15-496: A Hand-on Introduction to Wireless Networks

Lecture 1: Organization, Wireless Networking Challenges

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Spring Semester 2008

http://www.cs.cmu.edu/~prs/wireless08/

TA: Haowen Chan

- Peter is currently travelling, will be back on Thursday

Schedule for Today

- Goals and structure of the course
- Administrative stuff
- Protocol stack review
- Wireless challenges
- Wireless emulator

Goals of the Course

- Learn about the unique challenges in wireless networking
  - » Starting point is "regular" wired networks
- Gain an understanding of wireless technologies at the physical, MAC, and higher layers
  - » Focus is on the wireless protocol layer
- Get experience in working with wireless networks
  - » Investigating protocols, algorithms
  - » Measurements of wireless networks
- Get a broad view of the ongoing research in the wireless domain
  - » Focus on the protocol level

Course Contents

- Lectures: unique features of wireless
  - » About 14 lectures on diverse topics
- Hands- on assignments
  - » Reinforce the concepts of the lectures
  - » Use the wireless network emulator testbed
  - » Concentrated in the first half of the semester
- Project: team-based (2-3), hands-on
  - » More in-depth study of a particular topic
  - » Project depth commensurate to team size
  - » Topic is flexible
  - » Second half of the mini-semester

Overview of Lectures

- Wireless challenges (today)
  - » Why is wireless different?
- Physical layer concepts (2-3)
  - » Focus on understand impact on higher layers
  - » Not an in-depth course on the communications field!
- MAC protocols (5-6)
  - » Protocol mechanisms
  - » Important protocols: WiFi, Bluetooth, WiMax, ..
- Hot topics wireless (4-5)
  - » Mesh networking, TCP over wireless, …

Assignments

- Simple experiments with small numbers of nodes to illustrate and reinforce the concepts introduced in the lectures:
  - How does throughput change with distance?
  - Can you access the web using WiFi while driving down the highway?
  - Can you recreate a hidden terminal situation?
  - Does RTS/CTS help?
- Assignments will use the CMU wireless network emulator
  - Supports repeatable controlled experiments
  - High level overview today – details in the lab sessions

Projects

- More in-depth study of a particular topic.
  - Performance evaluation studies, protocol modifications, applications, measurements, ..
  - Must be wireless, but otherwise flexible
  - List of sample topics will be provided
- Must carefully consider platform options:
  - Emulator
  - Real-world experiments
  - Simulator based (last resort)
- Can start thinking about topics now …
- Can use the class Blackboard discussion forum to find partners

Administrative Stuff

- "Wireless Communications and Networks", William Stallings, Prentice Hall, 2002
  - Will not cover all the material in the book
  - Not all material is in the book - slides are fairly detailed
- Web page is primary source for information
  - Use blackboard for submission of assignments
- Course secretary: Angela Miller, Wean Hall 8215, amiller@cs.cmu.edu
- Teaching assistant: Haowen Chan, haowen+15496ta@cs.cmu.edu

Grading

Tentative grade distribution:

- Assignments: 20%
- Quizzes: 20%
- Project: 30%
- Final: 30%

Collaboration

- Traditional rules of collaboration apply
  - http://www.cmu.edu/policies/documents/Cheating.html
- You must complete individual assignments and tests by yourself
- You must collaborate with your partner in the team-based project
- It is acceptable and encouraged to help fellow student with generic problems
  - E.g. where to find documentation, use of tools, ..

Schedule for Today

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- Announcement:
  - Recitation cancelled this week (19 March)
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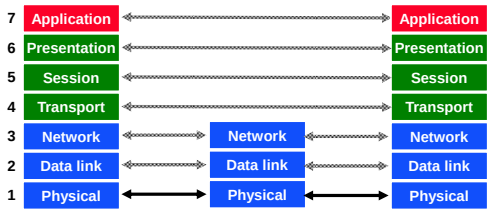
Networking 101
Layer Network Model

The Open Systems Interconnection (OSI) Model.



OSI Motivation

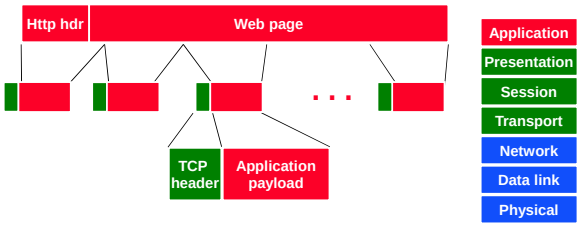
- Standard approach of breaking up a system in a set of components, but the components are organized as a set of layers.
  - » Only horizontal and vertical communication
  - » Components/layers can be implemented and modified in isolation
- Each layer offers a service to the higher layer, using the services 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

OSI Functions

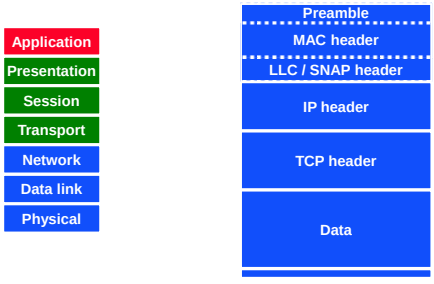
- (1) Physical: transmission of a bit stream.
- (2) Data link: flow control, framing, error detection.
- (3) Network: switching and routing.
- (4) Transport: reliable end to end delivery.
- (5) Session: managing logical connections.
- (6) Presentation: data transformations.
- (7) Application: specific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

Multiplexing takes place in multiple layers

Example: Sending a Web Page



A TCP / IP / 802.11 Packet



Benefits of Layered Architecture

- Significantly reduces the complexity of maintaining the system.
  - Effort is 7 x 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
  - Does not impact the other components in the system
  - Different implementation versus different protocols

True For Wireless?

- 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

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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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, …

What is Hard about Wireless?

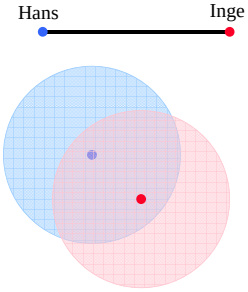
There are no wires!

Causes problems in many areas:

- High attenuation
- Interference and noise
- Capacity of the network
- Effects of mobility
- Security

Communication based on Broadcasting

- Wired communication is usually point-to-point.
  - Broadcast is hard to scale
- Wireless communication is inherently broadcast.
  - Well, usually
- Of course: it does allow nodes to move



Mobility

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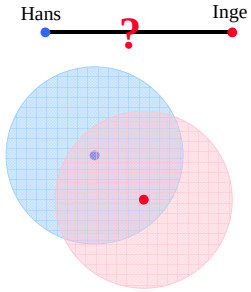
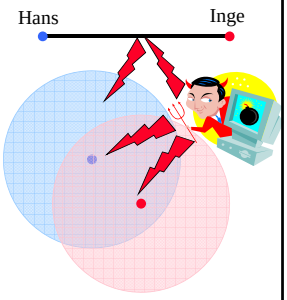


Wireless is very Sensitive to Noise …

- 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.



… and Interference

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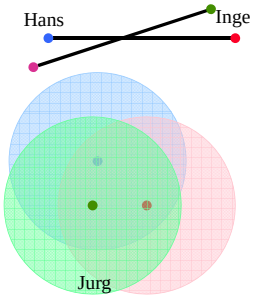
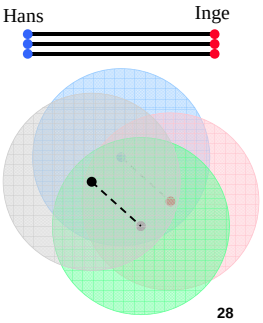


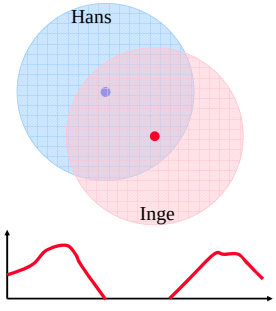
How Do We Increase Network Capacity?

- 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.



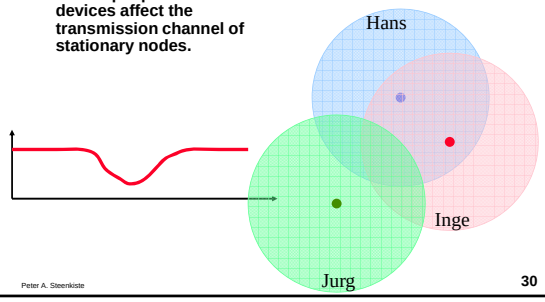
Mobility Affects the Link Throughput

- 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!



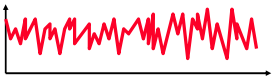
Mobility is an Issue even for Stationary Users

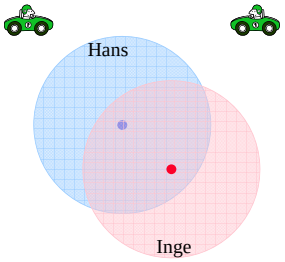
- Mobile people and devices affect the transmission channel of stationary nodes.



And It Gets Worse …

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





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!
- The focus of this course is on how to make it work, despite all the challenges

How Do We Address These Problems?

- Physical layer
  - Lecture 2-4, assignments
- MAC layer
  - Lecture 4-9, assignments
- Higher layer protocols, applications
  - Lectures 10+, assignments
- Unique challenges with specific environments
  - Lectures 10+
- Projects can be at any level

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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

Simulator — Emulator — Testbed

Control & Repeatability — Realism

- Emulator provides an attractive middle ground between simulation and testbeds

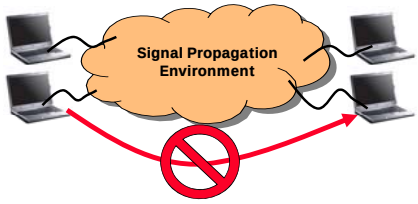
Traditional Testbed Limitations

Distributed uncontrolled signal propagation environment

Controlled but highly-constrained signal propagation environment

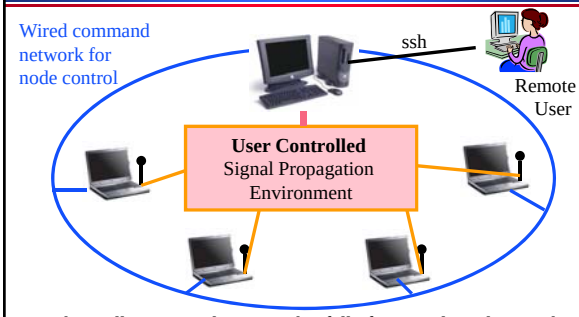
Can be extremely cumbersome to work with!

Physical Layer Emulation



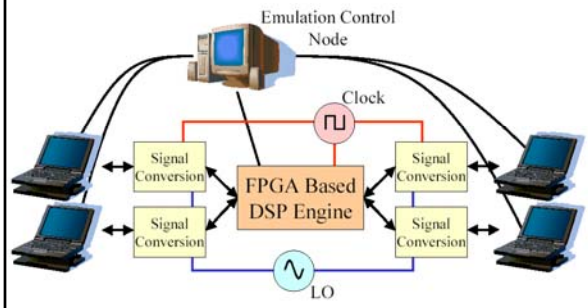
- **Key idea:**
  - Virtualize signal propagation environment
  - Highly controlled and extremely flexible signal propagation environment

Logical Architecture



Physically existing devices with a fully functional wireless stack

Emulator Architecture Details



Why Better than Simulation?

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

Main Advantage

- You're testing the *actual* code and hardware of the wireless devices
- With a "repeatable" (well-specified) physical layer
- High specificity
  - "yes, that's how the protocol really behaves on live hardware, we actually implemented it, we didn't just simulate it!"
- High generality
  - "we tested it for a wide variety of physical models, and you can repeat these tests for yourself"

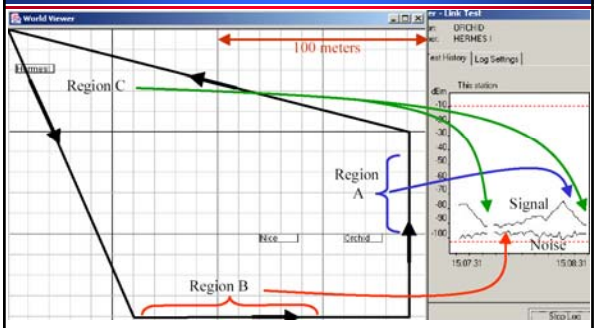
Main Advantage for this Course

- Ease of use!
- You will be effectively conducting experiments on a "real" wireless testbed without having to carry four or five laptops and deploy them all over campus

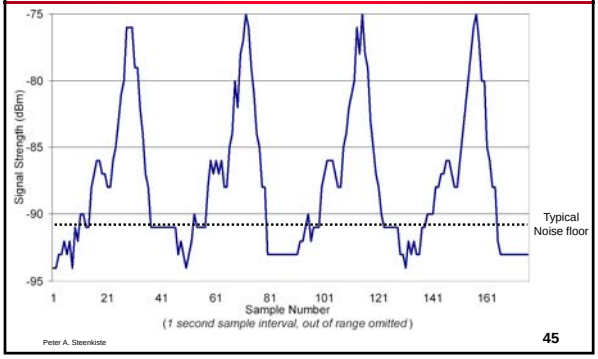
Main Limitations?

- Harder to implement new protocols
  - » Need to fit in the stack and talk to other layers properly
- Existing hardware / software must be tweakable / programmable
  - » E.g. open source OS (Linux), open source drivers (Madwifi)
  - » Less flexibility with e.g. Windows
  - » Changing and reloading drivers may be time consuming
- Dependent on applicability of physical models
  - » If model is inaccurate, results are irrelevant

Simple Mobility Experiment

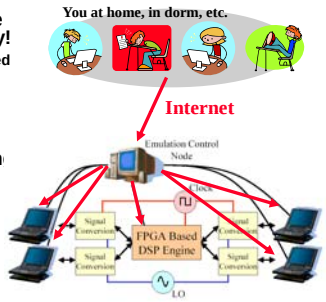


Observed Signal Strength



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 definin 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

What is Next?

	Tuesday	Wednesday	Thursday
Week 1	Introduction	No Recitation	Physical layer 1
Week 2	Physical layer 2	Emulator Programming	Phy/MAC layer
Week 3	MAC layer	More emulator programming	MAC layer
Week 4	MAC layer	Review	MAC layer
Week 5	MAC layer		Wireless & Internet

Announcement

- **No recitation on Wednesday**
- **See you in class on Thursday (20 March)**