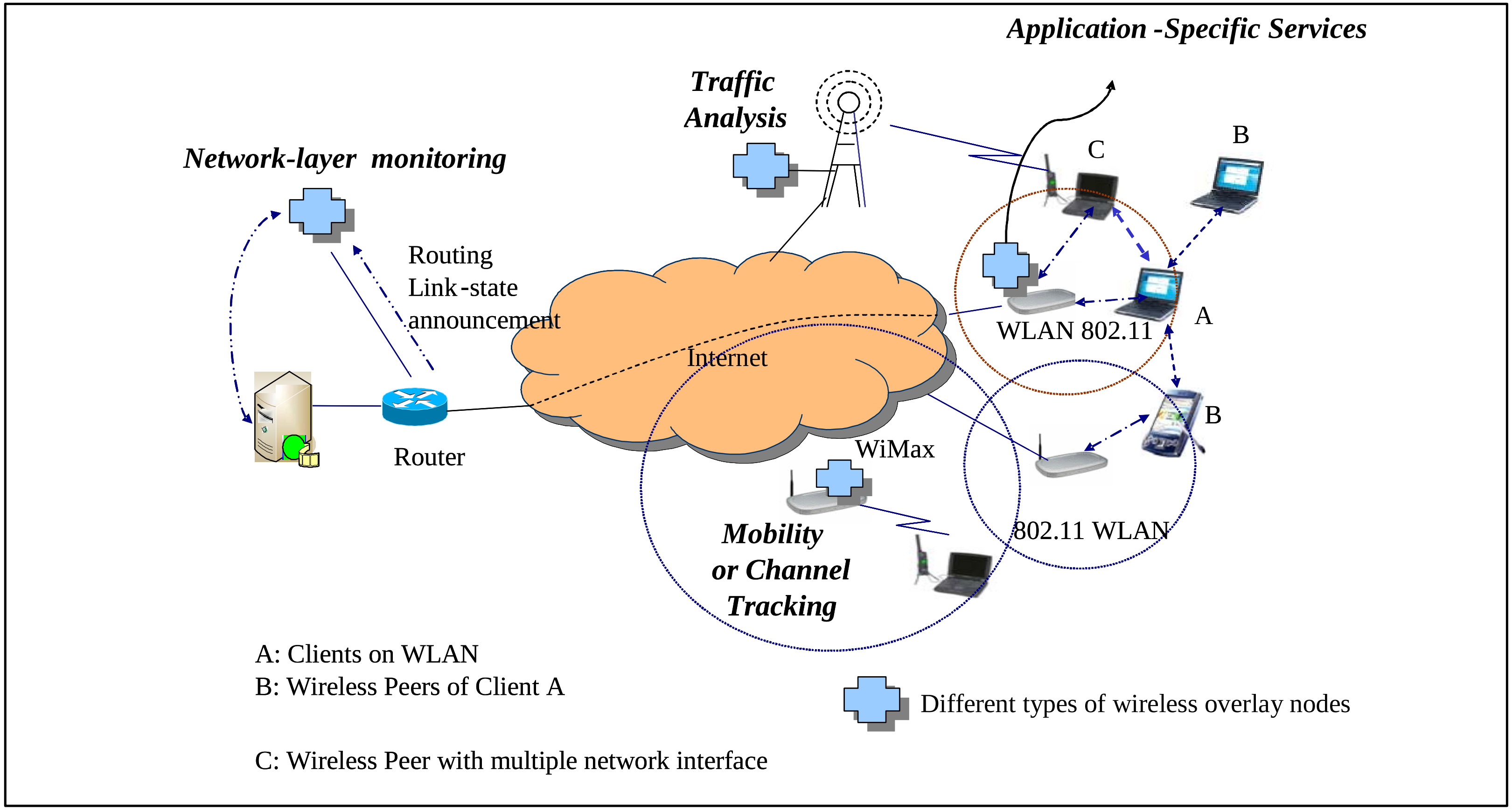
TDMA-based Scheme for QoS Provisioning in Wireless Mesh

- Integrated scheme for admission control, routing, and flow scheduling
- Flow-based scheduling does not cause unfairness problem as observed in hop based scheduling
- We adopt centralized scheduling approach
- The Admission Controller and Scheduler (ACS) is maintained at a gateway node or a switch/server
- Admission control makes incoming flows interference-free with existing flows, reducing contention and improving utilization.

Overlays on Mesh

- Heterogeneous wireless networks will prevail in the future
  - Multi-hop wireless mesh networks with Wifi/WiMax access points
  - Long-haul links via WiMax and wireless cellular network
- Problem
  - Design and develop an open wireless architecture that is scalable, reliable, efficient, secure, flexible, and easy to manage
- Challenges
  - Heterogeneity of radio interface/wireless protocols => interoperability issues, complexity in management
  - Node mobility
  - Wireless broadcast media is prone to interference
- Proposed Solution: Wireless Management Overlay
  - A common overlay control layer for managing network resources

Multi-Tier Wireless Management Networks



Access points and (may be) a subset of clients (semi-static, resource-rich nodes, e.g., laptops) can be overlay nodes that coordinate resource allocation and routing at the application layer

Future Plans

- Expand the mesh size
- Include heterogeneity – WiFi, WiMAX, Bluetooth
- Development of tools for wireless mesh design, maintenance, and monitoring, and management
- Study Multi-*(channel, radio, path, flow, layer, rate, antenna, IO) protocols – MAC and routing, and cross-layer designs
- Facilitate remote study access