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

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**
- Physical link properties are fixed and specified in standards
- Designed for low error rates and throughput is fixed and known
- Datalink layer is simple and optimized for the physical layer
- Internet was designed assuming wires

**Wireless**
- Physical link properties can change rapidly in unpredictable ways
- Error rates vary a lot and throughput is very dynamic
- How do you design an efficient datalink protocol?
- How well will higher layer protocols work?

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

Packet Transmission

Sender → Receiver

Packets

Header/Body

Bit Stream

0 0 1 0 1 1 1 0 0 0 1

“Digital” Signal

Analog Signal
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

Wireless Spectrum in the 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 changes over time with a certain frequency and has an amplitude and phase
  » Think: sine wave
- Relevance to networking?
  » The sender can change the properties of the EM signal over time to convey information
  » Receivers can observe these changes and extract the information

Time and Point View of Signal

- Can look at a point in space: signal will change in time according to a sine function
  » But transmitter can change phase, amplitude, frequency
- Can take a snapshot in time: signal will “look” like a sine function in space
  » Signal at different points are (rough) copies of each other
- Receiver can observe transmitter’s changes

Relevance to Networking?

Communication

- 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) \( A = 1, f = 1 \text{ Hz}, \phi = 0; \text{ thus } T = 1s \)
  b) Reduced peak amplitude; \( A=0.5 \)
  c) Increased frequency; \( f = 2, \text{ thus } T = \frac{1}{2} \)
  d) Phase shift; \( \phi = \pi/4 \text{ radians (45 degrees)} \)
- note: \( 2\pi \text{ radians} = 360^\circ = 1 \text{ period} \)
Space and Time View Revisited

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.”

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Challenge

- Cats, really? 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!
Time Domain View: Periodic versus Aperiodic Signals

- **Periodic signal** - analog or digital signal pattern that repeats over time
  
  » \( s(t+T) = s(t) \)
  
  – where \( T \) is the period of the signal
  
  » Allows us to take a frequency view – important to understand wireless challenges and solutions

- **Aperiodic signal** - analog or digital signal pattern that doesn't repeat over time
  
  » Hard to analyze

- Can “make” an aperiodic signal periodic by taking a time slice \( T \) and repeating it
  
  » Often what we do implicitly

Key Parameters of (Periodic) Signal

- **Peak amplitude** (\( A \)) - maximum value or strength of the signal over time; typically measured in volts

- **Frequency** (\( f \))
  
  » Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

- **Period** (\( T \)) - amount of time it takes for one repetition of the signal
  
  » \( T = 1/f \)

- **Phase** (\( \phi \)) - measure of the relative position in time within a single period of a signal

- **Wavelength** (\( \lambda \)) - distance occupied by a single cycle of the signal
  
  » Or, the distance between two points of corresponding phase of two consecutive cycles

Key Property of Periodic EM Signals

- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases

- The period of the total signal is equal to the period of the fundamental frequency
  
  » All other frequencies are an integer multiple of the fundamental frequency

- There is a strong relationship between the “shape” of the signal in the time and frequency domain
  
  » Discussed in more detail later

Signal = Sum of Sine Waves

\[
\begin{align*}
\text{Signal} &= + 1.3 \times \\
&+ 0.56 \times \\
&+ 1.15 \times 
\end{align*}
\]
The Frequency Domain

A (periodic) signal can be viewed as a sum of sine waves of different strengths.
- Corresponds to energy at a certain frequency
- Every signal has an equivalent representation in the frequency domain.
- What frequencies are present and what is their strength (energy)

We can translate between the two formats using a Fourier transform.