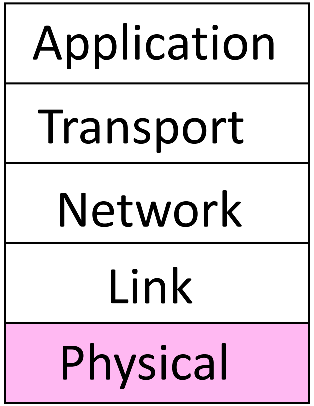
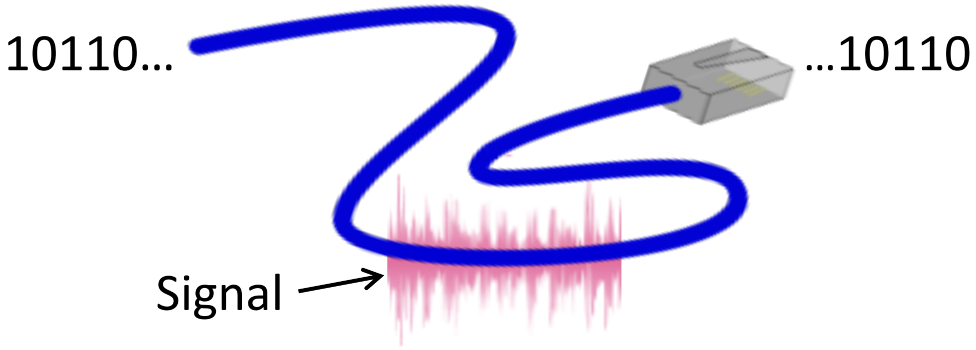
Where we are in the Course

- Beginning to work our way up starting with the Physical layer



Scope of the Physical Layer

- Concerns how signals are used to transfer message bits over a link
  - Wires etc. carry analog signals
  - We want to send digital bits

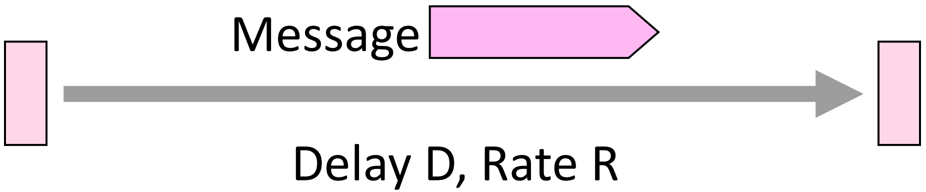


Topics

1. Properties of media
   - Wires, fiber optics, wireless
2. Simple signal propagation
   - Bandwidth, attenuation, noise
3. Modulation schemes
   - Representing bits, noise
4. Fundamental limits
   - Nyquist, Shannon

Simple Link Model

- We'll end with an abstraction of a physical channel
  - Rate (or bandwidth, capacity, speed) in bits/second
  - Delay in seconds, related to length



- Other important properties:
  - Whether the channel is broadcast, and its error rate

Message Latency

- Latency is the delay to send a message over a link
  - Transmission delay: time to put M-bit message "on the wire"
  - Propagation delay: time for bits to propagate across the wire
  - Combining the two terms we have:

Message Latency (2)

- Latency is the delay to send a message over a link
  - Transmission delay: time to put M-bit message "on the wire"

    T-delay = M (bits) / Rate (bits/sec) = M/R seconds

  - Propagation delay: time for bits to propagate across the wire

    P-delay = Length / speed of signals = Length / ⅔c = D seconds

  - Combining the two terms we have: L = M/R + D

Metric Units

- The main prefixes we use:

Prefix	Exp.	prefix	exp.
K(ilo)	10^3	m(illi)	10^{-3}
M(ega)	10^6	μ(micro)	10^{-6}
G(iga)	10^9	n(ano)	10^{-9}

- Use powers of 10 for rates, 2 for storage
  - 1 Mbps = 1,000,000 bps, 1 KB = 2^{10} bytes
- "B" is for bytes, "b" is for bits

Latency Examples

- "Dialup" with a telephone modem:
  - D = 5 ms, R = 56 kbps, M = 1250 bytes

- Broadband cross-country link:
  - D = 50 ms, R = 10 Mbps, M = 1250 bytes

Latency Examples (2)

- "Dialup" with a telephone modem:

  D = 5 ms, R = 56 kbps, M = 1250 bytes

  $L = 5\text{ ms} + (1250\text{x}8)/(56 \times 10^3)\text{ sec} = 184\text{ ms!}$

- Broadband cross-country link:

  D = 50 ms, R = 10 Mbps, M = 1250 bytes

  $L = 50\text{ ms} + (1250\text{x}8) / (10 \times 10^6)\text{ sec} = 51\text{ ms}$

- A long link or a slow rate means high latency
  - Often, one delay component dominates

Bandwidth-Delay Product

- Messages take space on the wire!

- The amount of data in flight is the <u>bandwidth-delay (BD) product</u>

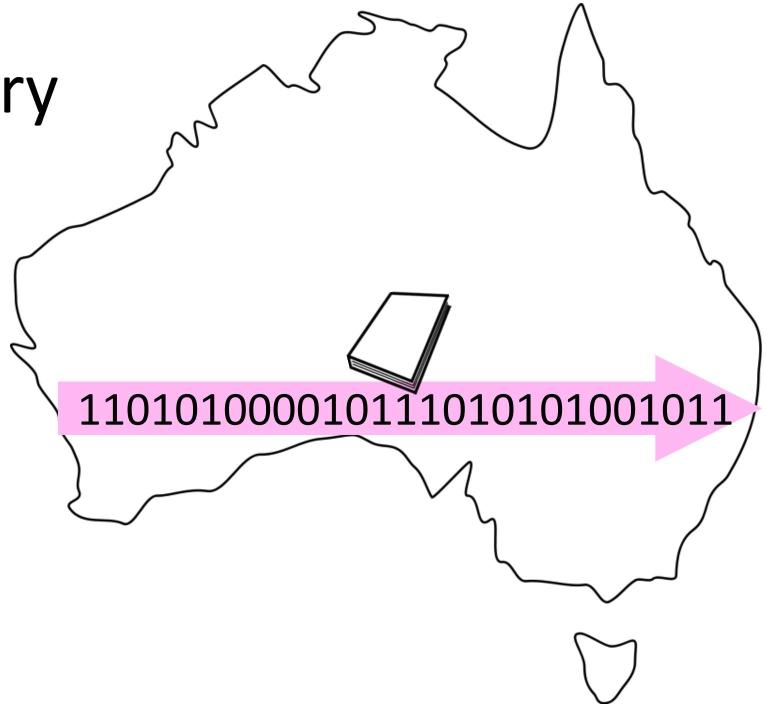
$$BD = R \times D$$

  - Measure in bits, or in messages
  - Small for LANs, big for "long fat" pipes

Bandwidth-Delay Example

- Fiber at home, cross-country

  R=40 Mbps, D=50 ms



Bandwidth-Delay Example (2)

- Fiber at home, cross-country

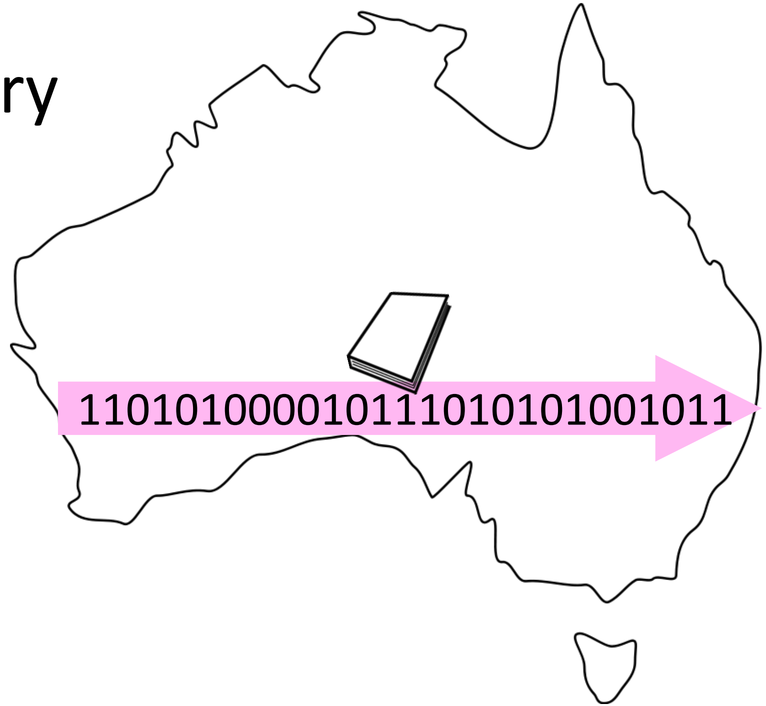
  R=40 Mbps, D=50 ms

  BD $= 40 \times 10^6 \times 50 \times 10^{-3}$ bits

  $= 2000$ Kbit

  $= 250$ KB

- That's quite a lot of data "in the network"!

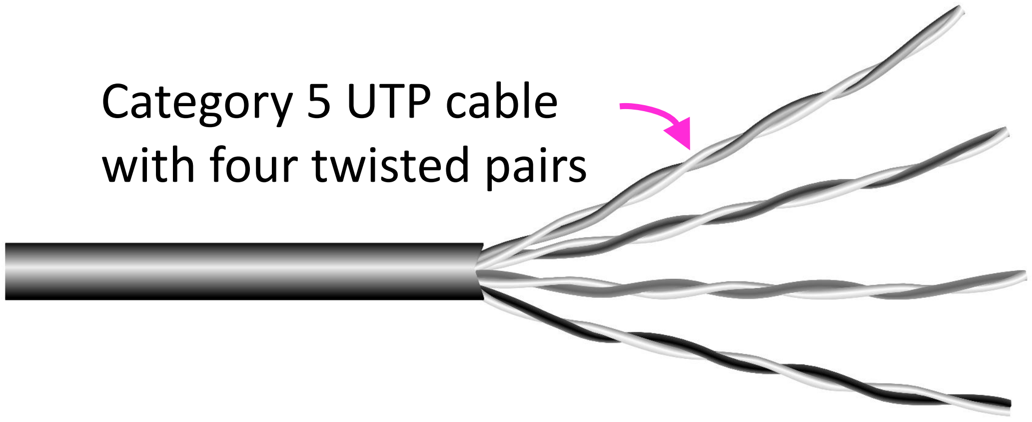


Types of Media

- Media propagate signals that carry bits of information
- We'll look at some common types:
  - Wires »
  - Fiber (fiber optic cables) »
  - Wireless »

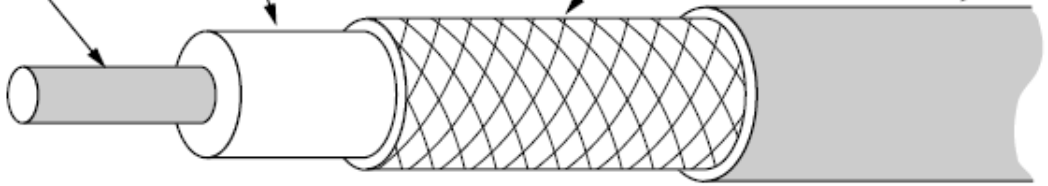
Wires – Twisted Pair

- Very common; used in LANs and telephone lines
  - Twists reduce radiated signal



Wires – Coaxial Cable

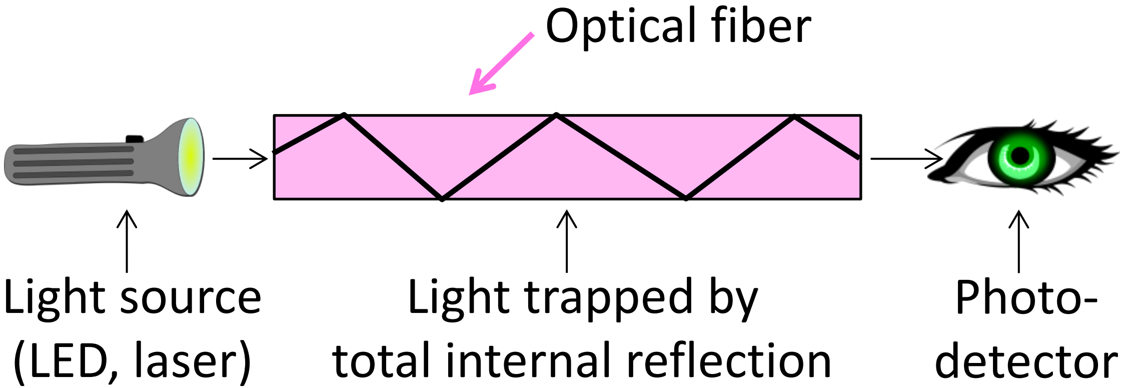
- Also common. Better shielding for better performance



- Other kinds of wires too: e.g., electrical power (§2.2.4)

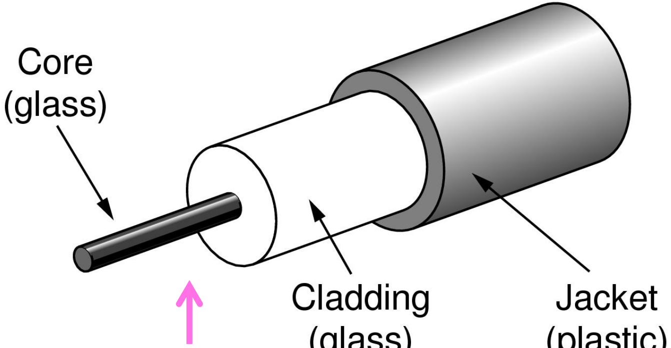
Fiber

- Long, thin, pure strands of glass
  - Enormous bandwidth (high speed) over long distances

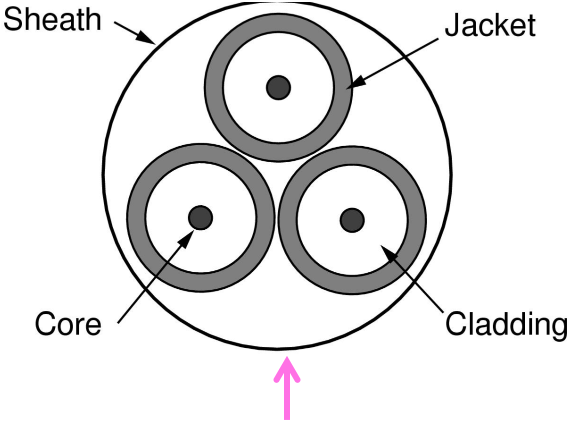


Fiber (2)

- Two varieties: multi-mode (shorter links, cheaper) and single-mode (up to ~100 km)



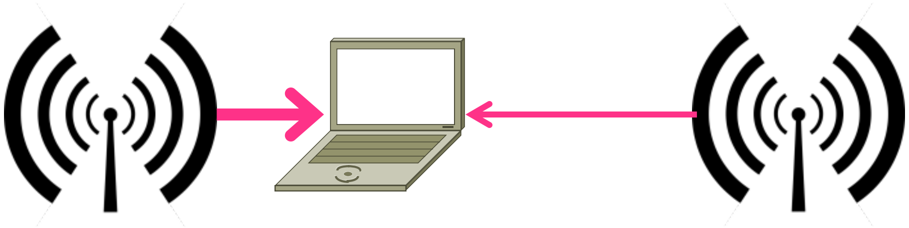
One fiber

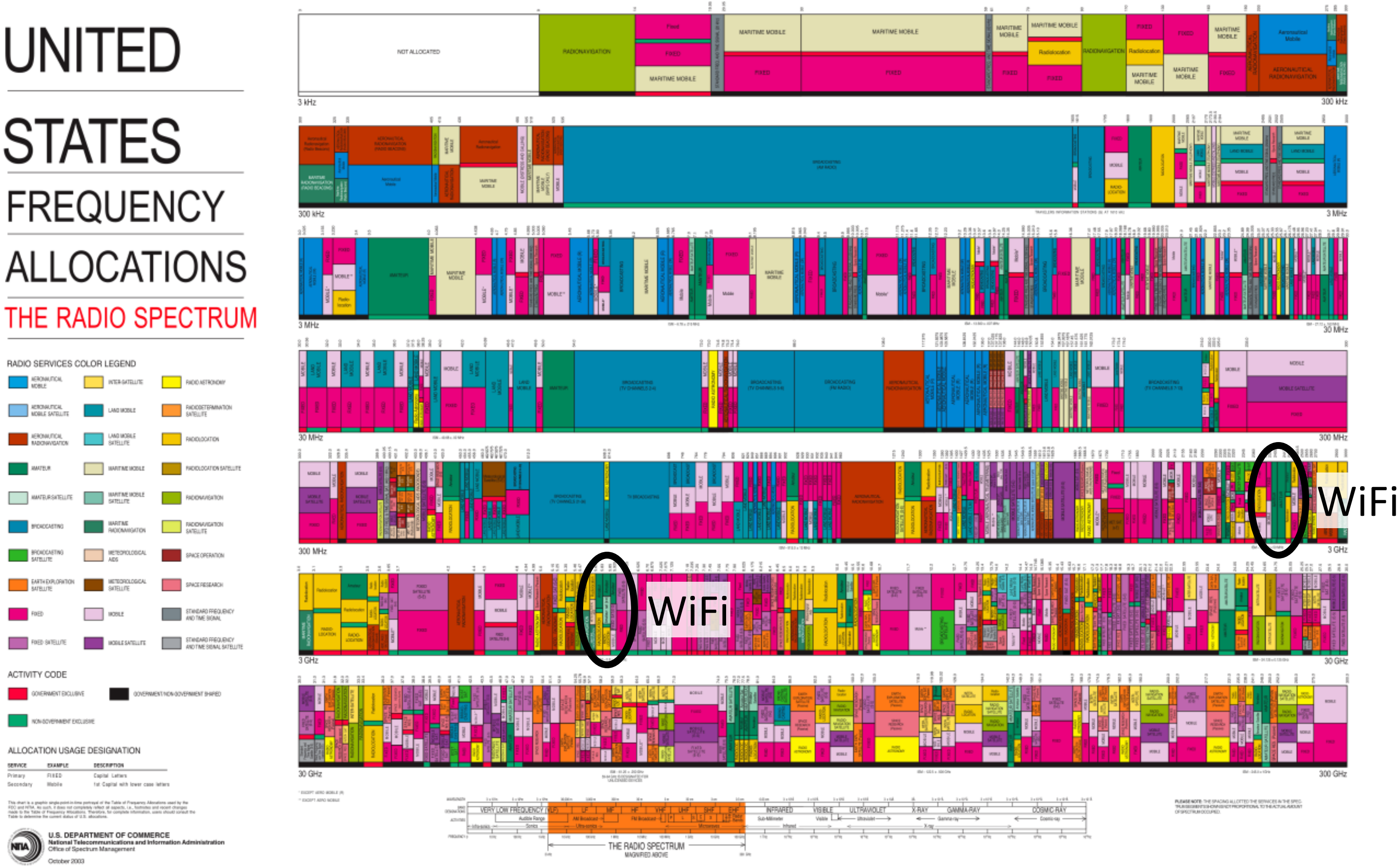


Fiber bundle in a cable

Wireless

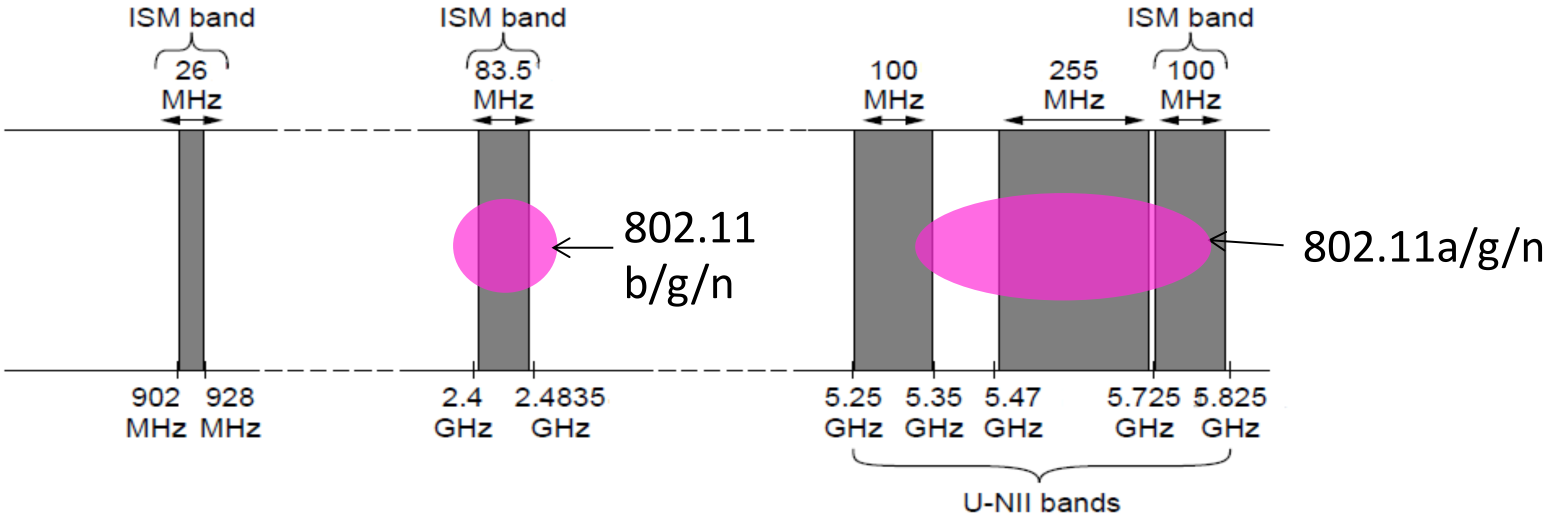
- Sender radiates signal over a region
  - In many directions, unlike a wire, to potentially many receivers
  - Nearby signals (same freq.) <u>interfere</u> at a receiver; need to coordinate use




UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
WiFi
WiFi
THE RADIO SPECTRUM

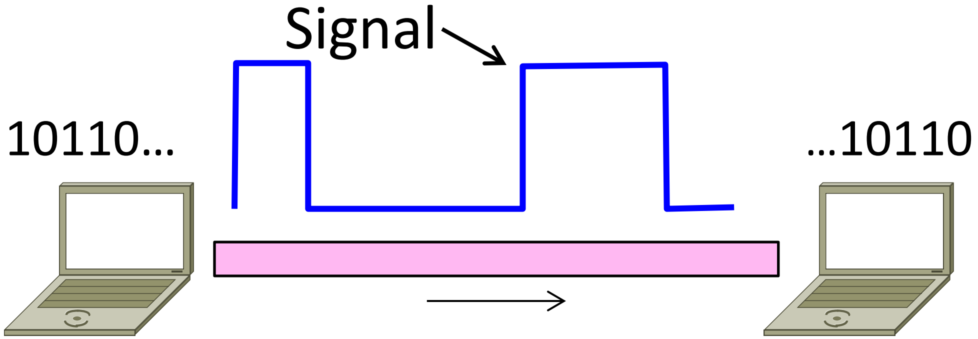
Wireless (2)

- Microwave, e.g., 3G, and unlicensed (ISM) frequencies, e.g., WiFi, are widely used for computer networking



Topic

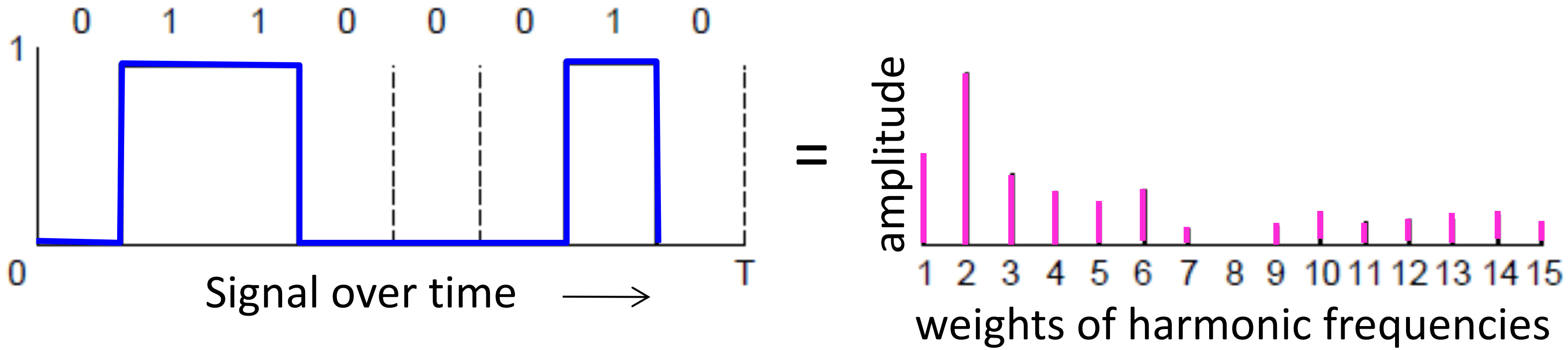
- Analog signals encode digital bits. We want to know what happens as signals <u>propagate</u> over media



Frequency Representation

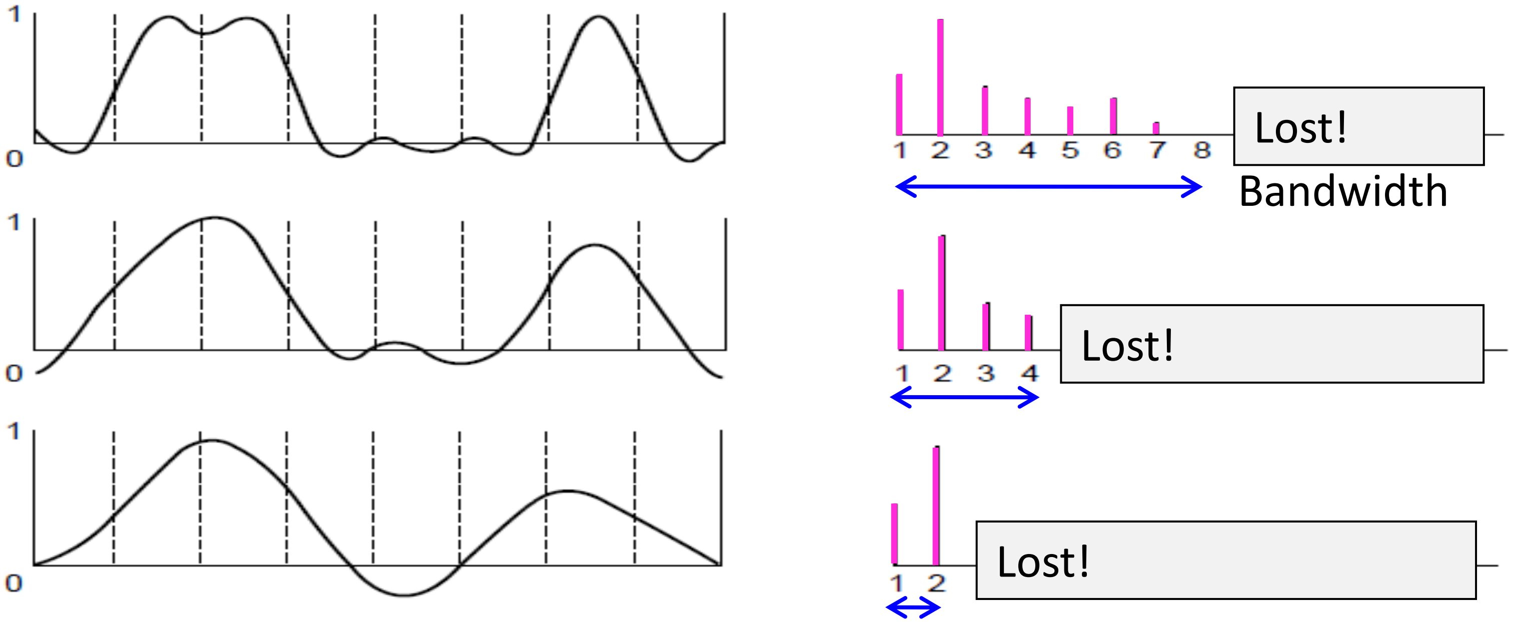
- A signal over time can be represented by its frequency components (called Fourier analysis)

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



Effect of Less Bandwidth

- Fewer frequencies (=less bandwidth) degrades signal



Signals over a Wire

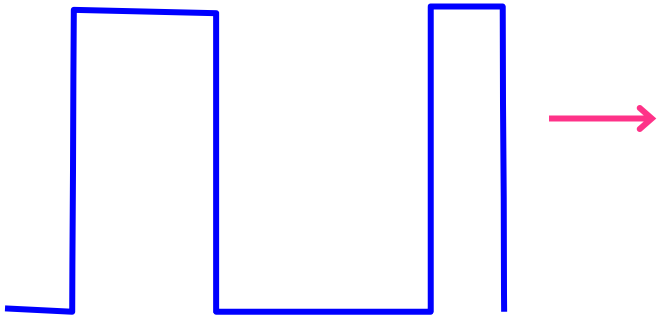
- What happens to a signal as it passes over a wire?
  1. The signal is delayed (propagates at ⅔c)
  2. The signal is attenuated (goes for m to km)
  3. Frequencies above a cutoff are highly attenuated
  4. Noise is added to the signal (later, causes errors)

EE: Bandwidth = width of frequency band, measured in Hz
CS: Bandwidth = information carrying capacity, in bits/sec

Signals over a Wire (2)

- Example:

Sent signal



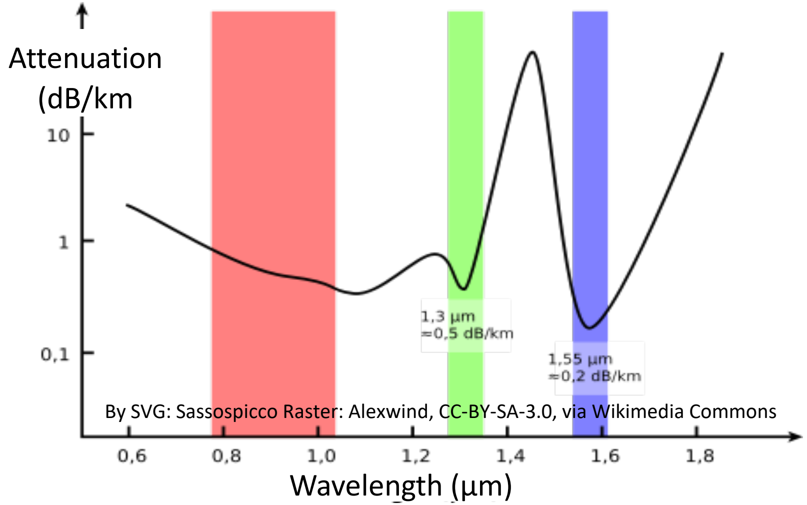
2: Attenuation:

3: Bandwidth:

4: Noise:

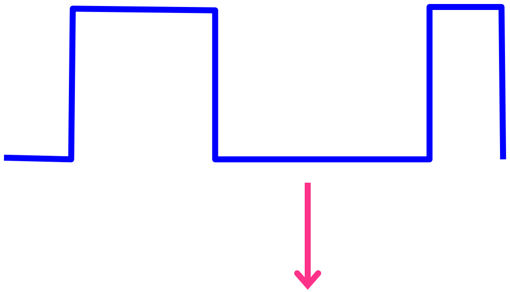
Signals over Fiber

- Light propagates with very low loss in three very wide frequency bands
  - Use a carrier to send information



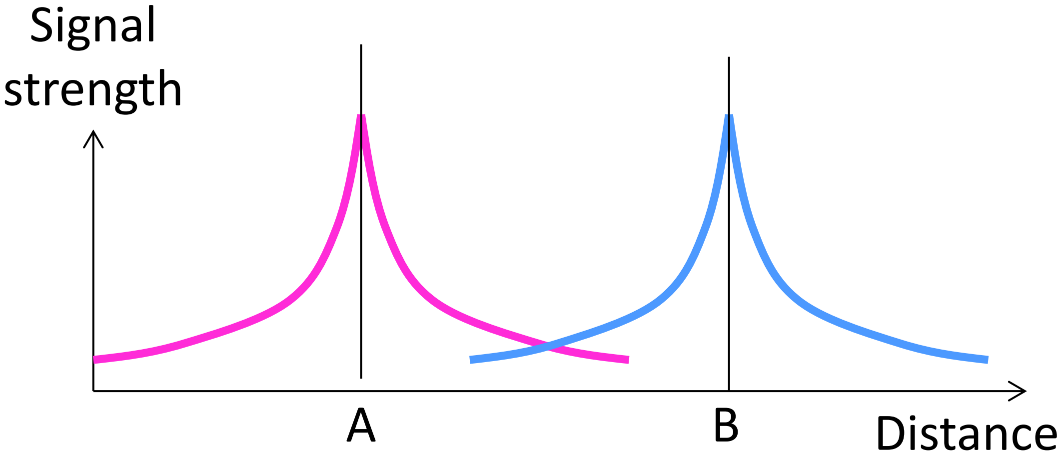
Signals over Wireless

- Signals transmitted on a carrier frequency, like fiber (more later)



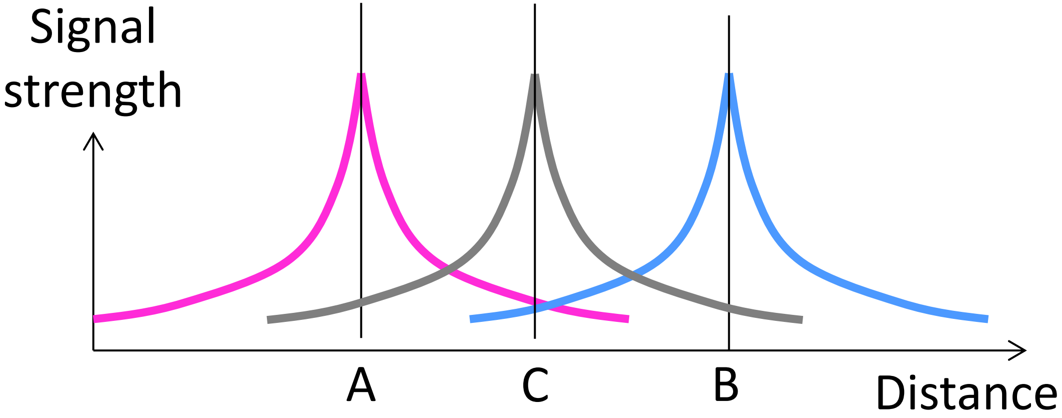
Signals over Wireless (2)

- Travel at speed of light, spread out and attenuate faster than $1/dist^2$



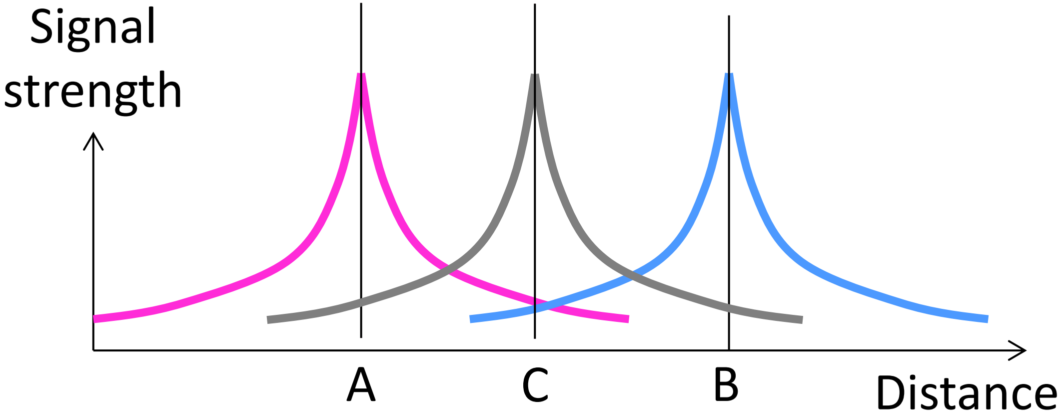
Signals over Wireless (3)

- Multiple signals on the same frequency interfere at a receiver



Signals over Wireless (4)

- Interference leads to notion of <u>spatial reuse</u> (of same freq.)



Signals over Wireless (5)

- Various other effects too!
  - Wireless propagation is complex, depends on environment

- Some key effects are highly frequency dependent,
  - E.g., multipath at microwave frequencies

Wireless Multipath

- Signals bounce off objects and take multiple paths
  - Some frequencies attenuated at receiver, varies with location
  - Messes up signal; handled with sophisticated methods (§2.5.3)