18-452/18-750
Wireless Networks and Applications
Lecture 2: Networking Overview and Wireless Challenges

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http://www.cs.cmu.edu/~prs/wirelessS17/

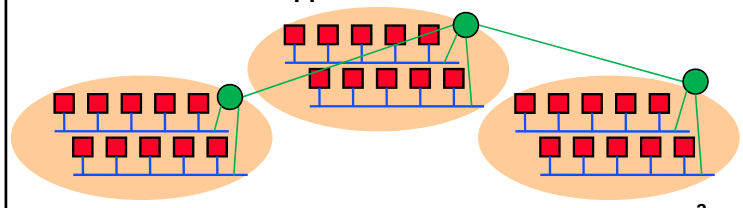
Outline

- Goals and structure of the course
- Administrative stuff
- A bit of history
- Wireless technologies
- Building a network
  - » Designing a BIG system
  - » The OSI model
  - » Packet-based communication
  - » Challenges in Wireless Networking
- Please ask questions!

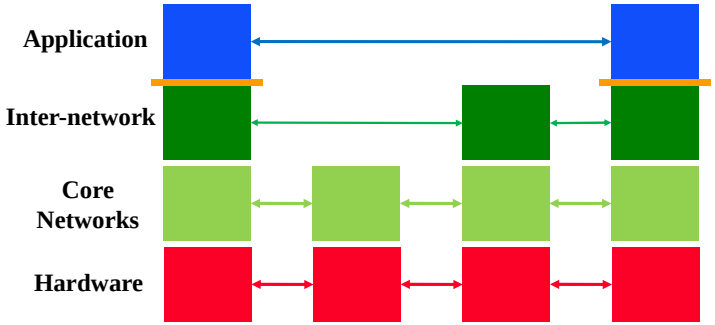
Let Us Try to be More Concrete and Practical

- Two or more hosts talk over a wire
- Groups of hosts can talk at two levels
  - » Hosts talk in a network is homogeneous in terms of administration and technology
  - » Hosts talk across networks that have different administrators and my use different technology
- We run some applications over that

Physical
Datalink
Internet



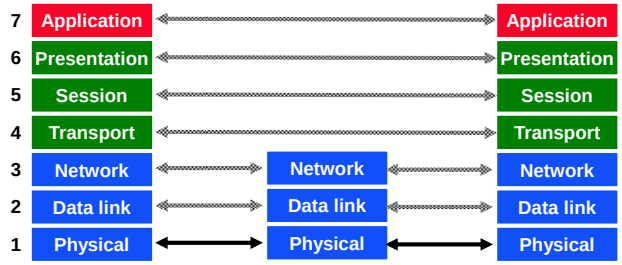
Protocol and Service Levels



- Having two different types of protocols helps with scalability and network management

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 with well defined interfaces, but components are organized as a set of layers.
  - » Only horizontal and vertical communication
  - » Components/layers can be implemented and modified in isolation without affecting the other components
- 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.

Benefits of Layered Architecture

- Significantly reduces the complexity of building and 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
  - » Only the Internet Protocol in the "middle" layer

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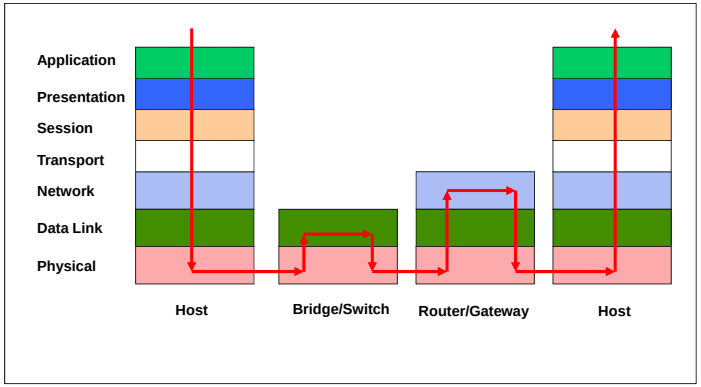
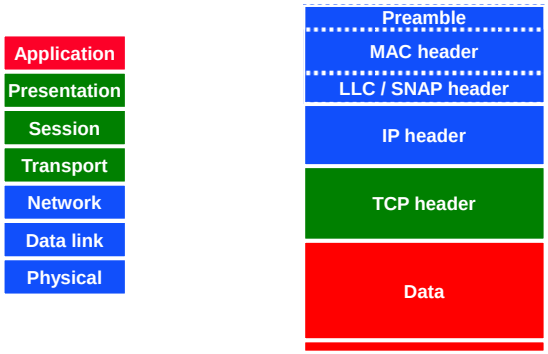
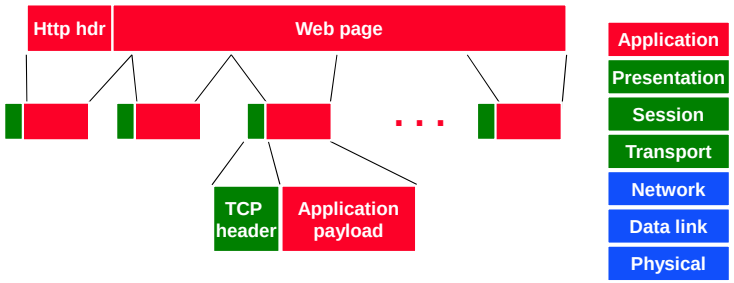
Life of Packet



A TCP / IP / 802.11 Packet



Example: Sending a Web Page



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Why Use Wireless?

There are no wires!

Has several significant advantages:

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

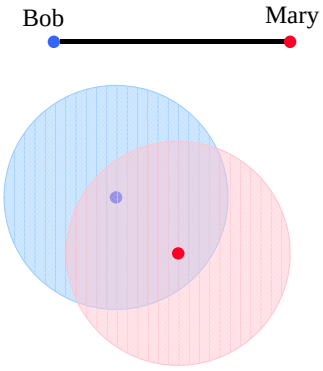
What is Hard about Wireless?

There are no wires!

- In wired networks links are constant, reliable and physically isolated
  - A 100 Mbs Ethernet always has the same properties
  - This is definitely not true for "54 Mbs" 802.11a
- In wireless networks links are variable, error-prone and share the ether with each other and other external, uncontrolled sources
  - Link properties can be extremely dynamic

Wireless is a shared medium

- In wired communication, signals are contained in a conductor
  - Copper or fiber
  - Guides energy to destination
  - Protects signal from external signals
- Wireless communication uses broadcasting over the shared ether
  - Energy is distributed in space
  - Signal must compete with many other signals in same frequency band

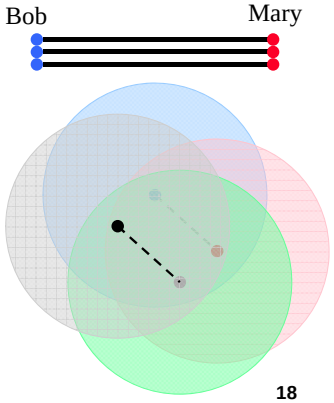


Attenuation and Errors

- In wired networks error rate 10^{-10} or less
  - » Wireless networks are far from that target
- Signal attenuates with distance and is affected by noise and competing signals
- Obstacles further attenuate the signal
- Probability of a successful reception depends on the "signal to interference and noise ratio" - the SINR
- More details later in the course

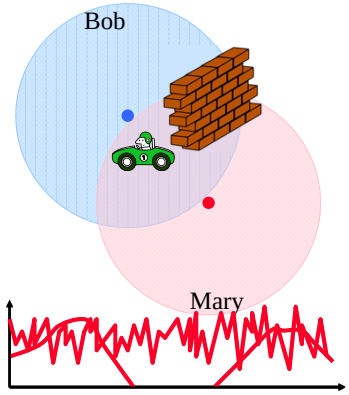
How Do We Increase Network Capacity?

- 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 obstacles blocking the "line of sight" (LOS)
  - » "Slow fading" – the signal strength changes slowly
- Reflections off obstacles combined with mobility can cause "fast fading"
  - » Very rapid changes in the signal
  - » More on this later
- Hard to predict signal!



How is Wireless Different?

Wired	Wireless
• Physical link properties are fixed and specified in standards	• Physical link properties can change a lot rapidly in unpredictable ways
• Designed for low error rates and throughput is fixed and known	• Error rates vary a lot and throughput is very dynamic
• Datalink layer is simple and optimized for the physical layer	• How do you design an efficient datalink protocol?
• Internet was designed assuming wires	• How well will higher layer protocols work?

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- In practice: most significant evolution and diversity at the top and bottom:
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FALSE For Wireless?

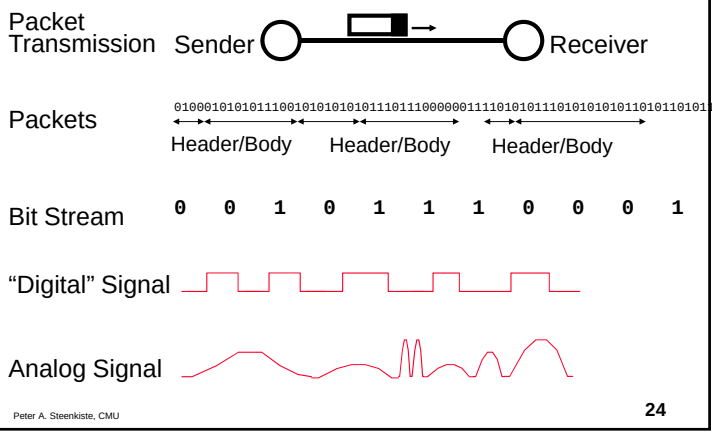
Implications of Variability in Wireless PHY Layer

- Wireless datalink protocols must optimize throughput across an unknown and dynamic transmission medium
  - » It helps to understand what causes the changes
- Wireless "links" as observed by layers 3-7 will be unavoidably different from wired links
  - » Variable bandwidth and latency
  - » Intermittent connectivity
  - » Must adapt to changes in connectivity and bandwidth
- Understanding the physical layer is the key to making wireless work well
  - » Both at the wireless network and Internet level

Outline

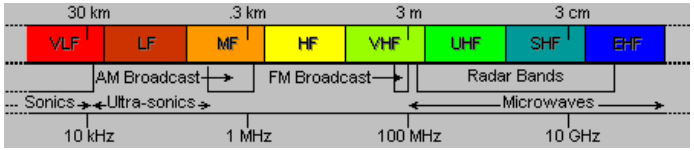
- RF introduction
  - » A cartoon view
  - » Communication
  - » Time versus frequency view
- Modulation and multiplexing
- Channel capacity
- Antennas and signal propagation
- Modulation
- Diversity and coding
- OFDM

From Signals to Packets



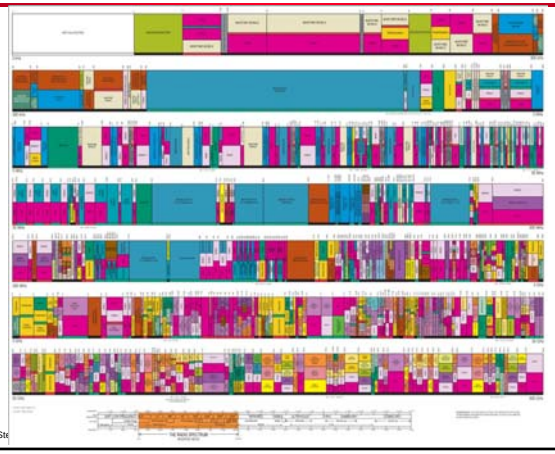
RF Introduction

- RF = Radio Frequency
  - Electromagnetic signal that propagates through "ether"
  - Ranges 3 KHz .. 300 GHz
  - Or 100 km .. 0.1 cm (wavelength)



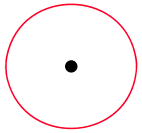
- Travels at the speed of light
- Can take both a time and a frequency view

Spectrum Allocation in US



Cartoon View 1 – A Wave of Energy

- Think of it as energy that radiates from an antenna and is picked up by another antenna.
  - Helps explain properties such as attenuation
  - Density of the energy reduces over time and with distance



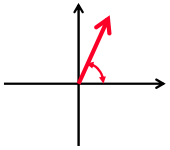
- Useful when studying attenuation
  - Receiving antennas catch less energy with distance
  - Notion of cellular infrastructure

Cartoon View 2 – Rays of Energy

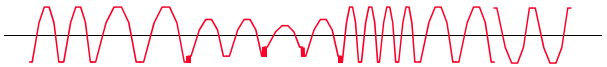
- Can also view it as a "ray" that propagates between two points
- Rays can be reflected etc.
  - We can have provide connectivity without line of sight
- A channel can also include multiple "rays" that take different paths – "multi-path"
  - Helps explain properties such as signal distortion, fast fading, …

(Not so) Cartoon View 3 – Electro-magnetic Signal

- Signal that propagates and has an amplitude and phase
  - » Can be represented as a complex number
- … and that changes over time with a certain frequency
- Simple example is a sine wave
  - » Has an amplitude, phase, and frequency
  - » … that can change over time



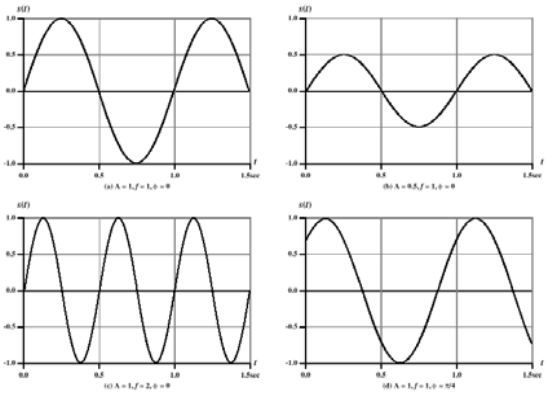
Relevance to Networking?



Sine Wave Parameters

- General sine wave
  - » $s(t) = A \sin(2\pi ft + \phi)$
- Example on next slide shows the effect of varying each of the three parameters
  - a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s
  - b) Reduced peak amplitude; $A=0.5$
  - c) Increased frequency; $f = 2$, thus $T = ½$
  - d) Phase shift; $\phi = \pi/4$ radians (45 degrees)
- note: 2π radians = 360° = 1 period

Space and Time View Revisited

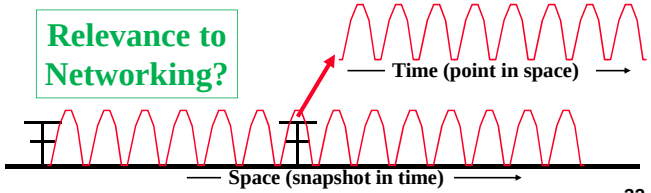


$s(t) = A \sin(2 ft + \phi)$

Simple Example: Sine Wave

- RF signal travels at the speed of light
- Can look at a point in space: signal will change in time according to a sine function
  - » Signal at different points are (roughly) copies of each other
- Can take a snapshot in time: signal will "look" like a sine function in space

Relevance to Networking?



Key Idea of Wireless Communication

- **The sender sends an EM signal and changes its properties over time**
  - » **Changes reflect a digital signal, e.g., binary or multi-valued signal**
  - » **Can change amplitude, phase, frequency, or a combination**
- **Receiver learns the digital signal by observing how the received signal changes**
  - » **Note that signal is no longer a simple sine wave or even a periodic signal**

"The wireless telegraph is not difficult to understand.
The ordinary telegraph is like a very long cat.
You pull the tail in New York, and it meows in Los Angeles.
The wireless is exactly the same, only without the cat."

Challenge

- **Cats? This is very informal!**
  - » **Sender "changes signal" and receiver "observes changes"**
- **Wireless network designers need more precise information about the performance of wireless "links"**
  - » **Can the receiver always decode the signal?**
  - » **How many Kbit, Mbit, Gbit per second?**
  - » **Does the physical environment, distance, mobility, weather, season, the color of my shirt, etc. matter?**
- **We need a more formal way of reasoning about wireless communication:**

  Represent the signal in the frequency domain!