

18-759: Wireless Networks

Lecture 2: Wireless Networking Challenges

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Spring Semester 2009
<http://www.cs.cmu.edu/~prs/wirelessS10/>

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Announcements

- Good news: no more waiting list!
- Results of survey

		Wireless Comm	
		Yes	No
Networking	Yes	18	6
	No	3	0

- Most popular topics: ad hoc, QoS, mesh, network coding
- Next: spectrum access, vehicular, DTN, opportunistic communication
- Least popular: management & planning, self-tuning,

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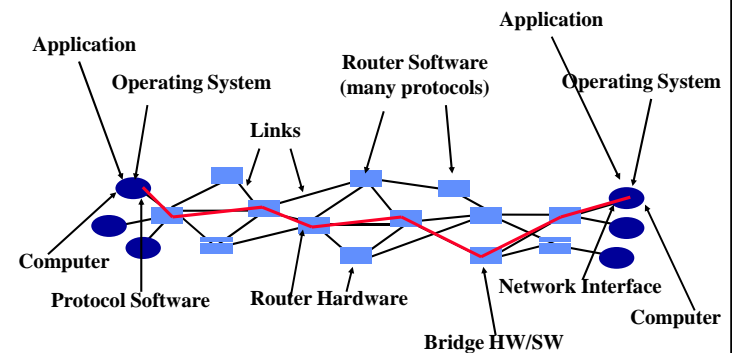
Schedule for Today

- The OSI model
- Challenges in Wireless Networking
- Evaluation techniques
- Wireless emulator

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Motivation: Many many Network Components



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How Do We Design a Network?

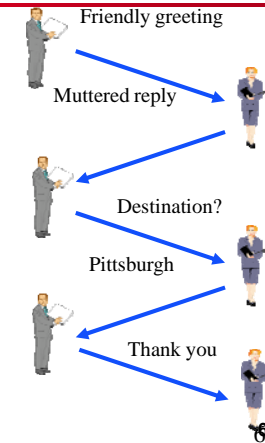
- **Need to deal with**
 - » Complexity
 - » Many parties involved
 - » Very long life time
- **Key is modularity**
 - » Natural solution to deal with complexity
 - » Independent parties can develop components that will interoperate
 - » Different pieces of the system can evolve independently, at a different pace
- **Need well-defined interfaces ...**

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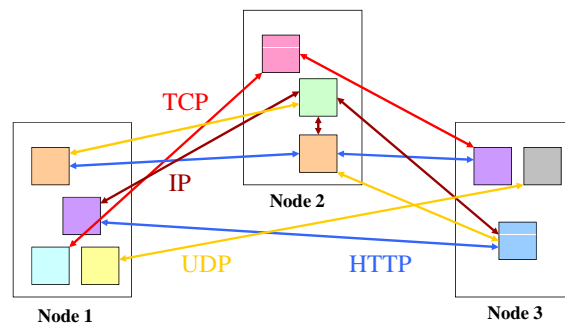
What is a Protocol

- **An agreement between parties on how communication should take place.**
- **Protocols may have to define many aspects of the communication.**
- **Syntax:**
 - » Data encoding, language, etc.
- **Semantics:**
 - » Error handling, termination, ordering of requests, etc.
- **Protocols at hardware, software, *all* levels!**
- **Example: Buying airline ticket by typing.**
- **Syntax: English, ascii, lines delimited by “\n”**



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Are Protocols All We need?

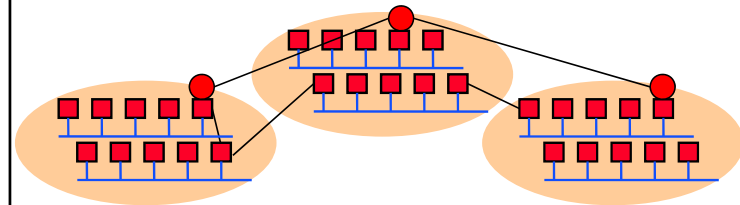


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Let Us Try Again

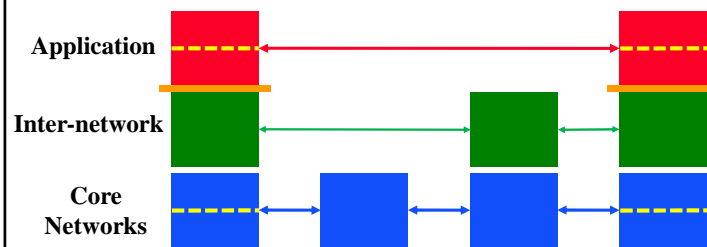
- **Two or more hosts talk over a wire**
- **Hosts talk in a homogeneous network (administratively, technology)**
- **Hosts talk across heterogeneous networks**
- **We run some applications over that**



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Protocol and Service Levels



- Can further split up the layers:
- **Application:** generic versus application-specific functionality
- **Core:** wires versus data delivery

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Interfaces

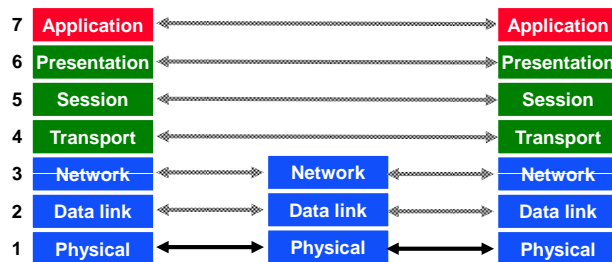
- Each protocol offers an interface to its users, and expects one from the layers on which it builds
 - » Syntax and semantics strike again
 - Data formats
 - Interface characteristics, e.g. IP service model
- Protocols build upon each other
 - » Add value
 - E.g., a reliable protocol running on top of IP
 - » Reuse
 - E.g., OS provides TCP, so apps don't have to rewrite

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Networking 101 Layer Network Model

The Open Systems Interconnection (OSI) Model.



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OSI Motivation

- Standard approach of breaking up a system in a set of components, but the components are organized as a set of layers.
 - » Only horizontal and vertical communication
 - » Components/layers can be implemented and modified in isolation
- Each layer offers a service to the higher layer, using the services of the lower layer.
- “Peer” layers on different systems communicate via a protocol.
 - » higher level protocols (e.g. TCP/IP, Appletalk) can run on multiple lower layers
 - » multiple higher level protocols can share a single physical network

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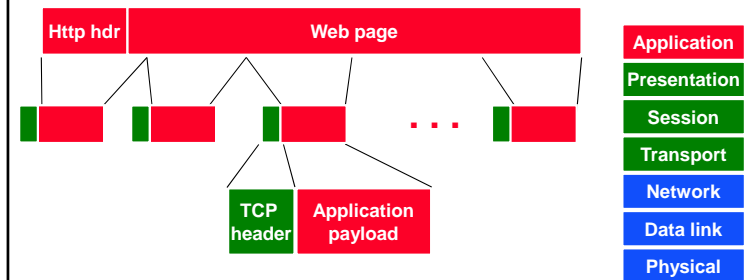
OSI Functions

- (1) Physical: transmission of a bit stream.
- (2) Data link: flow control, framing, error detection.
- (3) Network: switching and routing.
- (4) Transport: reliable end to end delivery.
- (5) Session: managing logical connections.
- (6) Presentation: data transformations.
- (7) Application: specific uses, e.g. mail, file transfer, telnet, network management.

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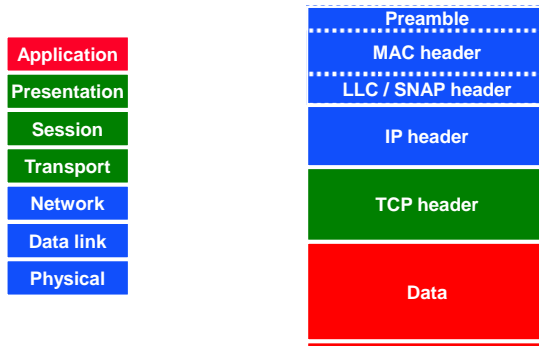
Example: Sending a Web Page



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A TCP / IP / 802.11 Packet

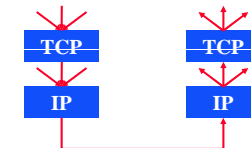


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Multiplexing and Demultiplexing

- There may be multiple implementations of each layer.
 - » How does the receiver know what version of a layer to use?
- Each header includes a demultiplexing field that is used to identify the next layer.
 - » Filled in by the sender
 - » Used by the receiver
- Multiplexing occurs at multiple layers.
 - » E.g., IP, TCP, ...



V/HL	TOS	Length
ID		Flags/Offset
TTL	Prot.	H. Checksum
Source IP address		
Destination IP address		
Options..		

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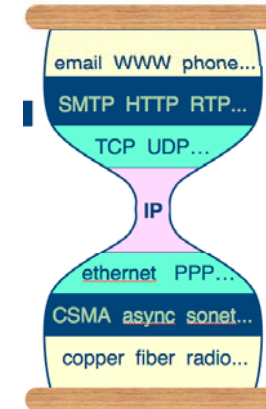
Benefits of Layered Architecture

- Significantly reduces the complexity of maintaining the system.
 - » Effort is $7 \times N$ instead of N^7 for N versions per layer
- The implementation of a layer can be replaced easily as long as its interfaces are respected **True For Wireless?**
 - » Does not impact the other components in the system
 - » Different implementation versus different protocols
- In practice: most significant evolution and diversity at the top and bottom:
 - » Applications: web, peer-to-peer, video streaming, ..
 - » Physical layers: optical, wireless, new types of copper

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The IP Hourglass



<http://www.iab.org/documents/docs/hourglass-london-ietf.pdf>

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Physical Layer Overview

- Optical fiber: very high bandwidth but relatively expensive
 - » Multi-mode fiber for campus deployments
 - » Single-mode fiber for long distances
- Copper wires: good performance for shorter distances
 - » Coax has high capacity but bulky and expensive
 - » Twisted pair is cheap but has lower capacity
- Wireless: lowest capacity, very diverse, most difficult technology
 - » Performance of a wireless "link" is determined by the physical world (buildings, object, people, other RF, ...)
 - » Inter-planetary .. satellite .. WAN .. MAN .. LAN .. PAN
 - » Capacity can be increased but gets expensive

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Schedule for Today

- The OSI model
- Challenges in Wireless Networking
- Evaluation techniques
- Wireless emulator

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Why Use Wireless?

There are no wires!

Has several significant advantages:

- No need to install and maintain wires
 - » Reduces cost – important in offices, hotels, ...
 - » Simplifies deployment – important in homes, hotspots, ...
- Supports mobile users
 - » Move around office, campus, city, ... - users get hooked
 - » Remote control devices (TV, garage door, ..)
 - » Cordless phones, cell phones, ..
 - » WiFi, GPRS, WiMax, ...

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What is Hard about Wireless?

There are no wires!

- In **wired** networks links are constant, reliable and physically isolated
- In **wireless** networks links are variable, error-prone and share the ether with each other and other external, uncontrolled sources

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Attenuation and Errors



- In wired networks error rate 10^{-10}
- Wireless networks are far from that target
- Signal attenuates with distance and is affected by noise
- Probability of a successful reception depends on $SINR = S/I+N$
- Modulation and coding schemes introduce redundancy to allow for decoding

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Throughput vs. distance (WiMAX)

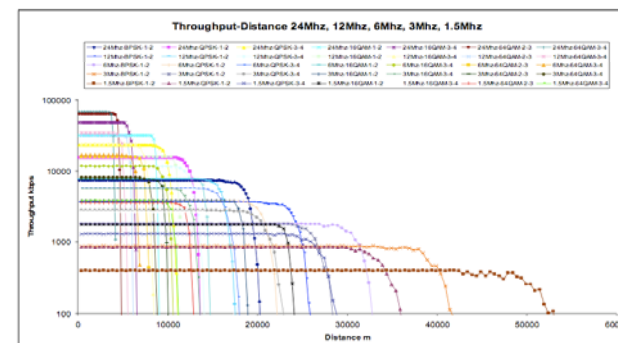


Fig. 6. Throughput-distance optimized lookup graph for IEEE 802.16e deployment.

<http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04526126>

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The Adversity of the Wireless Medium

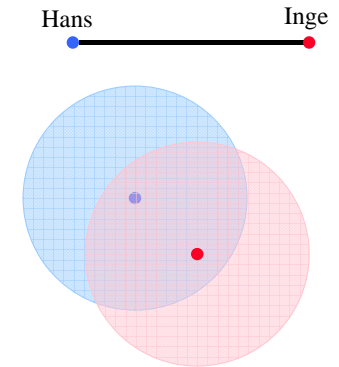
- Previous hold for line of sight transmissions
- In the presence of reflectors signal may experience multipath fading
 - » Slow fading when a large obstruction such as a hill or a large building obscures the main signal path
 - » Fast fading that could be taken advantage of using error correcting codes and time diversity
- Very hard to predict what the signal strength will be at a given location – models exist for indoors and outdoors spaces (PHY lectures)

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Wireless is a shared medium

- Transmitters broadcast
- Devices can operate either in transmit or receive mode
- How do you coordinate access to the medium?

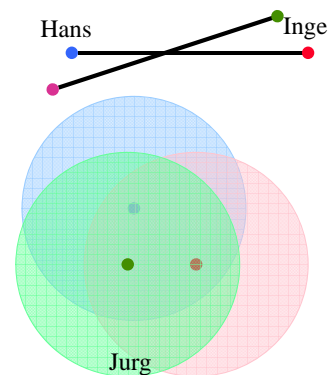


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Interference

- Noise is naturally present in the environment from many sources.
- Interference can be from other users or from malicious sources.
- Impacts the throughput users can achieve.



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Medium Access Control

- Different transmitters/receivers use:
 - » Different frequencies (FDMA – Frequency Division Multiple Access)
 - » Different time slots (TDMA – Time Division Multiple Access)
 - » Different codes (CDMA – Code Division Multiple Access)
 - » Randomly access the medium (CSMA/CA – Carrier Sense Multiple Access/Collision Avoidance)
- Main goal: avoid collisions while making efficient use of the medium

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Wireless Losses

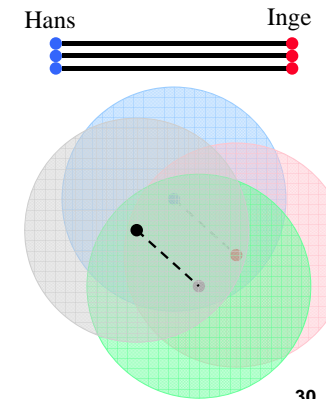
- Can be due to:
 - » Signal errors that lead to a packet that cannot be decoded
 - » OR
 - » Corruption of the transmitted information due to collisions, $SINR=S/(N+I)$ too low
- Understanding the reason behind a loss requires cross-layer information.
 - » Is it PHY?
 - » Or MAC-related?
- Information required by more than one layers.

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How Do We Increase Network Capacity?

- Easy to do in wired networks: simply add wires.
 - » Fiber is especially attractive
- Adding wireless “links” increases interference.
 - » Frequency reuse can help ... subject to spatial limitations
 - » Or use different frequencies ... subject to frequency limitations
- The capacity of the wireless network is fundamentally limited.

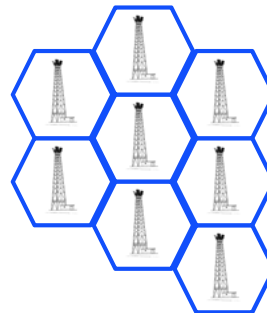


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Cellular architecture

- Deployment comprising cells
- Challenge to provide consistent service even at the edge of the cell – be able to deal with intensity given the capacity of the cell

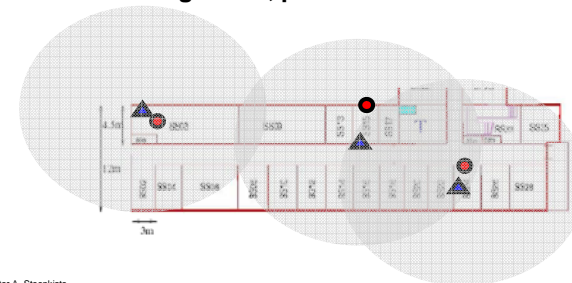


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WiFi architecture

- Could be chaotic or managed
- Limited spectrum – service guarantees hard to make
- Channel assignment, power control

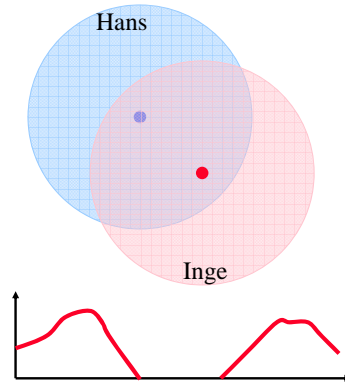


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Mobility Affects the Link Throughput

- Quality of the transmission depends on distance and other factors.
 - » Covered later in the course
- Affects the throughput mobile users achieve.
- Worst case is periods with no connectivity!

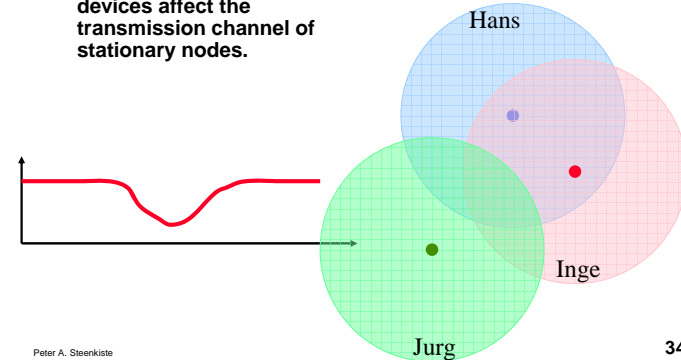


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Mobility is an Issue even for Stationary Users

- Mobile people and devices affect the transmission channel of stationary nodes.

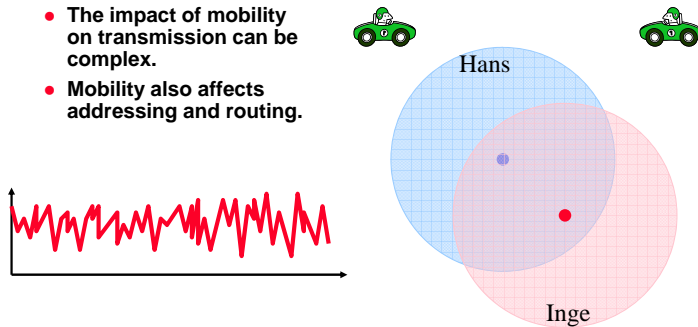


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And It Gets Worse ...

- The impact of mobility on transmission can be complex.
- Mobility also affects addressing and routing.



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Standardization and Technology

- Too many standards – a PCS IS-136 device won't work in an area with PCS IS-95
- Too many radios
 - » Radio co-existence is an issue
 - » Use cases hard to determine which radio to use where (cost, bandwidth, power consumption)
- Device limitations impose solutions
 - » Small screen

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Back to the Applications

WiFi applications:

- » GoogleWifi: provide sufficient coverage given that installation is on light posts – ensure adequate quality
- » Meraki: ensure mesh works and there is enough coverage to connect more customers at appropriate levels of quality
- » Developing regions: Make WiFi work across links that cover Kms – changes in the MAC
- » Home security: Ensure that interference will not adversely impact readings
- » Vehicle-to-vehicle: deal with fast moving vehicles, ensure that information is propagated to the relevant region
- **Key challenges tend to be different for various application domains, but almost all challenges must be considered everywhere**

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How Well Does the Layered Architecture Work for Wireless?

- **Works pretty well:**
 - » We all use WiFi and it usually works well
 - » Our cell phones usually work
- **But getting it to work is a lot more work than for a wired network!**
- **And a lot of solutions are kind of ugly!**
- **Some example ...**

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Examples

- **How do you multiplex at the physical layer?**
 - » Not an issue for wired communication!
- **Physical layer solutions to deal with signal propagation challenges**
 - » Use of redundancy, rate adaptation, dealing with multi-path, etc.
- **MAC layer solutions to deal with challenges**
 - » ACKs and retransmissions, hidden terminals, etc.
- **Higher layer challenges**
 - » TCP congestion control issues, highly variable bandwidth links, dealing with disconnected operation
 - » IP address used by applications as an identifier

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Schedule for Today

- **The OSI model**
- **Challenges in Wireless Networking**
- **Evaluation techniques**
- **Wireless emulator**

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Evaluation: Challenges and Tradeoffs

- **Wireless testbeds are hard to manage**
 - » Interference, production networks, control node movement, ..
- **Wireless network research has largely been simulation based**
 - » Questionable accuracy
 - » Difficult to evaluate real hardware and applications



- **Emulator provides an attractive middle ground between simulation and testbeds**

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Simulation

- **Commercial and publicly available products**
- **Ns-2 the most popular network simulator**
<http://www.isi.edu/nsnam/ns/>
 - » But ns3 is gaining in popularity
- **Wireless extensions cover a wide range of effects:**
 - » Better propagation models (<http://www.ece.cmu.edu/wireless/welcome.html>)
 - » Mobility (<http://www.monarch.cs.rice.edu/cmuhns.html>)
- **Commercial products are OPNET and Globosim**
 - » Main benefit – very rigorous propagation models, can deal with larger networks, more “realistic”

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Wireless Testbeds

- **A number of testbeds are now available over the Internet**
- **Orbit at Rutgers: indoor grid of 200 nodes in a big room**
 - » Good for certain classes of experiments
- **In the wild deployment examples:**
 - » Emulab in Utah: indoor, WiFi like deployment
 - » Outdoor Orbit
 - » Homenet at CMU
 - » MAP at Purdue
 - » Etc.

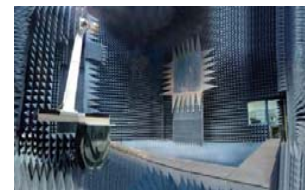
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Traditional Testbed Limitations



Distributed uncontrolled signal propagation environment



Controlled but highly-constrained signal propagation environment



Can be extremely cumbersome to work with!

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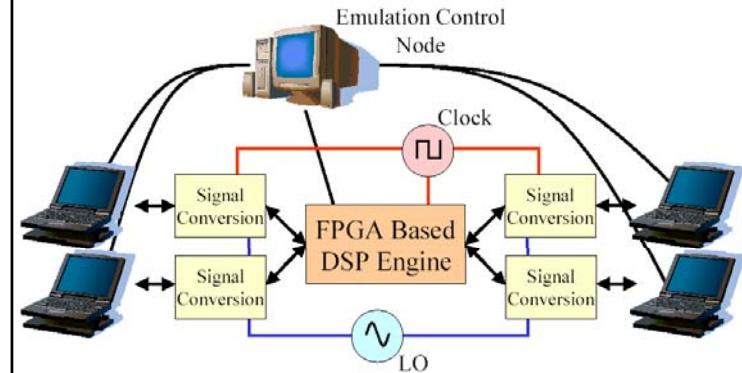
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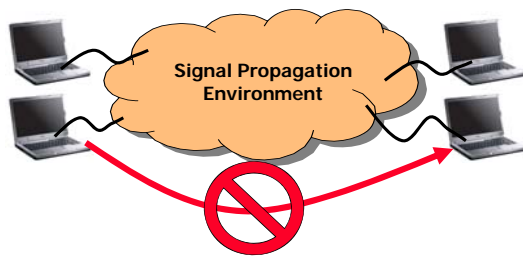
Emulator Architecture



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Physical Layer Emulation



- Key idea:
 - » Virtualize signal propagation environment
 - » Highly controlled and extremely flexible signal propagation environment

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Why Better than Simulation?

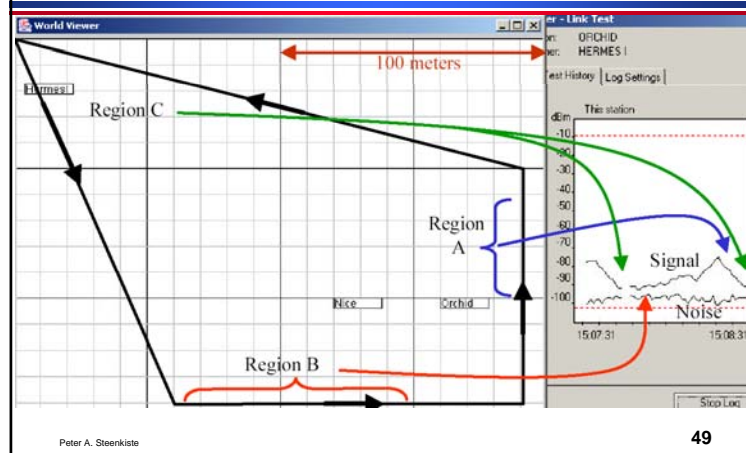
	Reality	Simulation	Physical Emulation
Applications	✓	✗	✓
OS	✓	✗	✓
Networking Stack	✓	~	✓
Host Device	✓	✗	✓
Wireless Device	✓	✗	✓
Antenna	✓	✗	✗
Signal Propagation	✓	✗	✗

✗ Gives Control

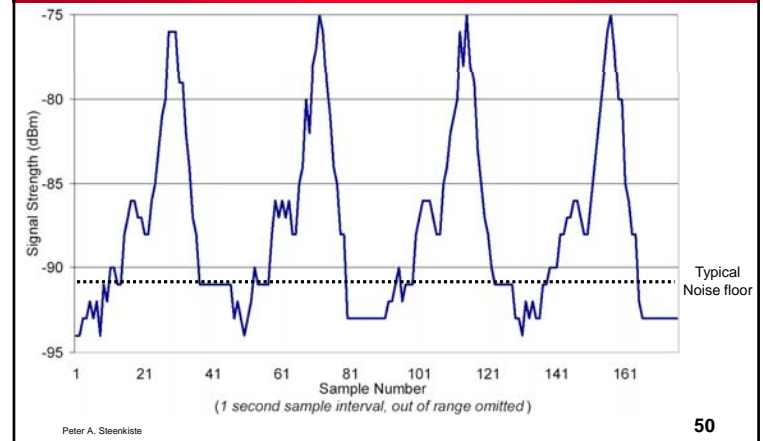
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Simple Mobility Experiment

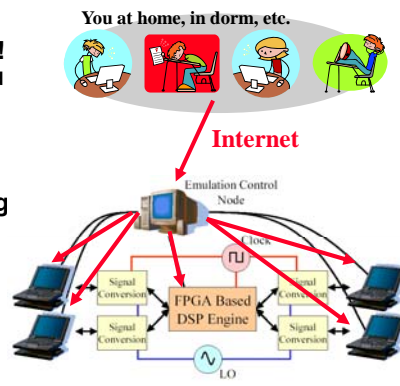


Observed Signal Strength



Running Wireless Experiments

- **Runs wireless mobile experiments remotely!**
 - » Devices are rack mounted in machine room
 - » Experiment is done by controlling the emulated channels (on FPGA) and the laptops
- **Three ways of defining and controlling experiments:**
 - » GUI based
 - » Script-based: simple sequence of commands
 - » Java-based: full control



Overview of Emulator Experiments

- **Range of wireless channels:**
 - » Traces: replay the real world (approximately)
 - » Statistical models: real world behavior (on average)
 - » Artificial models: to isolate specific effects
- **Different types of experiments:**
 - » Understanding wireless network behavior
 - » Characterization of channel, device properties
 - » Comparing performance of different protocols
 - » Testing and debugging prototypes
 - » Interoperability and standards compliance testing
- **Challenges:**
 - » Realistic traffic models and mobility patterns
 - » Extracting meaning for larger scale
 - » Understanding impact of heterogeneity

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What is Next?

- **No class on Monday (MLK)**
- **Wireless physical layer lectures start on Wednesday January 20th.**