GENI Wireless Overview
GPO-WWG Meeting
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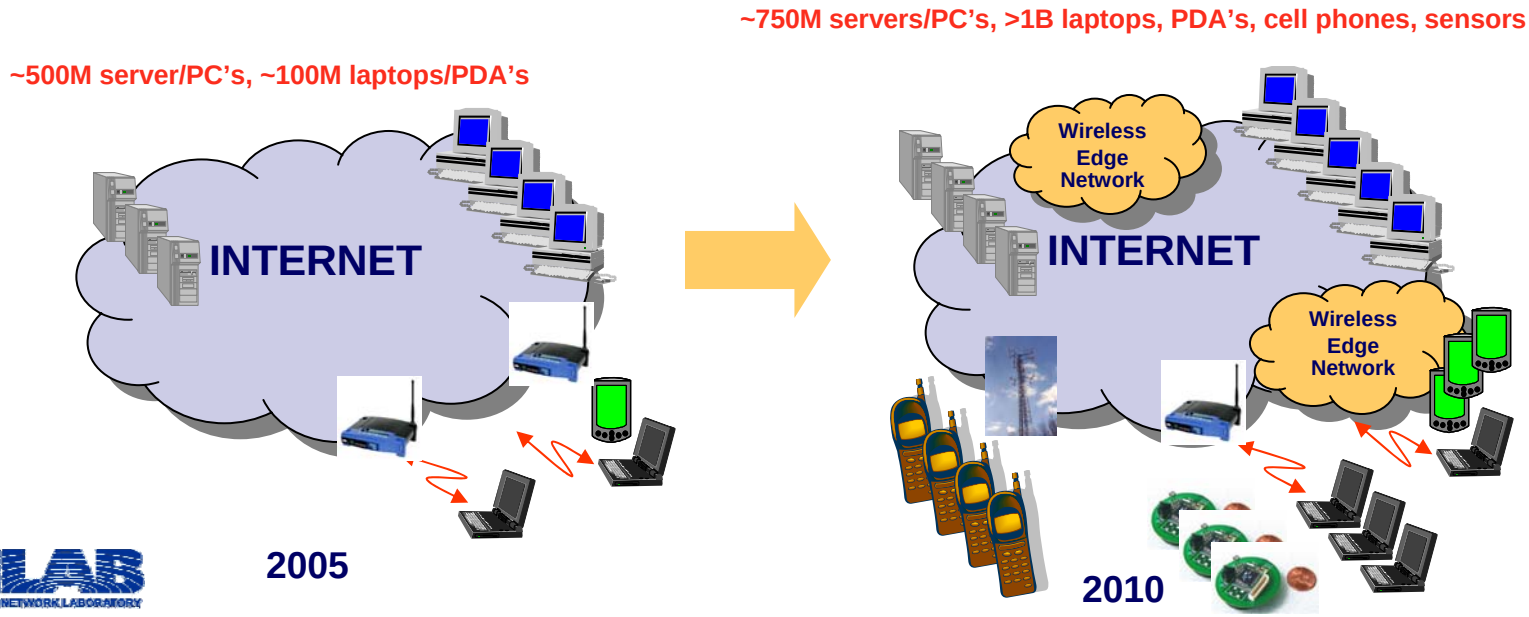
Wireless Research Scope and Agenda

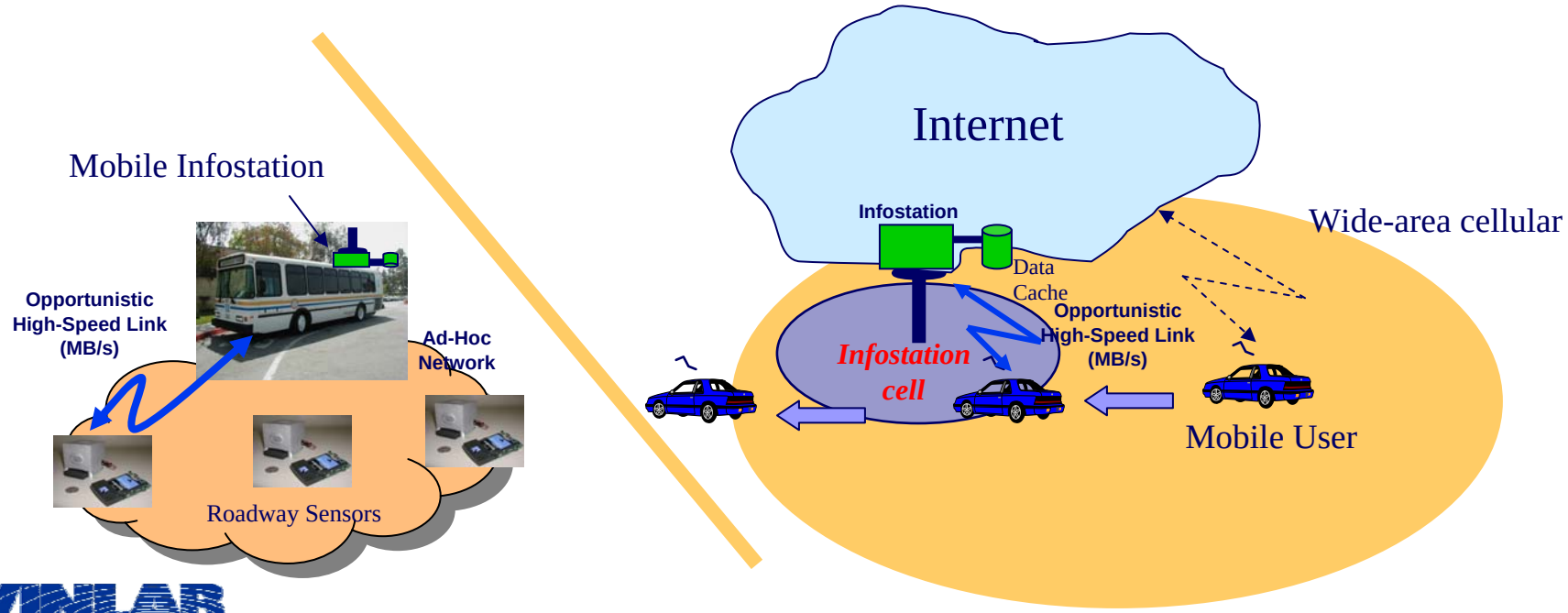
Introduction: Wireless as *the* key driver for the future Internet

- Historic shift from PC's to mobile computing and embedded devices…
  - >2B cell phones vs. 500M Internet-connected PC's in 2005
  - >400M cell phones with Internet capability, rising rapidly
  - New types of data devices (blackberry, PDA, iPoD) – distinctions becoming blurry
  - Sensor deployment just starting, but some estimates ~5-10B units by 2015



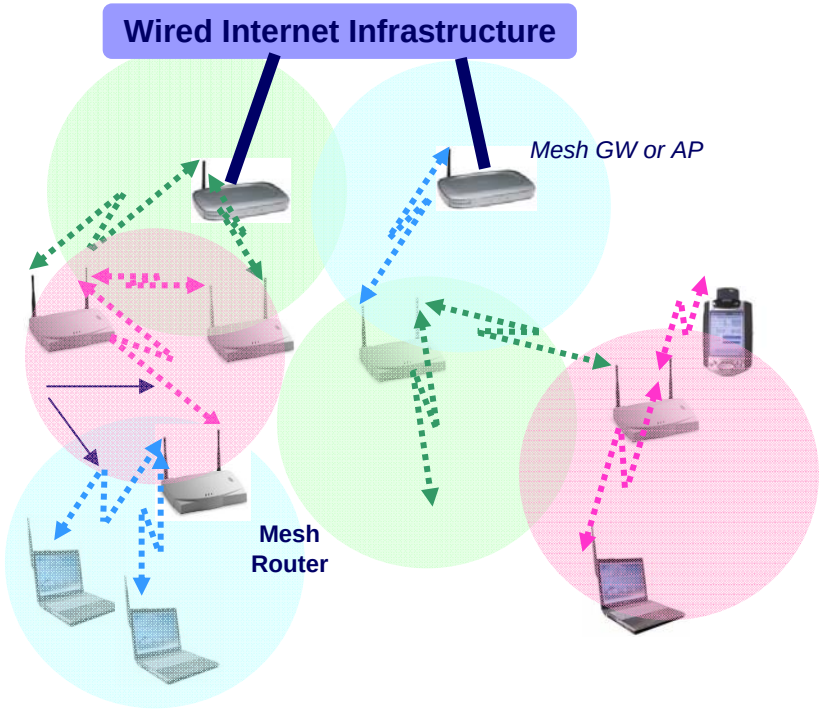
Wireless Scenarios: Mobile P2P

- P2P, DTN, Infostations etc. represent another emerging category of mobile applications on the Internet
  - Router mobility
  - Network may be disconnected at times …delayed delivery
  - Caching and opportunistic data delivery …. In-network storage
  - Content- and location- aware protocols



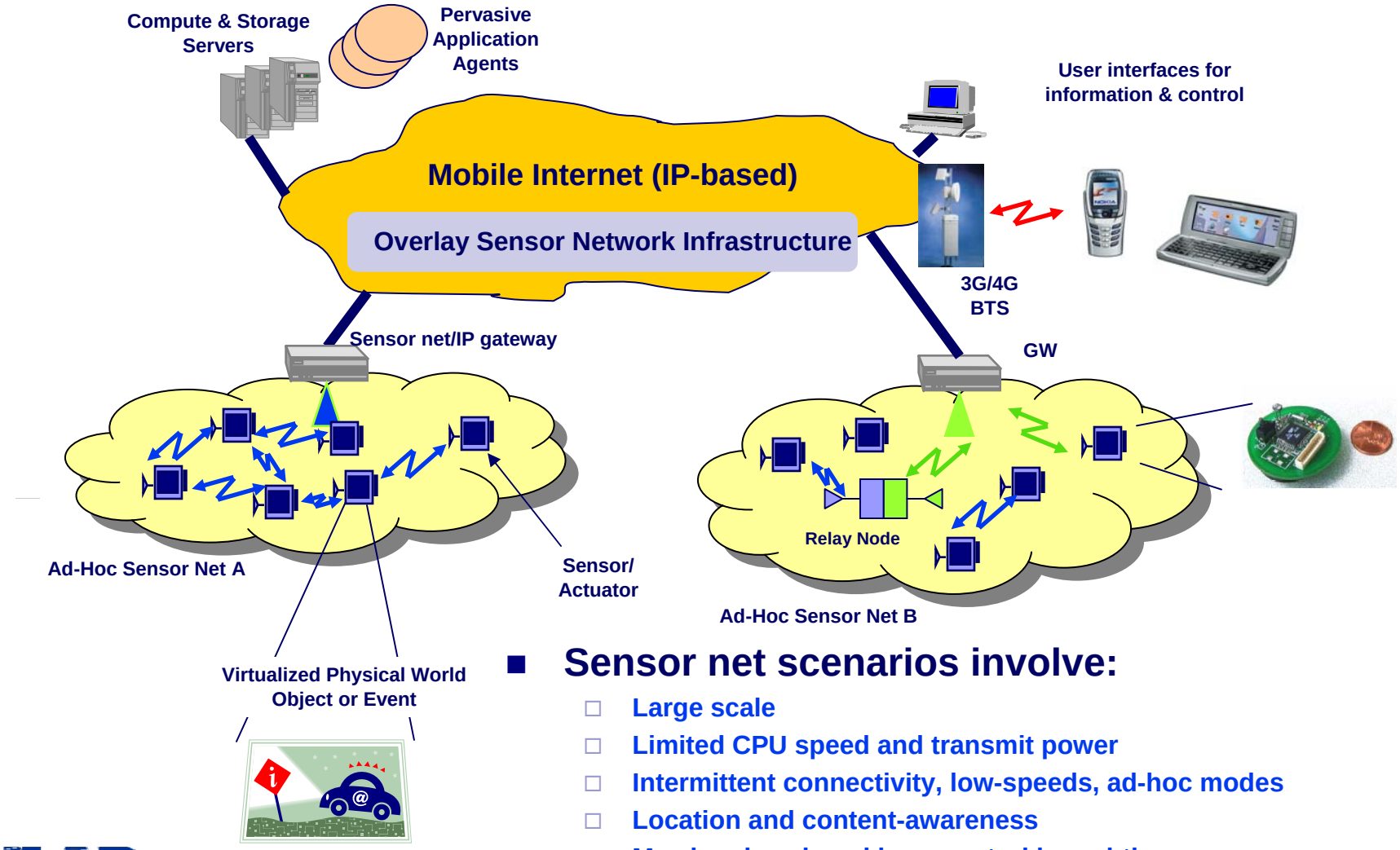
Wireless Scenarios: Ad-Hoc & Mesh Nets

- Multi-hop radio (ad hoc, mesh, vehicular, sensor) becoming increasingly important …
  - Leverages Moore's law cost/performance of commodity radios such as 802.11
  - Involves new routing & discovery protocols
  - Interactions between lower layers (PHY, MAC) and routing in dense deployments
  - Problems with TCP end-to-end model due to changing BW and channel quality



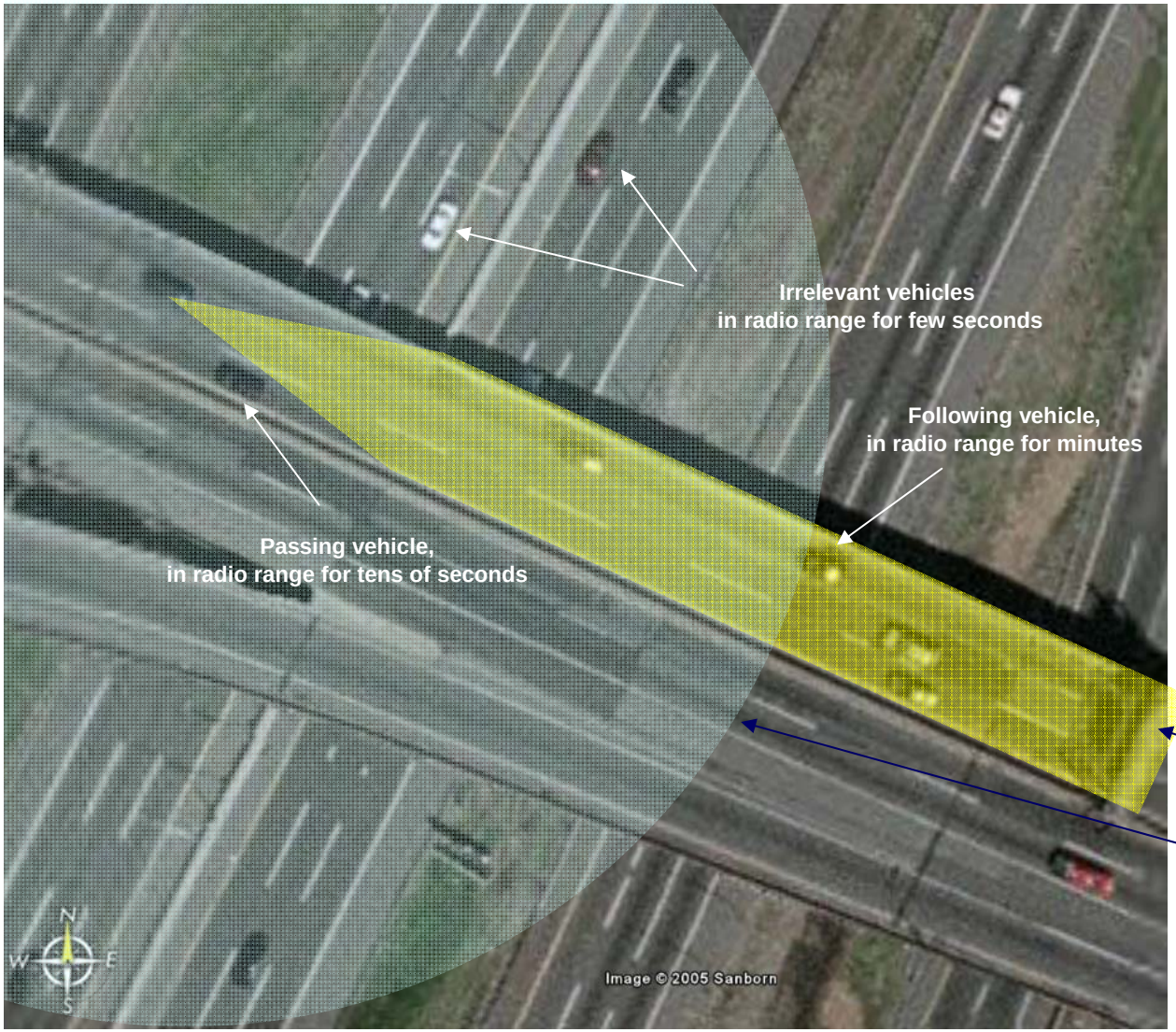
Hierarchical Mesh Network

Wireless Scenarios: Sensor Nets and Pervasive Systems



- **Sensor net scenarios involve:**
  - Large scale
  - Limited CPU speed and transmit power
  - Intermittent connectivity, low-speeds, ad-hoc modes
  - Location and content-awareness
  - May involve closed loop control in real-time

Wireless Scenarios: Vehicular Networks



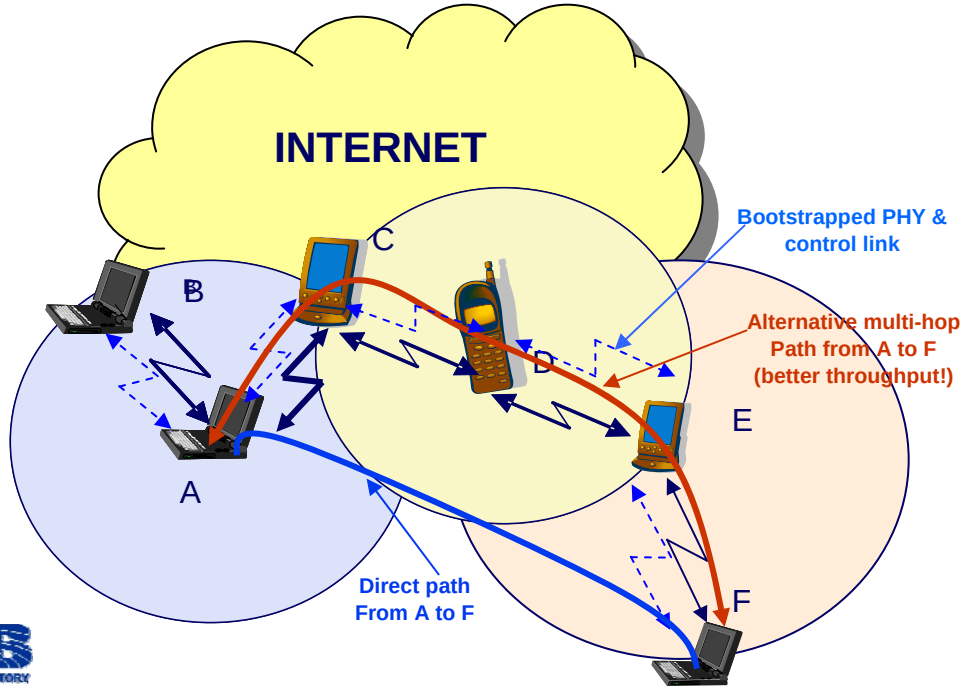
- Emerging vehicle safety, information and entertainment applications
- Networking requirements tend to be location-aware
  - e.g. geocast scenario shown
- Network mobility
- Potentially high density
- Ad hoc network formation and disconnections
- V2V and V2I modes

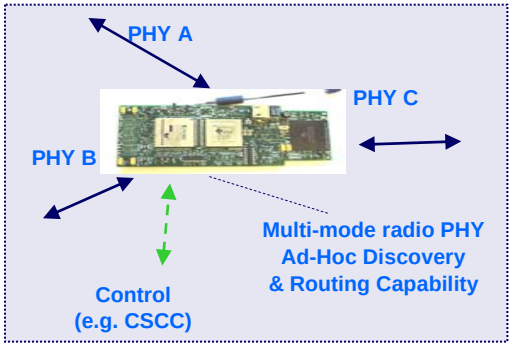
Desired message delivery zone

(Idealized) Broadcast range

Wireless Scenarios: Cognitive Radio

- Emerging cognitive radio technology makes it possible to adapt PHY and MAC in response to observed conditions
  - Spectrum sensing and dynamic coordination between devices
  - Possible to form “adaptive wireless networks” with multiple PHY/MAC in the same network – incentives for collaboration between radios?
  - New network control, bootstrapping and cross-layer routing issues





Adaptive Wireless Network Node

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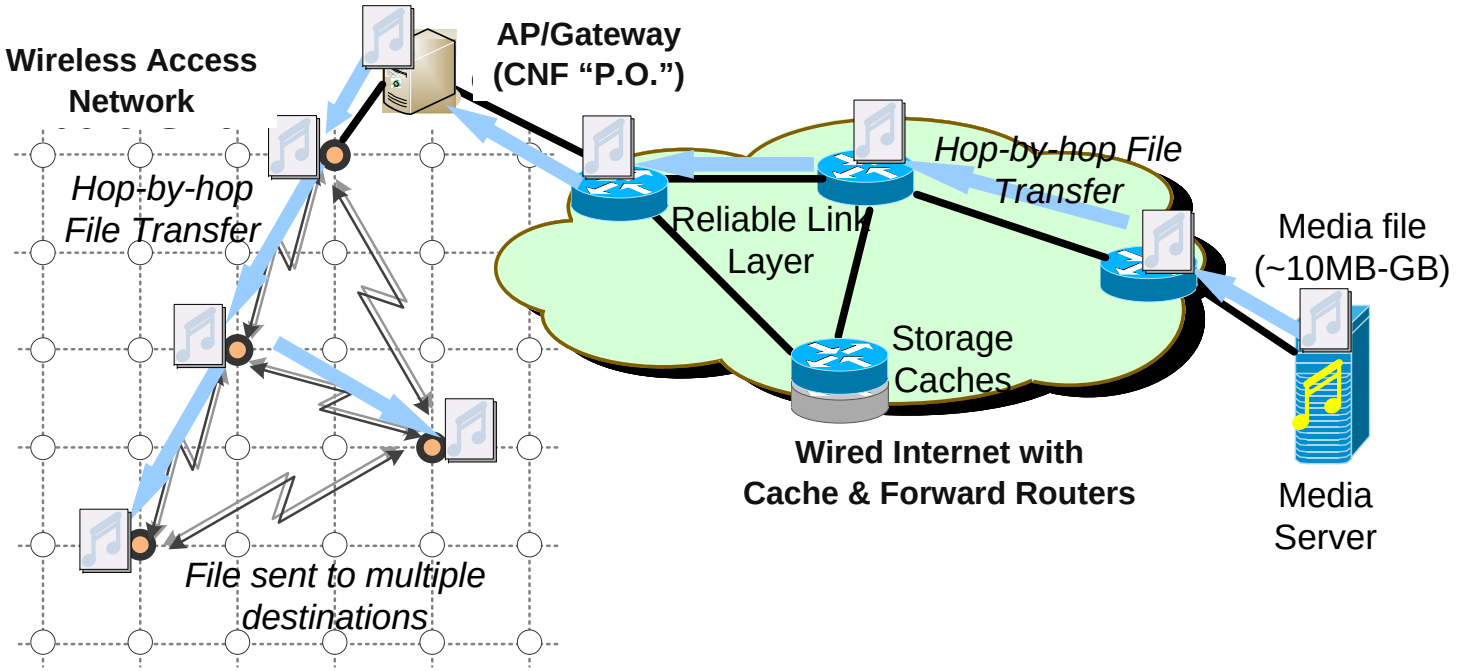
Sample Future Internet Research Projects

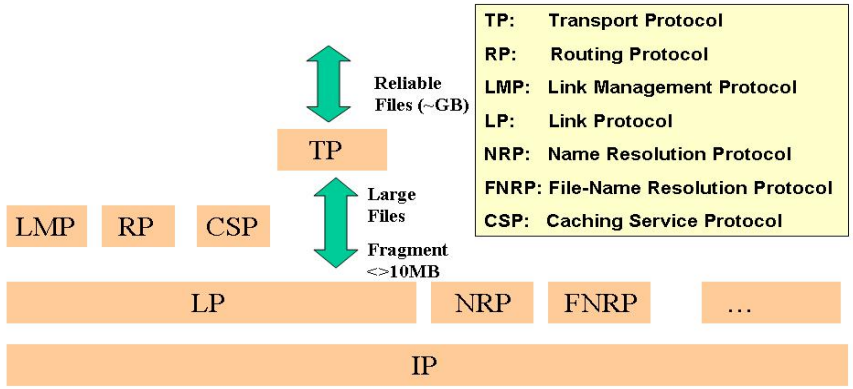
Future Internet Projects: Cache & Forward Architecture

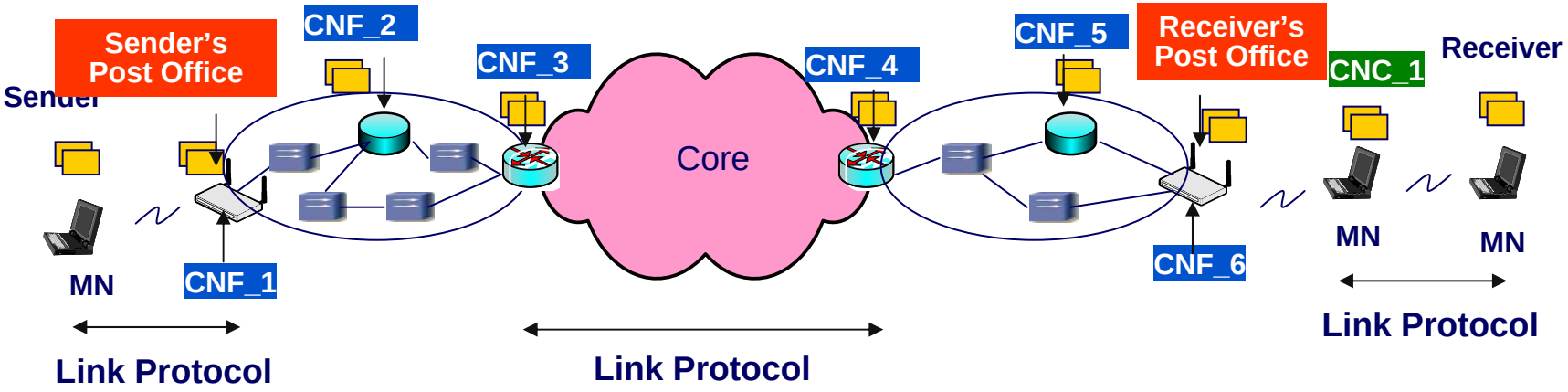
- New NSF FIND “postcards from the edge” project involving Rutgers & UMass
- Architecture designed to support efficient delivery of content to mobile users
- Concept based on hop-by-hop transport, storage and caching in the network



Future Internet Projects: CNF Architecture & Protocol

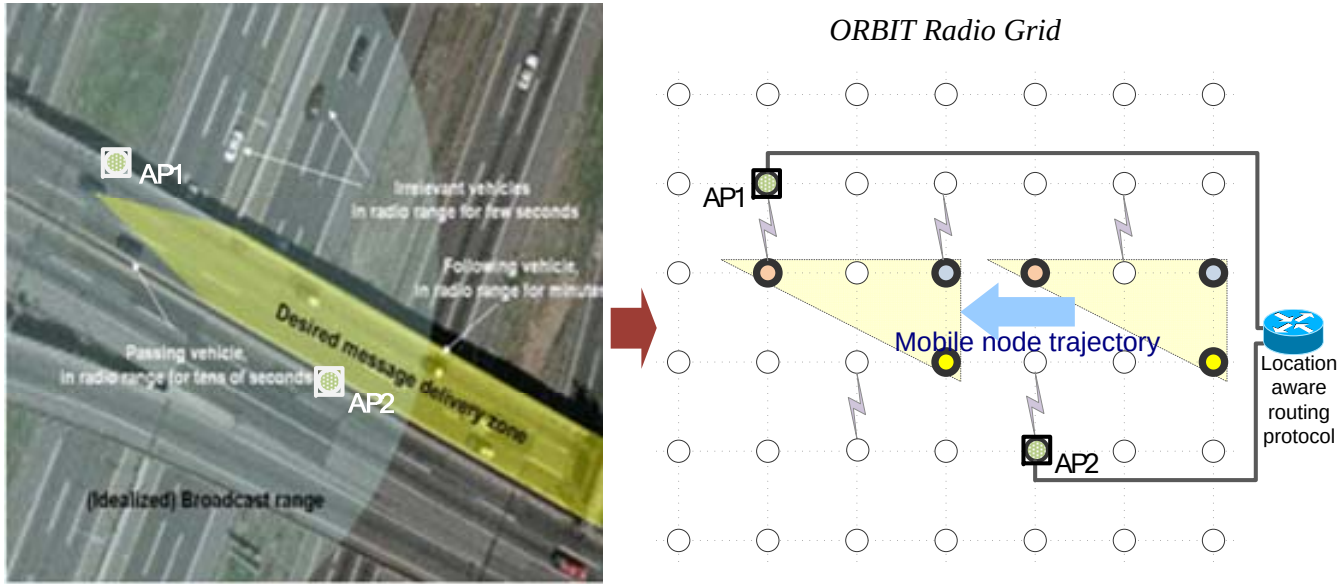
- Routing protocol with integrated support of address- and content-based modes of delivery (get “filename”, deliver ”filename” to “address”, etc.)
- Support for in-network caching of content
- Multi-hop wireless access with disconnections and mobility at access edge (..”postbox” concept)





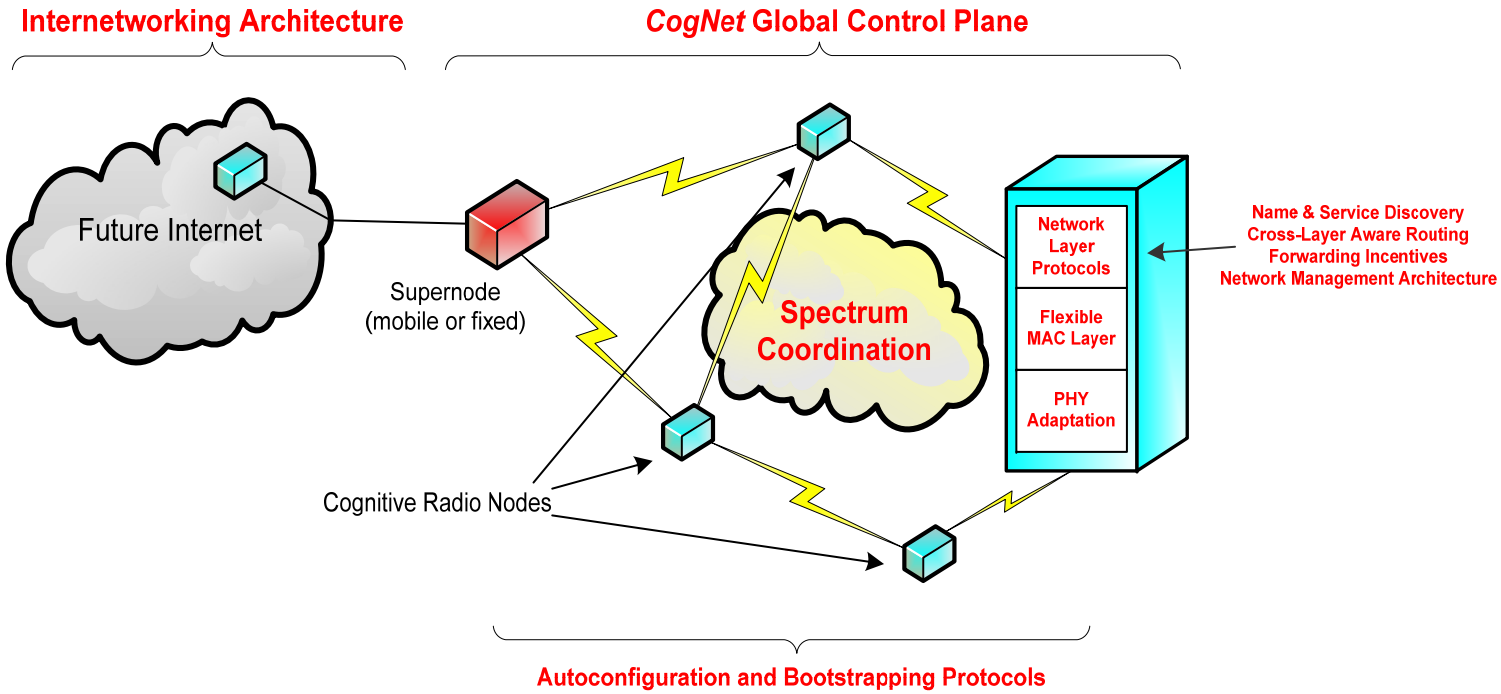
Future Internet Projects: Geometric Stack for Location Aware Networks

- Location-aware protocol architecture project funded under NSF FIND
- Intended to study future Internet architecture impact of location
- Evaluation of alternative methods, e.g. overlays vs. integrated layer 3, etc.



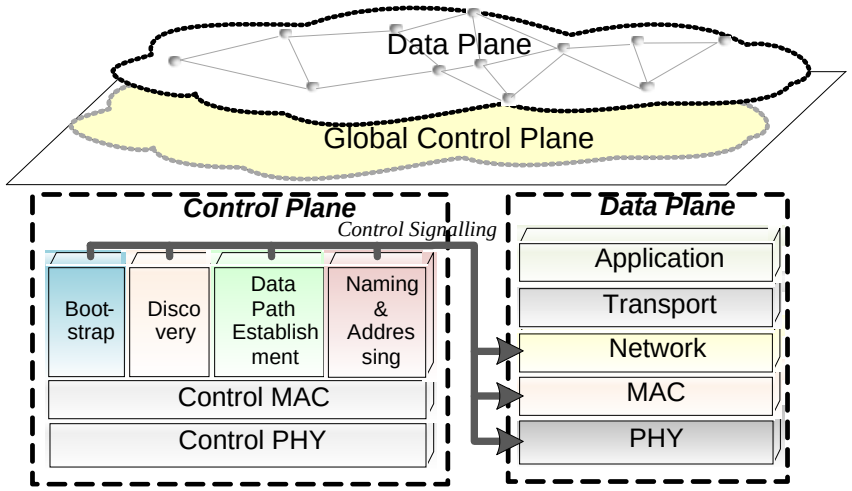
Future Internet Projects: "CogNet" Architecture

- New NSF project called "CogNet" aimed at development of prototype cognitive radio stack within GNU framework
- Joint effort between Rutgers, U Kansas, CMU and Blossom Inc.



Future Internet Projects: "CogNet" Protocol Stack

- Global Control Plane (GCP)
  - Common framework for spectrum allocation, PHY/MAC bootstrap, topology discovery and cross-layer routing
- Data plane
  - Dynamically linked PHY, MAC, Network modules and parameters as specified by control plane protocol



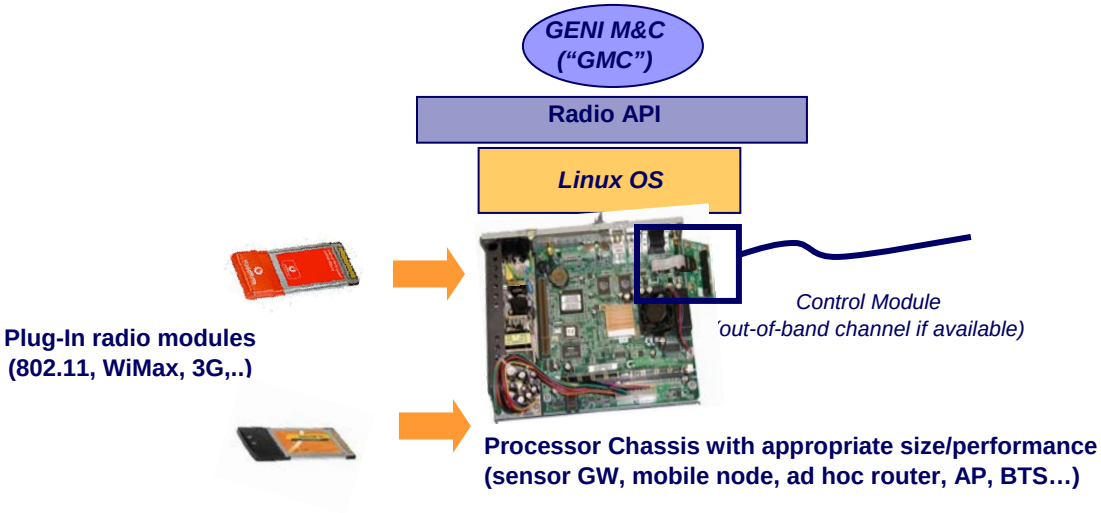
Wireless Platforms for GENI

Experimental Platforms: Programmable Wireless Devices

- Single wireless GENI node architecture that covers different wireless network element needs:
  - Standard set of CPU platforms with different size/performance
  - Multiple radio cards as “plug-in” – easy to change radios, upgrade
  - Linux OS with appropriate **“open API”** drivers for each radio
  - External control module for remote management (reboot, etc.)
  - GMC control module interfaced to uniform radio API

Linux OS w/
GENI drivers and “thin GMC client”

End-user Wireless Devices
(commercial sensors, phones, PDA’s, laptops)

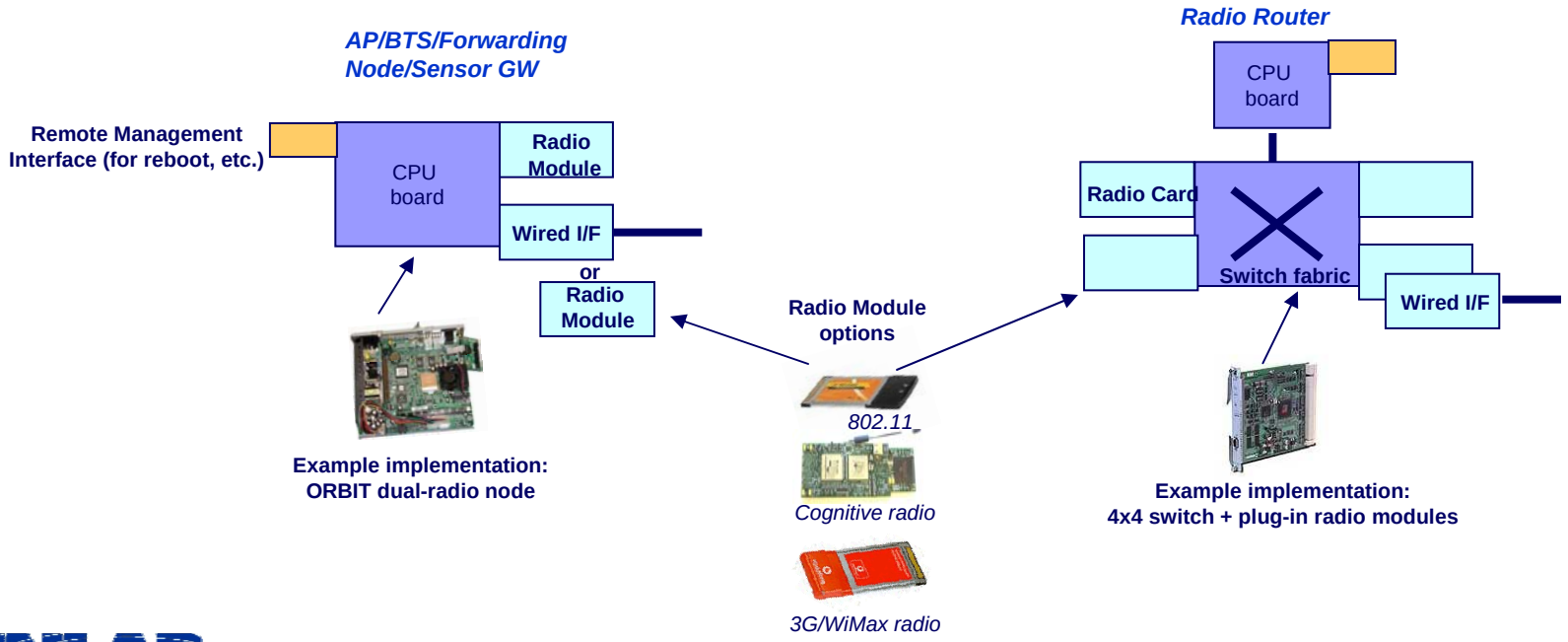


Typical Experimental Wireless Network Platform

All components also to be available as “GENI wireless kits”

Experimental Platforms: Open API Wireless AP's and Routers

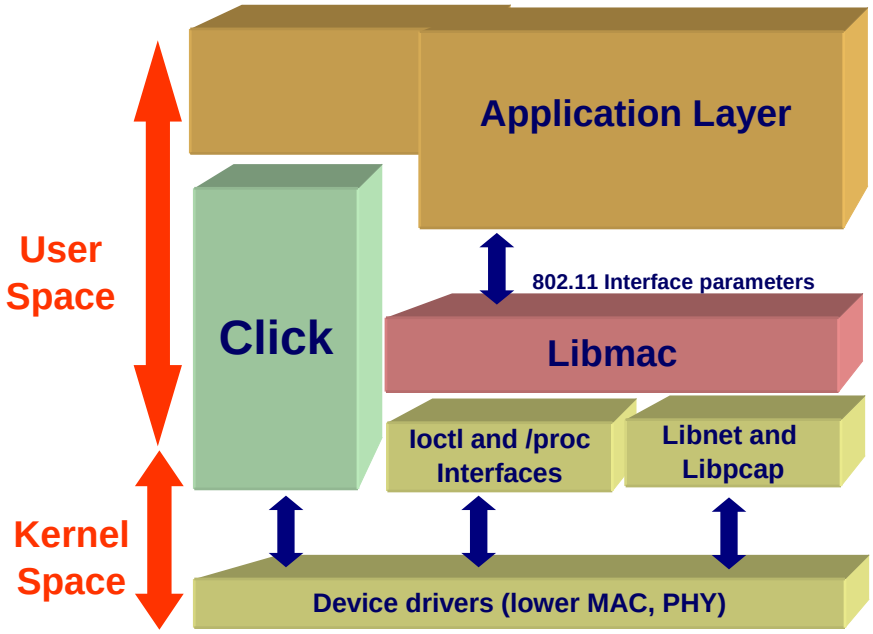
- Typical wireless network elements in GENI
  - Programmable Access Points (AP), Base Stations (BTS), Forwarding Nodes & Sensor Gateways, typically with 2 wired or wireless ports
  - More general *n*-port multi-radio router platform with hardware support for routing/switching



Experimental Platforms: Example of Open API Radio Node Implementation

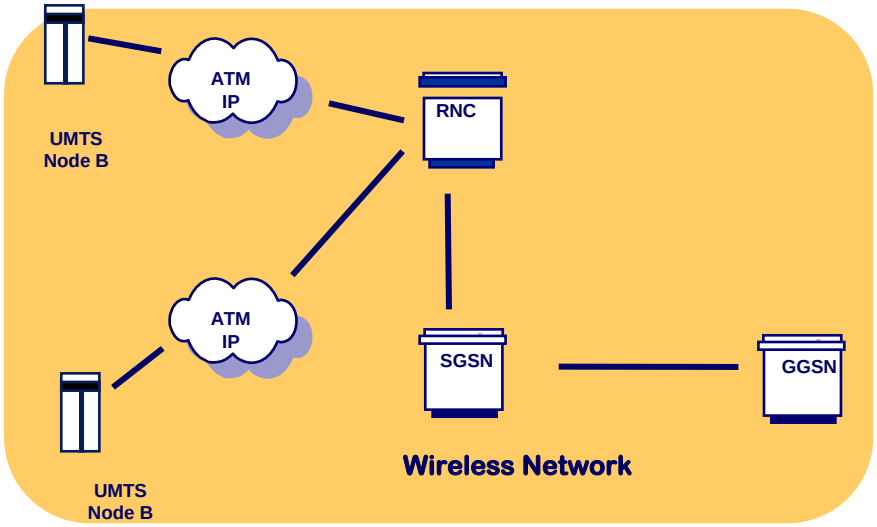
ORBIT Multi-Radio Node (v1.0)
with integrated Chassis Manager

COTS ORBIT Node (v2.0)
With GPS & GPRS control

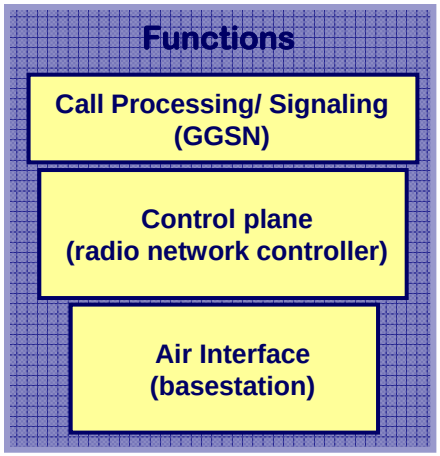


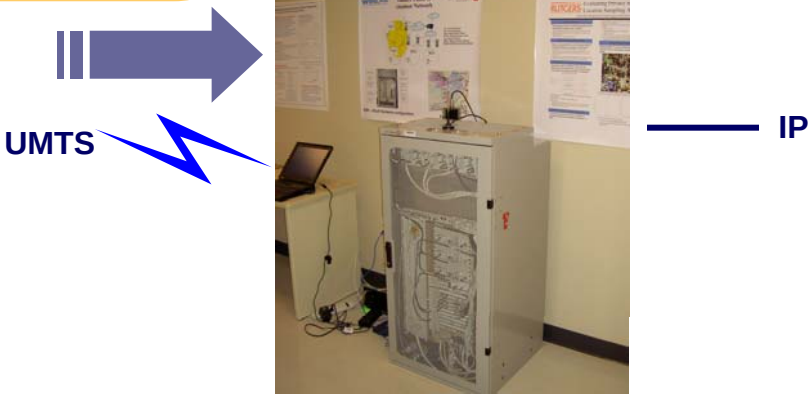
ORBIT Node Software

Experimental Platforms: Example of Open API Base Station (UMTS, WiMax)



- Open API BTS needed for wide-area mobile services
  - UMTS BSR prototype with IP interface available
  - Future work on WiMax BTS
  - Equipment vendor collaboration required for implementation





Lucent IP Base Station Router at WINLAB

Courtesy: Lucent Bell Labs

Experimental Platforms: Vehicular Nodes

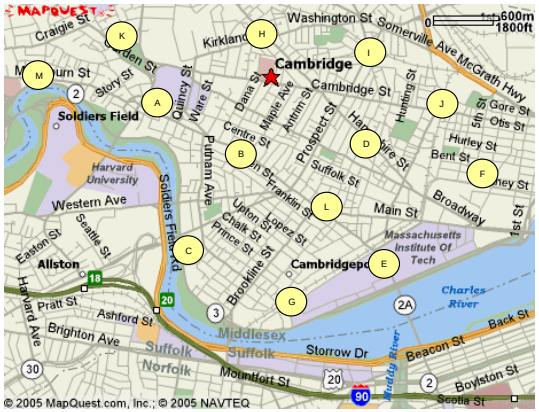
Example Vehicular Deployment (ORBIT outdoor)

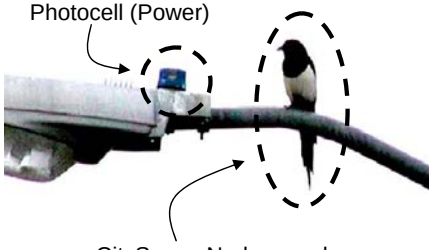
- System leverages urban mesh infrastructure for Internet connectivity
- Campus/city-wide deployment (~100s mobile nodes)
  - private cars, taxi, campus shuttles, buses
- On board equipment:
  - Radios: conventional (WiFi, 802.11p, Bluetooth, WiMax); next generation (MIMO, cognitive radios, etc);
  - Sensors: GPS; video cameras; acoustic sensors; on board sensors..
  - Data server, harvester: classify and store events; P2P applications

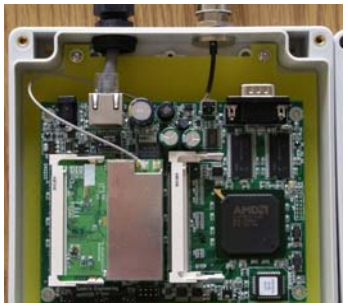
Experimental Platforms: Sensor Net Deployments

- Support urban-scale measurement and diverse applications
- Linux-based embedded PCs with 802.11a/b/g and 802.15.4
  - Mounted on top of light poles, buildings, etc.
  - Possible sensor types include meteorological, environmental, pollution, etc.
- Web-based interface for job scheduling, debugging, profiling
  - Open resource for the sensor network community

Harvard/BBN CitySense deployment plan







Metrix embedded PC

Vaisala meterological sensor

Courtesy: Matt Welsh, Harvard U

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Experimental Platforms: Sensor Kits

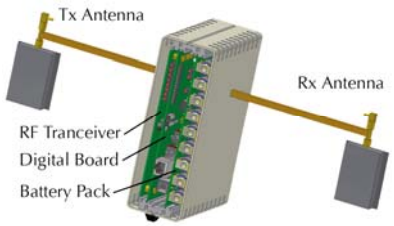
- Support diverse set of applications
  - Capture applications not amenable to regional testbed
  - Enable many researchers to hook-in to GENI, sharing common design
- Several designs
  - Inexpensive, small 8-bit platform (e.g., running TinyOS)
  - More capable 32-bit platform (e.g., running linux)
  - Sensors include standard packs (for identified applications) and expansion boards
- Two distribution models
  - Some distributed as part of GENI, will have strong requirements on providing data and integrating with testbeds
  - Designs made publicly available; suitable for researcher purchase
- Standard software to interface to GENI
  - Allow nodes to be reused by external researchers when not used by application user
  - Sensornet data can flow over GENI backbone

Courtesy: Matt Welsh, Harvard U

Experimental Platforms: Programmable and Cognitive Radios

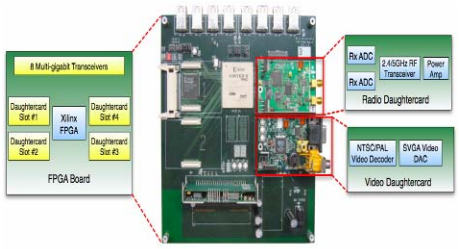
- Various experimental programmable radio platforms under development for wireless network research…
  - WARP programmable radio, GNU radio, KU agile radio & near-future cognitive radios, ….
  - Key issue: open software API's and protocol stacks for full control of physical and link/MAC layers

GNU USRP Software Radio



KU Agile Radio

WINLAB/Lucent Cognitive Radios

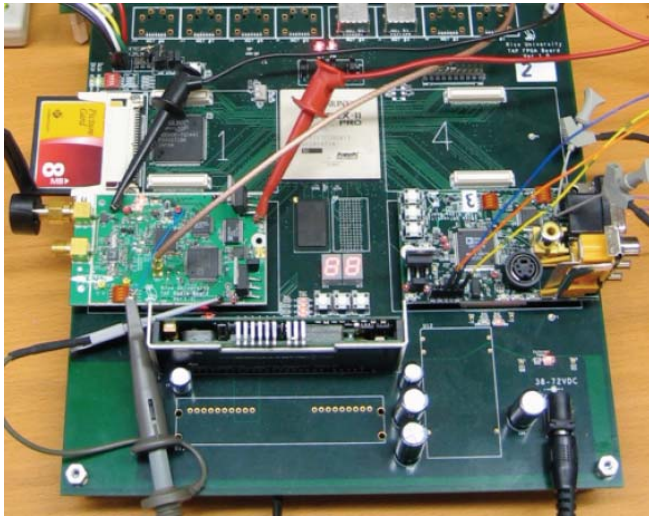


Rice "WARP" board

Experimental Platforms: Experience with Programmable Radios

- Transit Access Points (TAPs) – 2003-2007 project focusing on high-performance multi-hop wireless
- MIMO PHY in HDL
- MAC and higher layers in C with HDL optimization as needed
- Broad class of protocols encompassing 802.11s (mesh) and 802.16j (multi-hop mobile relay)

- Wireless Open Access Research Platform (WARP) – 2006-2008 project to develop platform as a shared community resource
  - Hardware
  - Source code for network protocols
  - HDL source for PHY



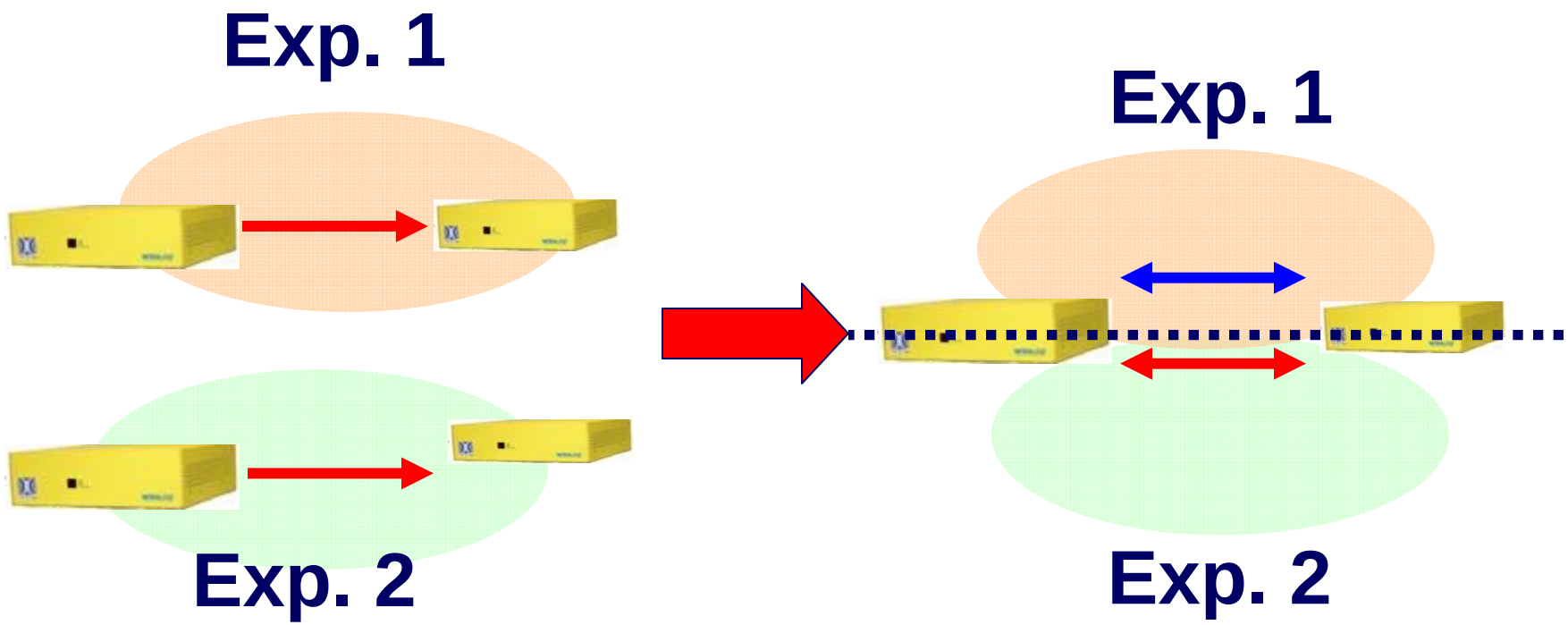
Courtesy: Ashu Sabharwal, Rice University

Key Technologies: Network Virtualization

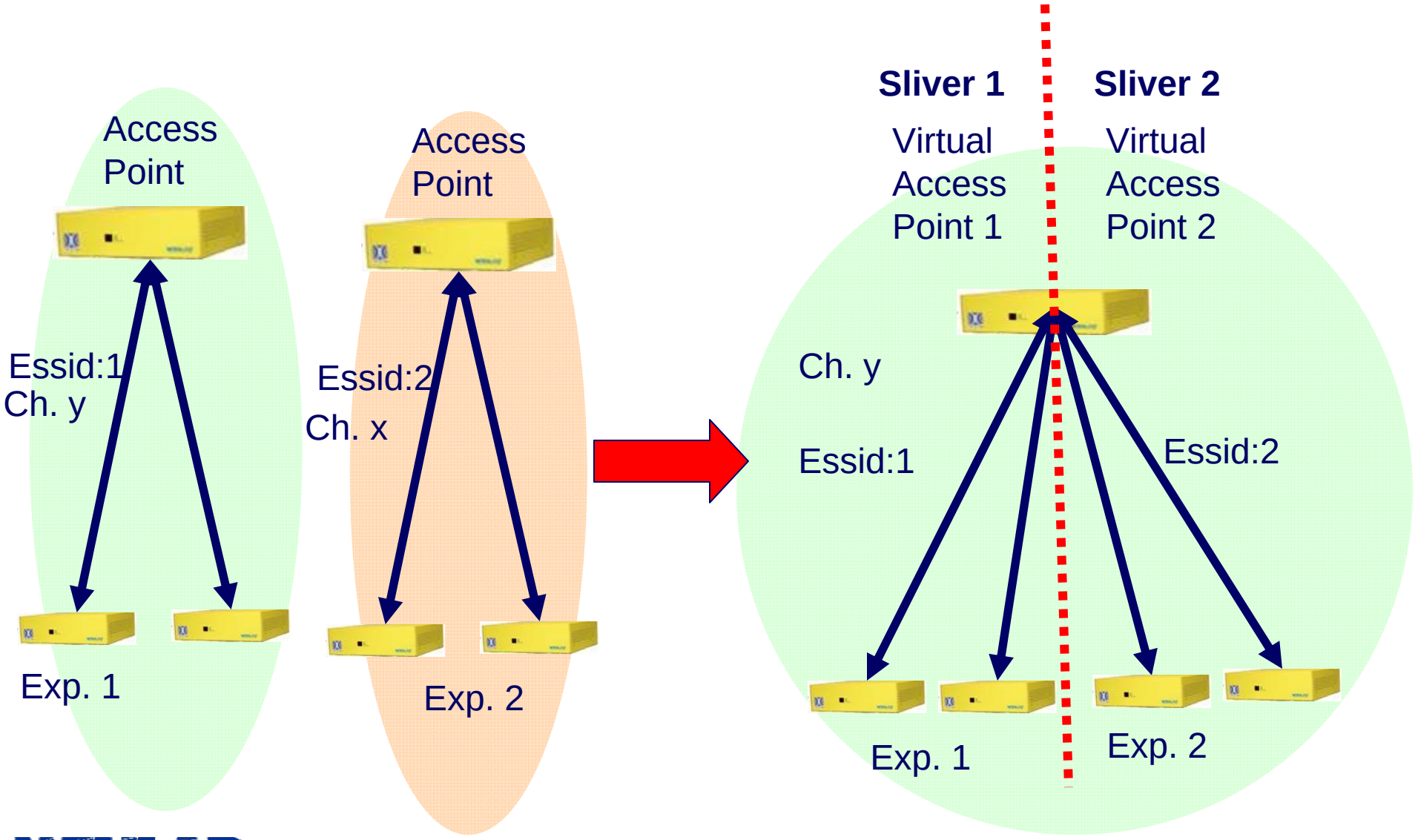
- Support concurrent experiments to increase capacity
- Support both short-term and **long-term service experiments**
- Virtualization in wireless networks complicated by PHY/MAC interactions between nodes
- Several techniques being investigated:
  - Virtual MAC (VMAC)
  - Space division
  - Frequency division
  - Time division

Wireless Network Virtualization: FDMA

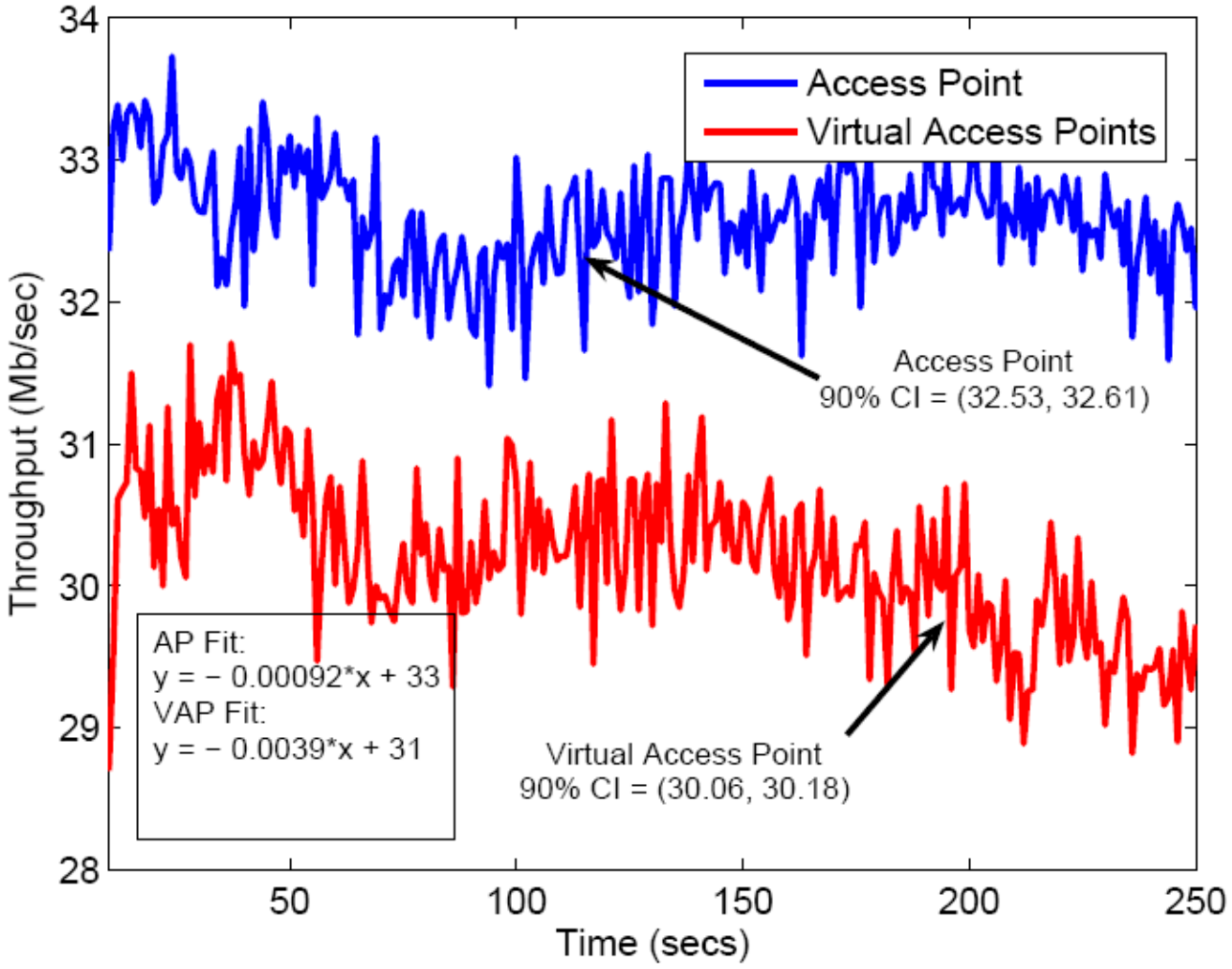
- Two concurrent experiments can coexist using the same hardware via multiple radio cards/frequencies



Wireless Network Virtualization: VMAC



Wireless Network Virtualization:
VMAC Experimental Results

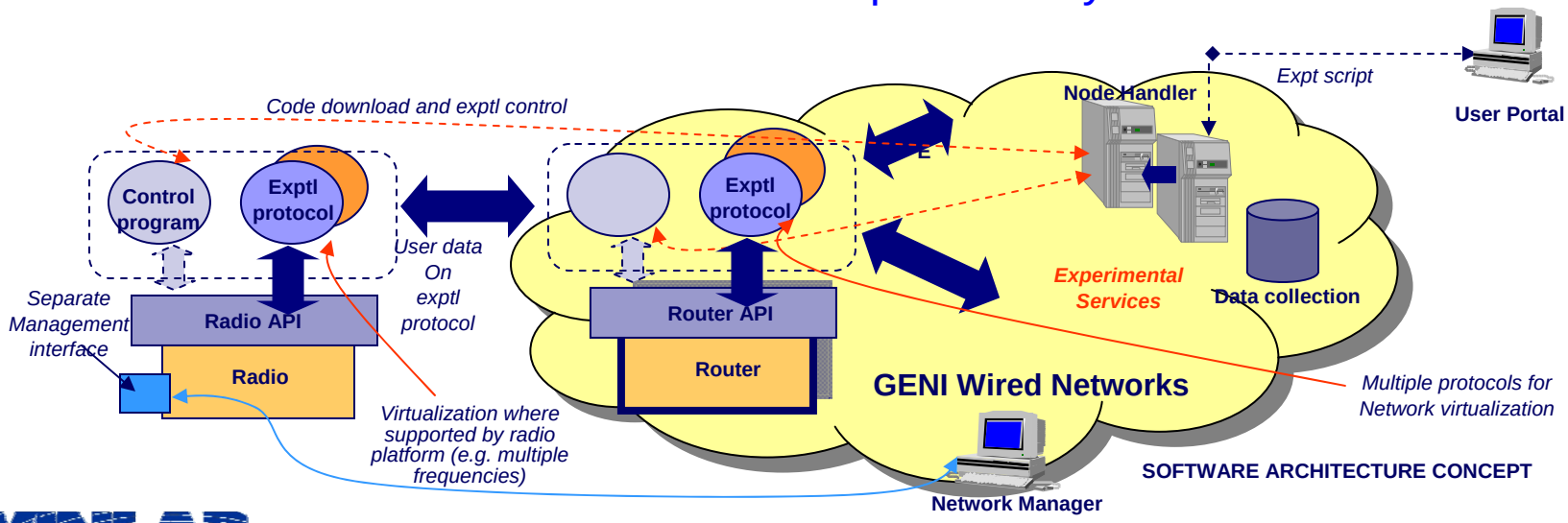


Key Technologies: Wireless Control & Management Requirements

- Specification of Experimental Scenario & Parameters (e.g. topology, bandwidth, mobility,…)
- Admission Control (allocation of slice resources)
- Service Level Agreement (SLA) for experimenter slice
- Network monitoring to ensure resource usage compliance
- Performance measurements at various protocol layers & time scales

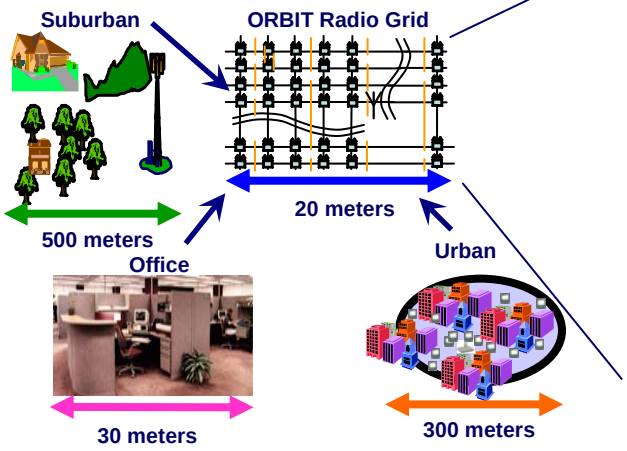
Key Technologies: Experiment Control Software

- Control & management software for large-scale experimental system deployment a key challenge
  - Interface to user for experiment definition and data collection
  - Scripting language etc. to support high-level programming abstractions
  - Automated downloading of experiment code
  - Topology and resource specification
  - Slice management across wired and wireless domains
  - Collection of measurements at various protocol layers

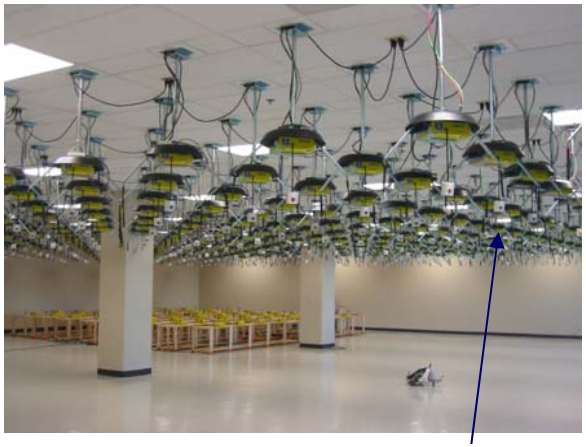


Key Technologies: ORBIT Radio Grid as an Example of Large-Scale Programmable Net

- ORBIT radio grid testbed currently supports networks with ~100's of radio nodes (both end-points and routers)
- Integration with wired network testbeds available (PlanetLab, VINI)
- GNU radio for programmable MAC/PHY beyond open API features



Radio Mapping Concept for ORBIT Emulator

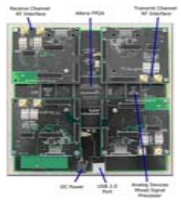


400-node Radio Grid Facility at WINLAB Tech Center

Current ORBIT sandbox with GNU radio

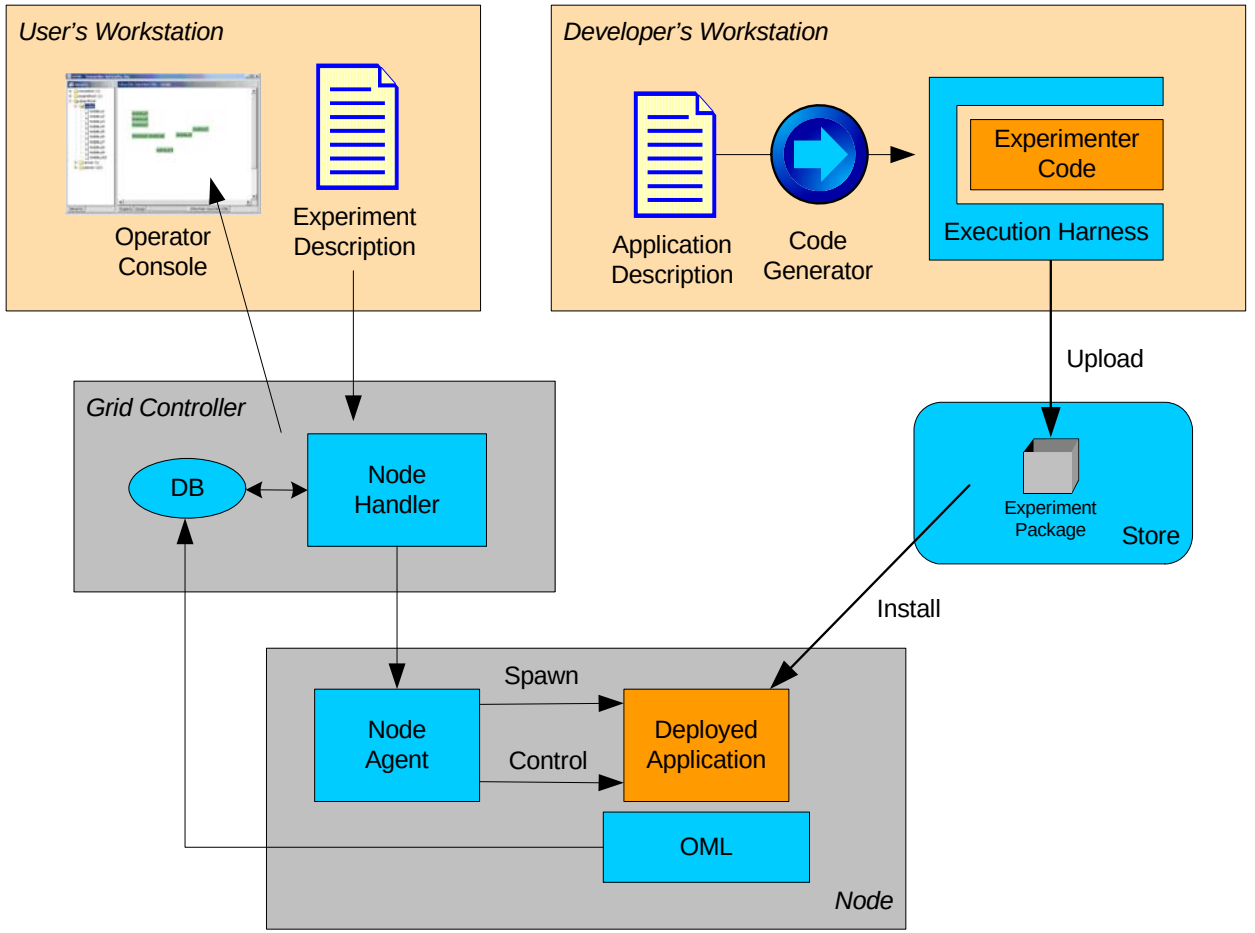
Planned upgrade (2007-08)

Programmable ORBIT radio node

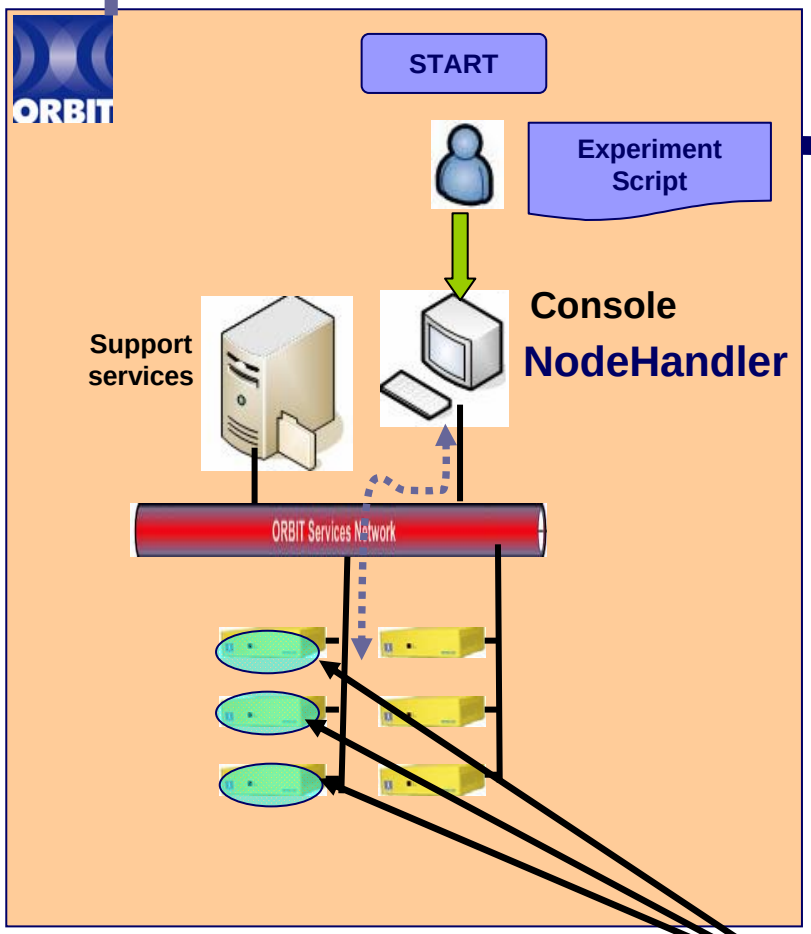


URSP2 CR board

Key Technologies: ORBIT Software Components



Key Technologies: ORBIT Execution Script




```
#
# Define nodes used in experiment
#
nodes([4,3], 'sender') {|node|
  node.image = nil  # Use default disk image

# experiment property space
  node.prototype("test:proto:sender",  {        # use prototype "sender"
    'destinationHost' => '192.168.5.4',         # Set it's property "destinationHost"
    'packetSize' => Experiment.property("packetSize"),
    'rate' => Experiment.property("rate")       # bind the remaining properties to defaults
  })                                            # Can be overridden later
  node.net.w0.mode = "master"
  node.net.w0.type = 'b'
  node.net.w0.essid = "helloworld"                      # Set wireless parameters
  node.net.w0.ip = "%192.168.%x.%y"
  node.net.w0.rate = "11m"
}
#
# Define nodes used in experiment
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}
```
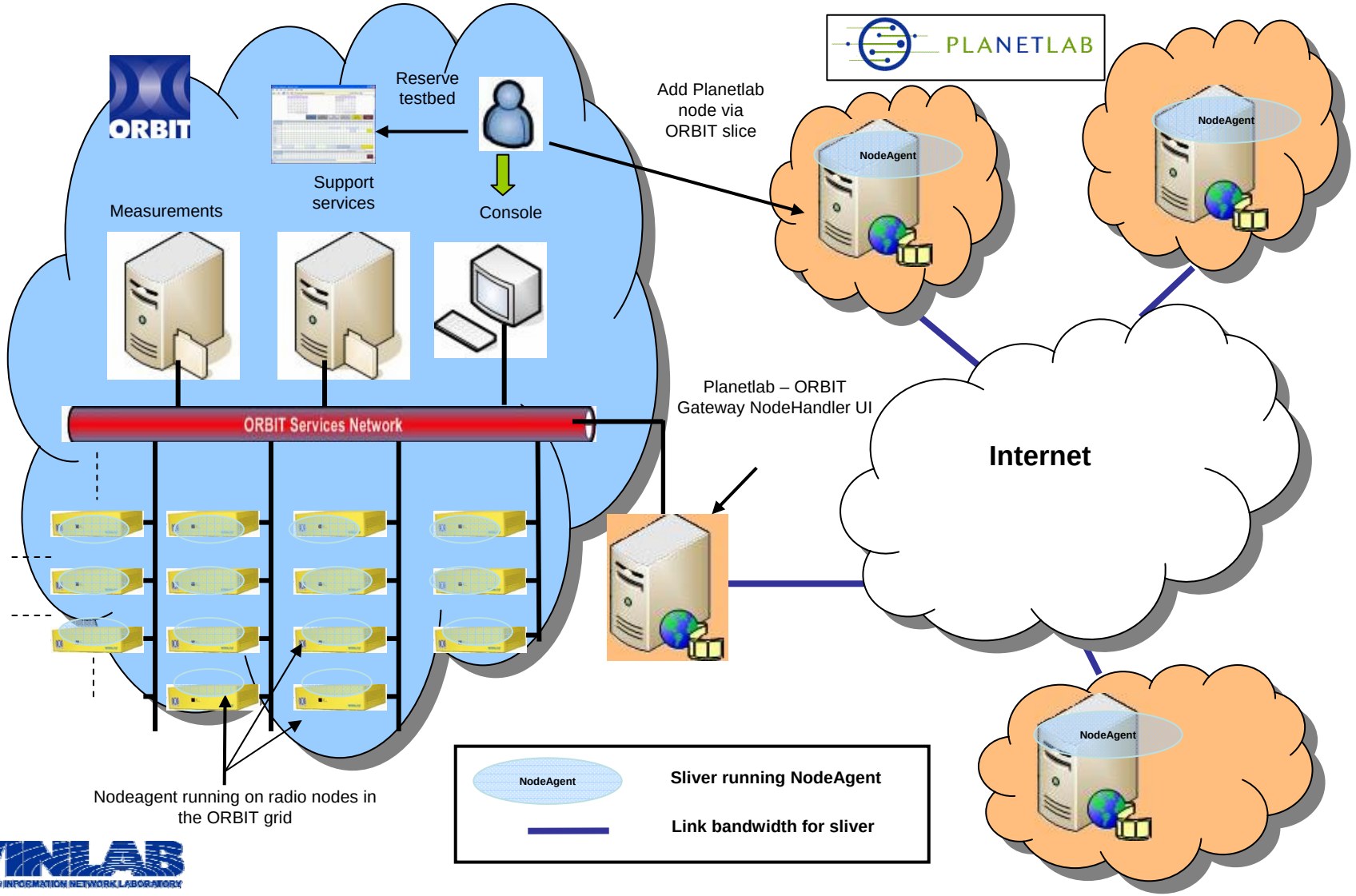
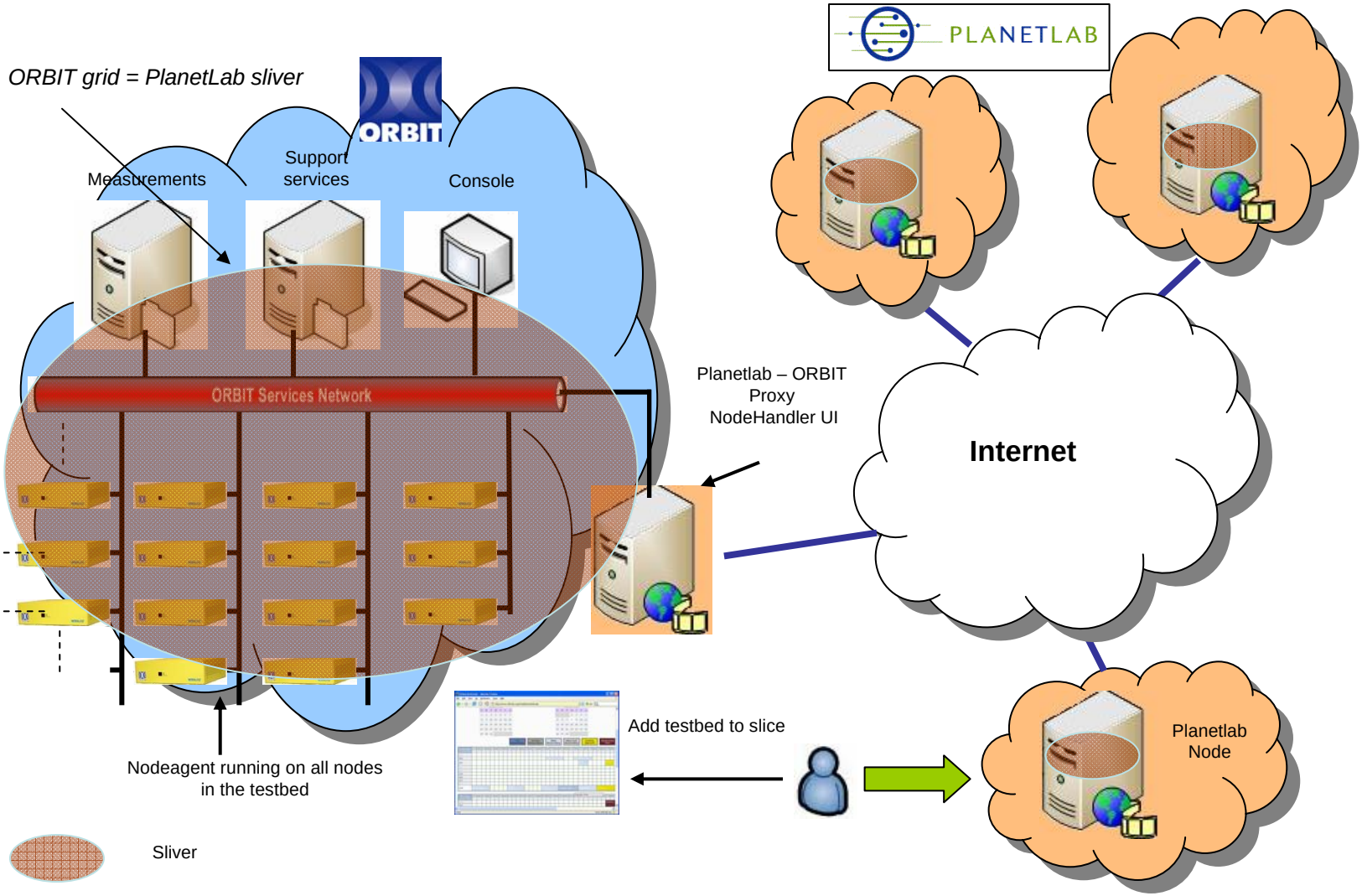

Key Technologies: Integrating PlanetLab with Wireless Testbeds – PL slice for ORBIT users

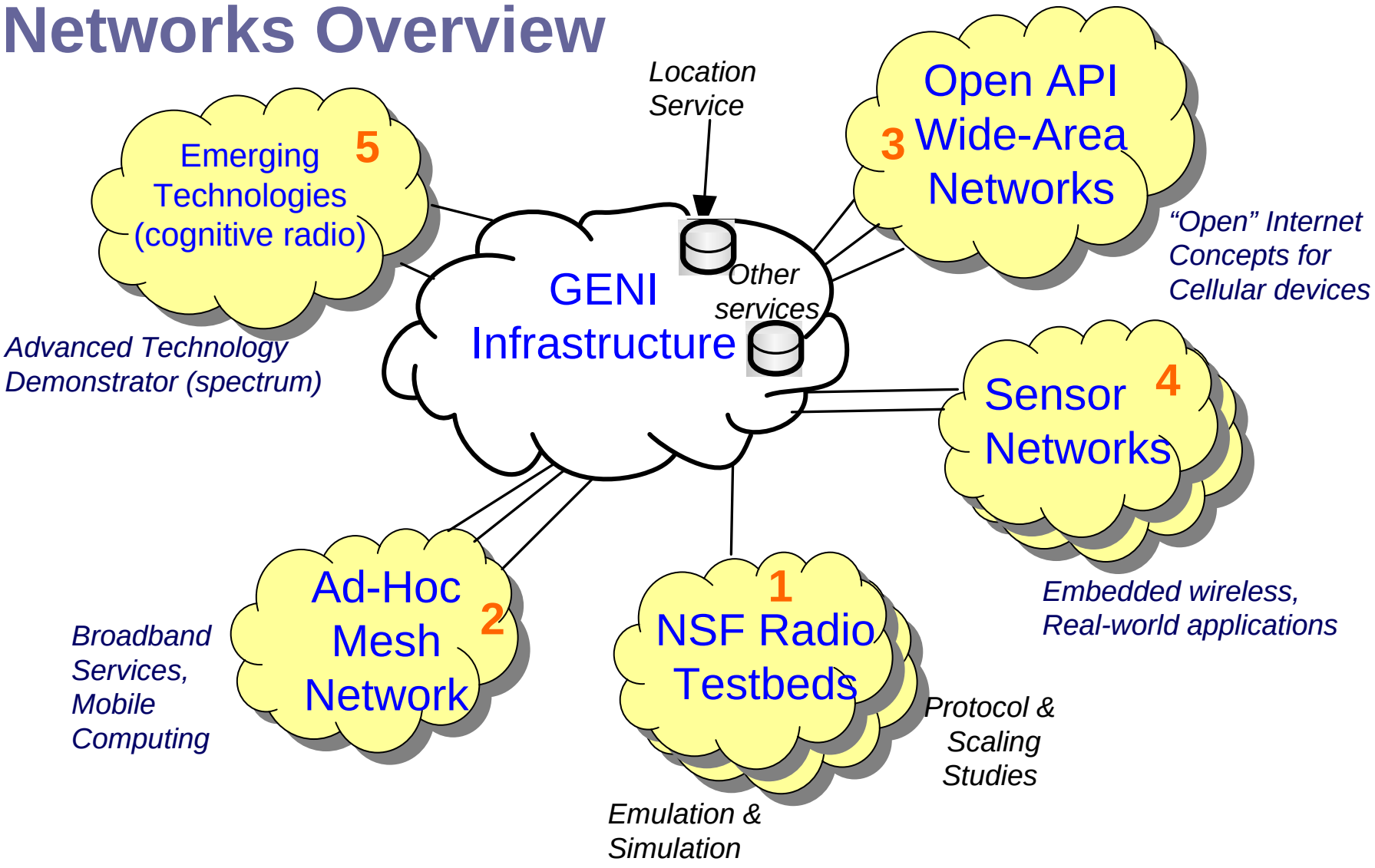


Key Technologies: Integrating PlanetLab with Wireless Testbeds – ORBIT Proxy for PL Users



GENI Implementation Plan for Wireless

GENI Implementation: Wireless Sub-Networks Overview

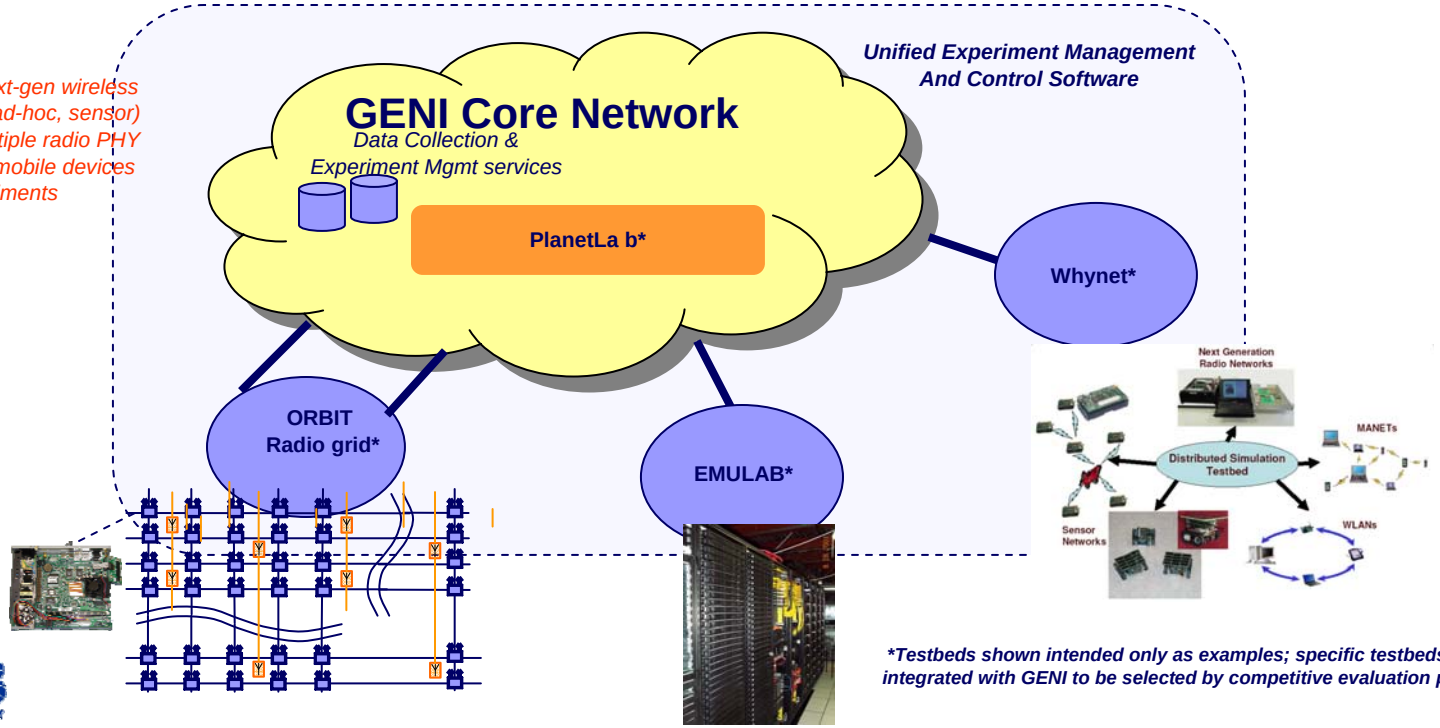


GENI Implementation: Wireless Emulators

- Large-scale emulators and simulators provide important protocol testing capabilities when connected to GENI
  - Enables end-to-end protocol tests with large numbers of nodes
  - Reproducible experiments with extensive data collection; virtualization per experiment

Research Focus:

1. *Protocol validation for next-gen wireless*
2. *Scalability experiments (ad-hoc, sensor)*
3. *Hybrid networks with multiple radio PHY*
4. *End-to-end transport for mobile devices*
5. *Controlled mobility experiments*



Testbeds shown intended only as examples; specific testbeds to be integrated with GENI to be selected by competitive evaluation process

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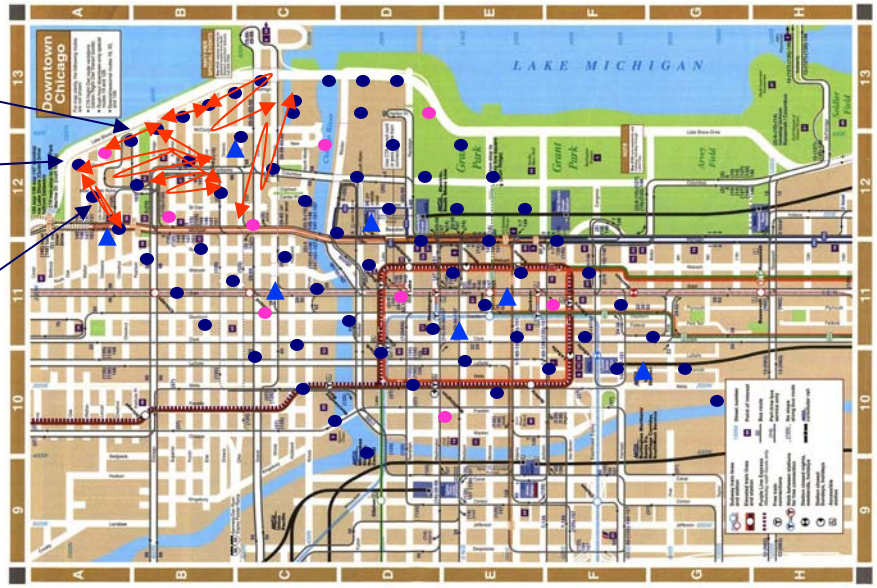
GENI Implementation: Open API Urban Ad-Hoc Mesh

- Ad-hoc wireless network providing full coverage of high-density urban area ~ 10 Km**2
  - Enables experimentation with mesh network protocols & broadband mobile applications
  - Dual-radio forwarding node as building block
  - Open API 802.11 with soft MAC, virtualization by frequency or space
  - Services for running expts, data collection, frequency assignment and spectrum meas

Dual-radio ad-hoc router (includes wired interface for AP sites)

Ad-hoc Radio links

Radio Nodes ~50-100 m spacing



Access Point (wired)

Ad-Hoc Radio Node

Spectrum Monitor

Research Focus:

1. *Ad-hoc routing*
2. *Self-organization & discovery*
3. *Cross-layer optimizations*
4. *MAC layer enhancements*
5. *Security with ad-hoc routing*
6. *Broadband QoS*
7. *Impact of mobility*
8. *Real-world application studies*

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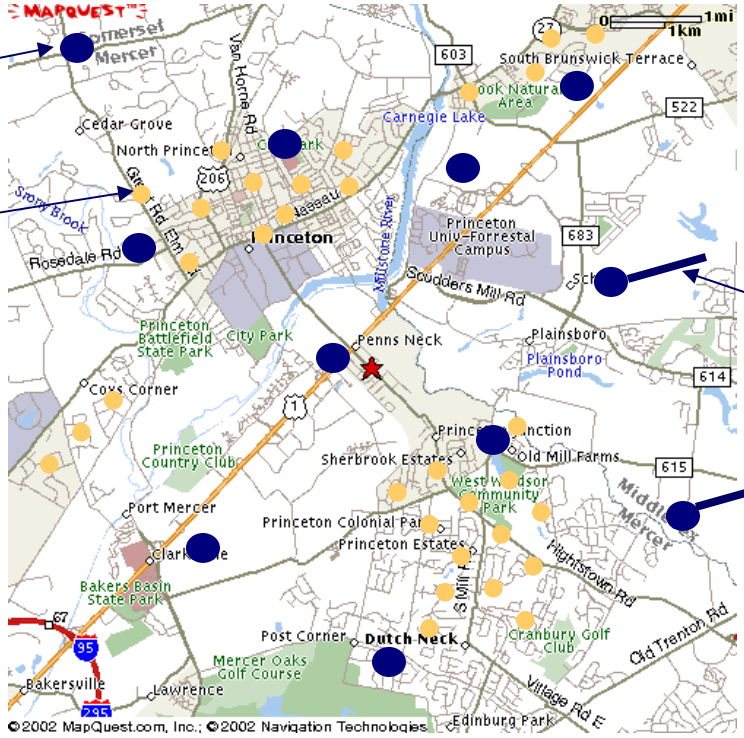
GENI Implementation: Open API Wide Area Mobile Network

- Open API wide-area wireless network to explore alternatives to cellular, hybrids with WLAN, Infostations, new mobile applications…
  - Suburban coverage ~50 Km**2 using ~10 wide-area BTS's + ~100 short-range AP's
  - Open API 3G or WiMax BTS and dual-radio 802.11 node as building blocks

WiMax or 3G Base Station Router

802.11 Relay Node Platform



Open API 3G/WiMax BTS

802.11 relay node or AP

Connections to GENI Infrastructure

Research Focus:

1. *Internet transport for 3G/cellular*
2. *Mobility support in future Internet*
3. *Hybrid 3G/WLAN handover, etc.*
4. *Multicasting*
5. *Transport layer for wireless*
6. *Security in future 3G/4G*
7. *Information caching and multimedia*

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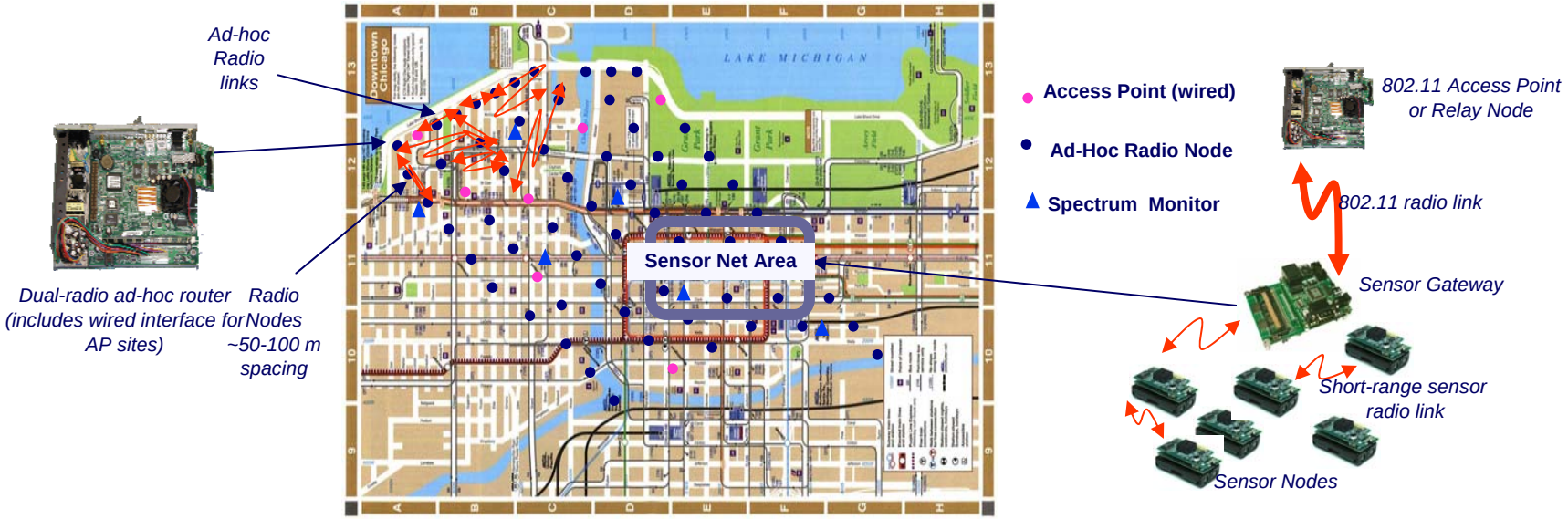
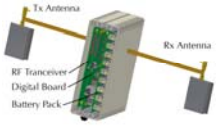
GENI Implementation: Urban Mesh + Sensor Network

- 2-3 sensor network projects to be selected via proposal process for integration into urban mesh deployment
  - Sensor network experiments will leverage 802.11 mesh or 3G wide area infrastructure in items 2,3
  - Provide “user deployment kit” with platforms including sensor nodes and sensor/WLAN or sensor/3G gateway



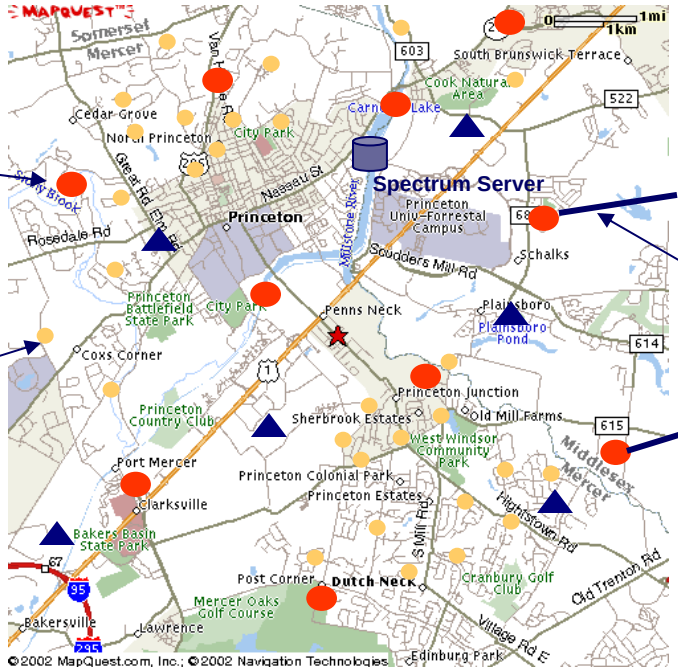
GENI Implementation: Cognitive Radio Technology Demonstrator

- Advanced technology demonstrator of cognitive radio networks for reliable wide-area services (over a ~50 Km**2 area) with spectrum sharing, adaptive networking, etc.
  - Basic building block is a cognitive radio platform, to be selected from competing research projects now in progress and/or future proposals
  - Requires enhanced software interfaces for control of radio PHY, discovery and bootstrapping, adaptive network protocols, etc. – suitable for protocol virtualization
  - New experimental band for cognitive radio (below 1 Ghz preferable)



Cognitive Radio Network Node

Cognitive Radio Client



Cognitive Radio Network Node

Cognitive Radio Client

Spectrum Monitors

Connections to GENI Infrastructure

Research Focus:

1. *New technology validation of cognitive radio*
2. *Protocols for adaptive PHY radio networks*
3. *Efficient spectrum sharing methods*
4. *Interference avoidance and spectrum etiquette*
5. *Dynamic spectrum measurement*
6. *Hardware platform performance studies*

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Concluding Remarks

Concluding Remarks: Next Steps

- Complete technology transfer for wireless design to GPO
- Transition WG expertise to new structure (..current GSC/GPO structure poses some real problems!)
- Continue risk-reduction prototyping
  - Platform development, open cellular/WiMax, mobile, cognitive radios, etc.
  - Virtualization of wireless networks
  - Integration with wired networks, e.g. VINI (..using GMC protocol baseline)
  - Measurement and monitoring techniques
- Open issues:
  - GMC control and management protocol baseline urgently needs to be finalized (…wireless specific requirements need to be incorporated)
  - Scope, scale and cost of wireless deployment (including spectrum)
  - Opt-in approach – how to best encourage organic growth of GENI wireless