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Wireless Networks and Applications
Lecture 2: Wireless Challenges

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http://www.cs.cmu.edu/~prs/wirelessS18/

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, …

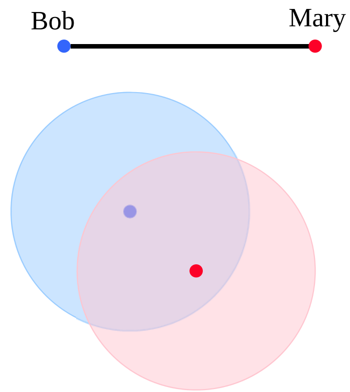
What is Hard about Wireless?

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

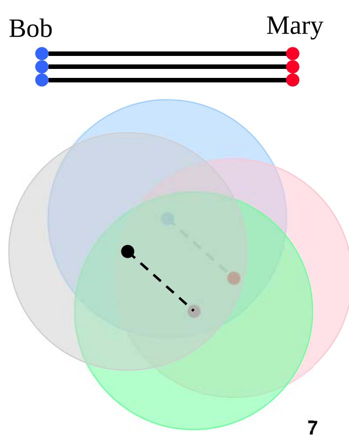


Attenuation and Errors

- 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

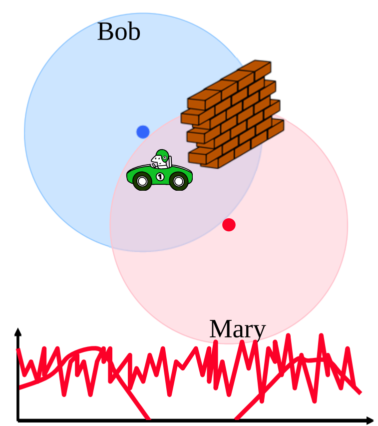
How Do We Increase Network Capacity?

- 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?

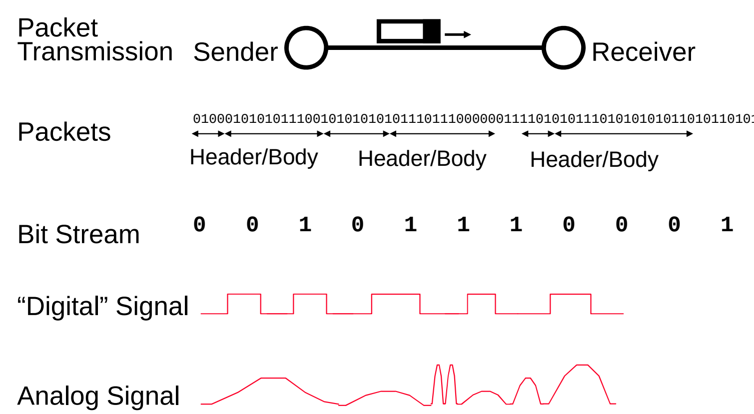
Implications of Variability in Wireless PHY Layer

- 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

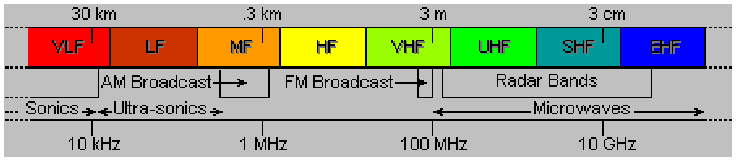
- RF introduction
  - » A cartoon view
  - » Communication
  - » Time versus frequency view
- Modulation and multiplexing
- Channel capacity
- Antennas and signal propagation
- Modulation
- Diversity and coding
- OFDM

From Signals to Packets



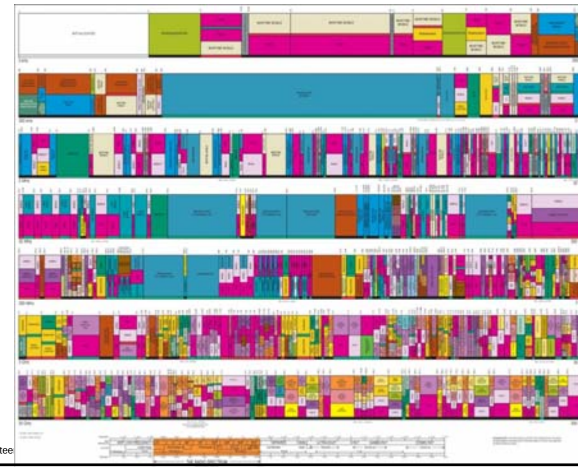
RF Introduction

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



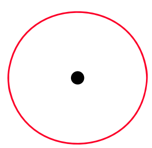
- Travels at the speed of light
- Can take both a time and a frequency view

Wireless Spectrum in the US



Cartoon View 1 – A Wave of Energy

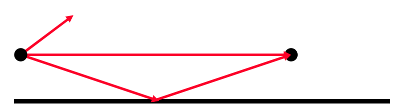
- Think of it as energy that radiates from an antenna and is picked up by another antenna.
  - » Helps explain properties such as attenuation
  - » Density of the energy reduces over time and with distance



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

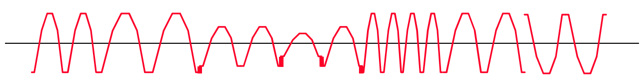
Cartoon View 2 – Rays of Energy

- 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

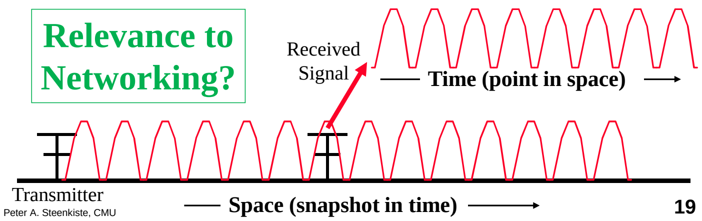
- Signal that propagates and changes over time with a certain frequency and has an amplitude and phase
  - » Think: sine wave
- Relevance to networking?
  - » The sender can change the properties of the EM signal over time to convey information
  - » Receivers can observe these changes and extract the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



Time and Point View of Signal

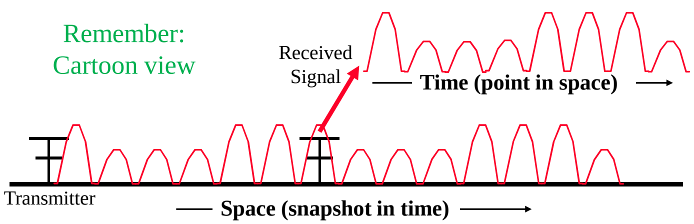
- Can look at a point in space: signal will change in time according to a sine function
  - » But transmitter can change phase, amplitude, frequency
- Can take a snapshot in time: signal will "look" like a sine function in space
  - » Signal at different points are (rough) copies of each other
- Receiver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

Relevance to Networking?



Communication

Remember: Cartoon view

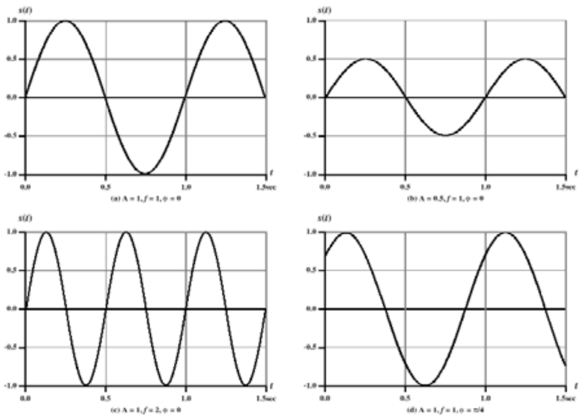


- Sender changes signal in agree upon way and receiver interprets the changes
  - » "Modulation" and "demodulation"
- Problem: the signal gets distorted on "channel"
  - » Makes it harder for receiver to interpret changes

Sine Wave Parameters

- General sine wave
  - » $s(t) = A \sin(2\pi f t + \phi)$
- 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



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

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

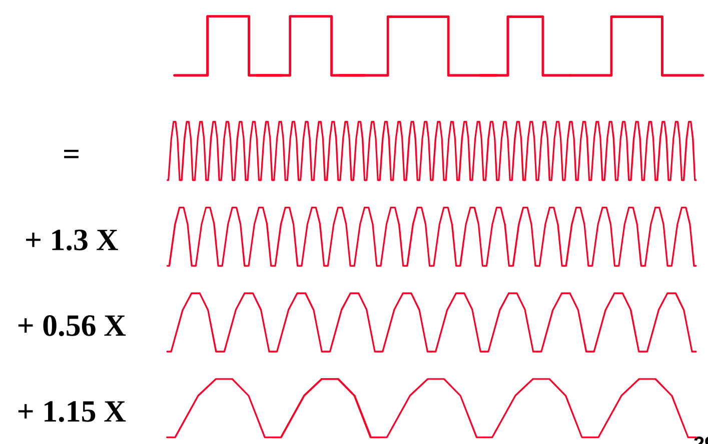
Key Parameters of (Periodic) Signal

- 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 (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - 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



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