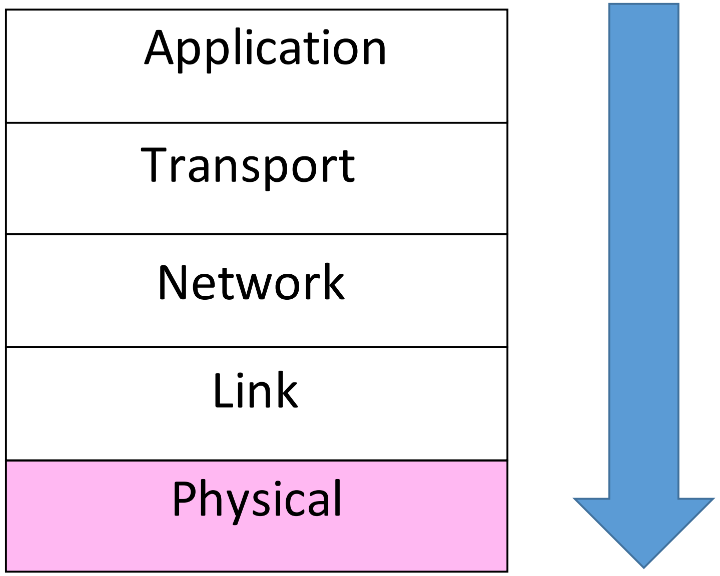
Physical Layer

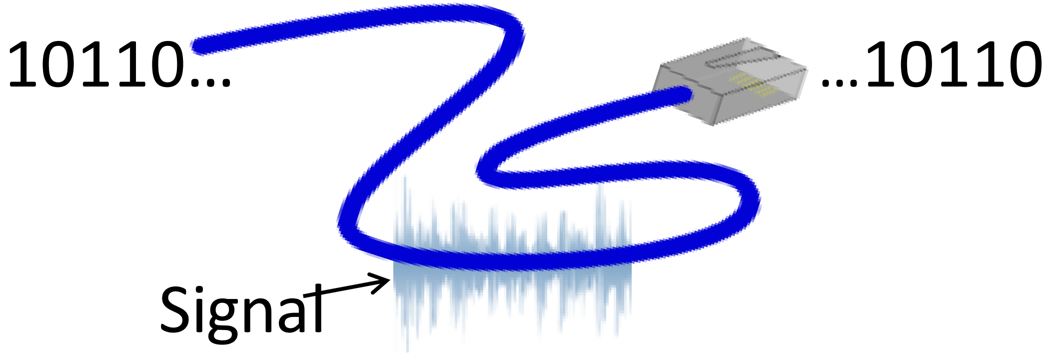
Where we are in the Course

- We've reached rock bottom



Scope of the Physical Layer

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



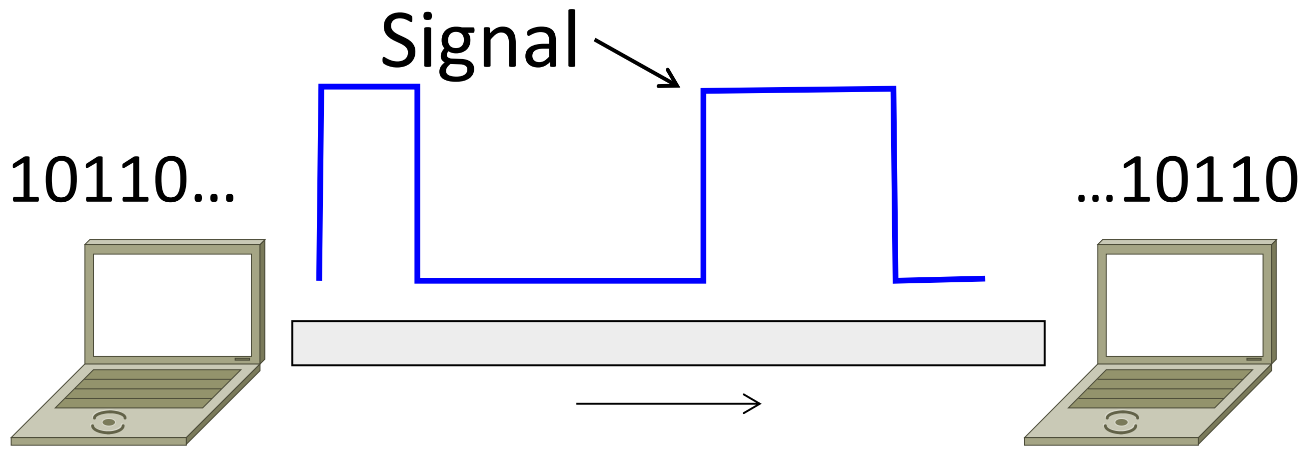
Topics

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

Modulation

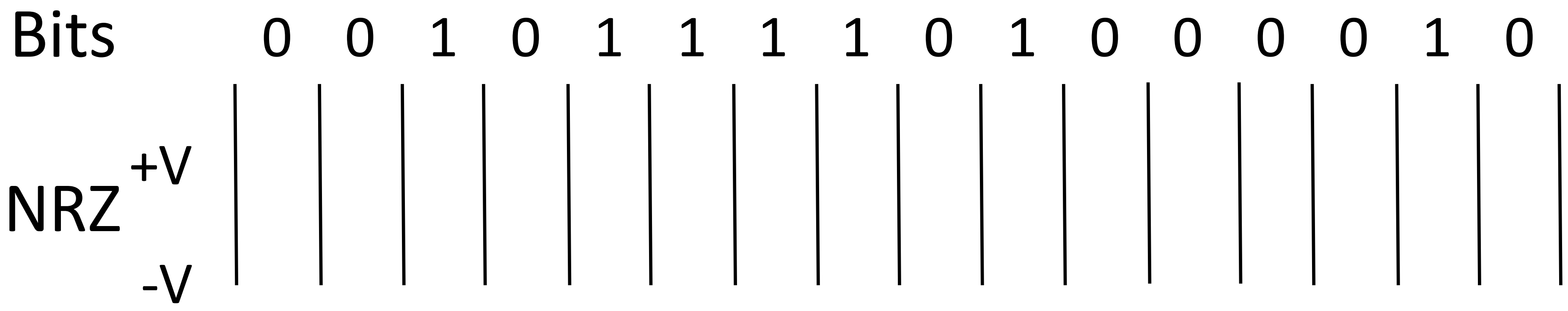
Topic

- How can we send information across a link?
  - This is the topic of modulation



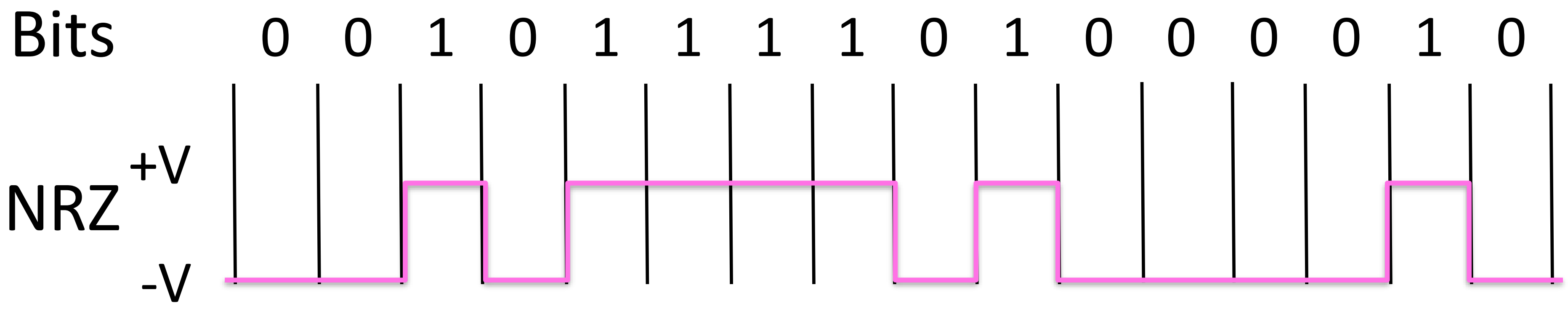
A Simple Modulation

- Let a high voltage (+V) represent a 1, and low voltage (-V) represent a 0
  - This is called NRZ (Non-Return to Zero)



A Simple Modulation (2)

- Let a high voltage (+V) represent a 1, and low voltage (-V) represent a 0
  - This is called NRZ (Non-Return to Zero)



Many Other Schemes

- Can use more signal levels
  - E.g., 4 levels is 2 bits per symbol
- Practical schemes are driven by engineering considerations
  - E.g., clock recovery »

Clock Recovery

- Um, how many zeros was that?
  - Receiver needs frequent signal transitions to decode bits

- Several possible designs
  - E.g., Manchester coding and scrambling (§2.5.1)

Clock Recovery – 4B/5B

- Map every 4 data bits into 5 code bits without long runs of zeros
  - 0000 → 11110, 0001 → 01001, 1110 → 11100, … 1111 → 11101
  - Has at most 3 zeros in a row
  - Also invert signal level on a 1 to break up long runs of 1s (called NRZI)

Clock Recovery – 4B/5B (2)

- 4B/5B code for reference:
  - 0000→11110, 0001→01001, 1110→11100, … 1111→11101
- Message bits: 1 1 1 1 0 0 0 0 0 0 0 1

Coded Bits:

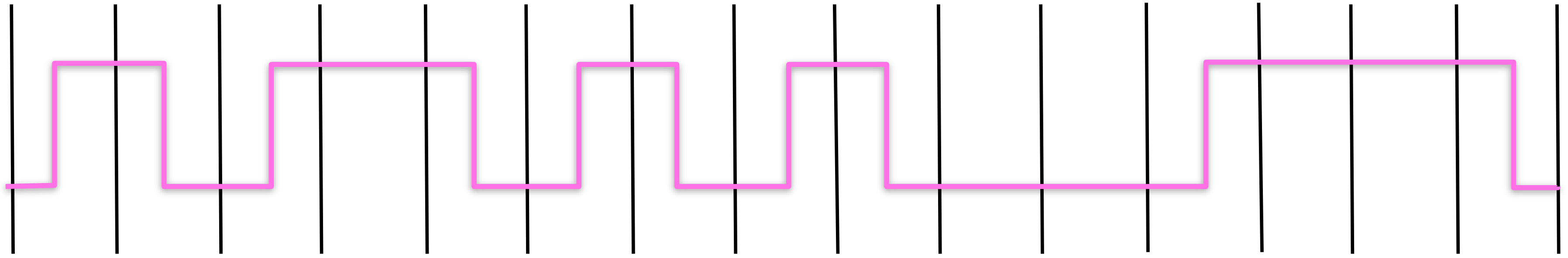
Signal:

Clock Recovery – 4B/5B (3)

- 4B/5B code for reference:
  - 0000→11110, 0001→01001, 1110→11100, … 1111→11101
- Message bits: 1 1 1 1 0 0 0 0 0 0 0 1

Coded Bits: 1 1 1 0 1 1 1 1 1 0 0 1 0 0 1

Signal:

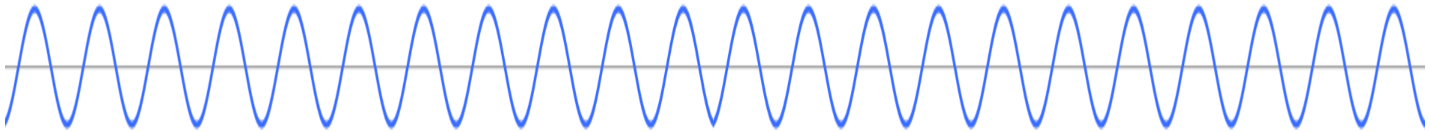


Passband Modulation

- What we have seen so far is <u>baseband</u> modulation for wires
  - Signal is sent directly on a wire
- These signals do not propagate well as RF
  - Need to send at higher frequencies
- <u>Passband</u> modulation carries a signal by modulating a carrier

Passband Modulation

- Carrier is simply a signal oscillating at a desired frequency:



- We can modulate it by changing:
  - Amplitude, frequency, or phase

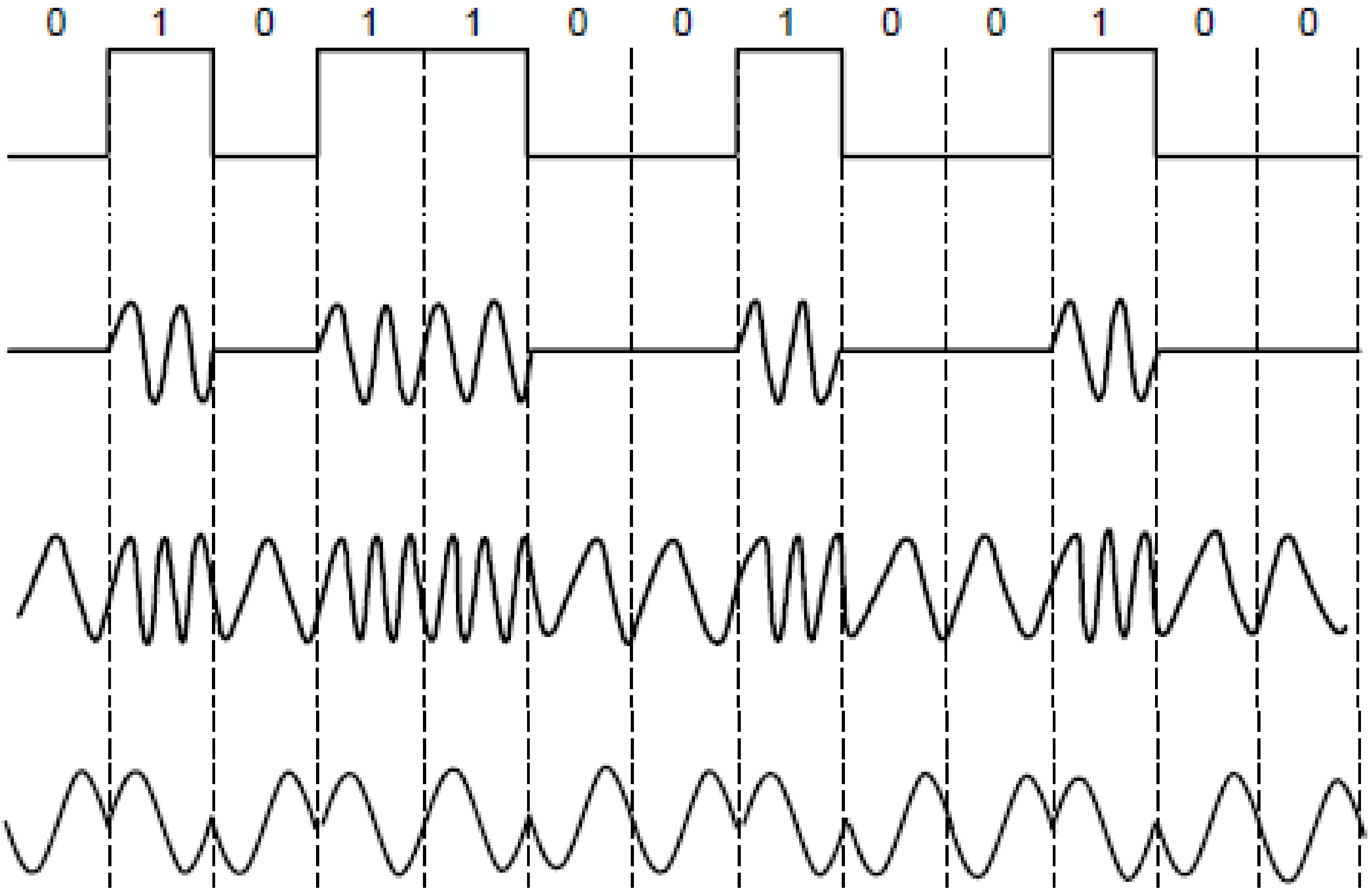
Passband Modulation (3)

NRZ signal of bits

Amplitude shift keying

Frequency shift keying

Phase shift keying



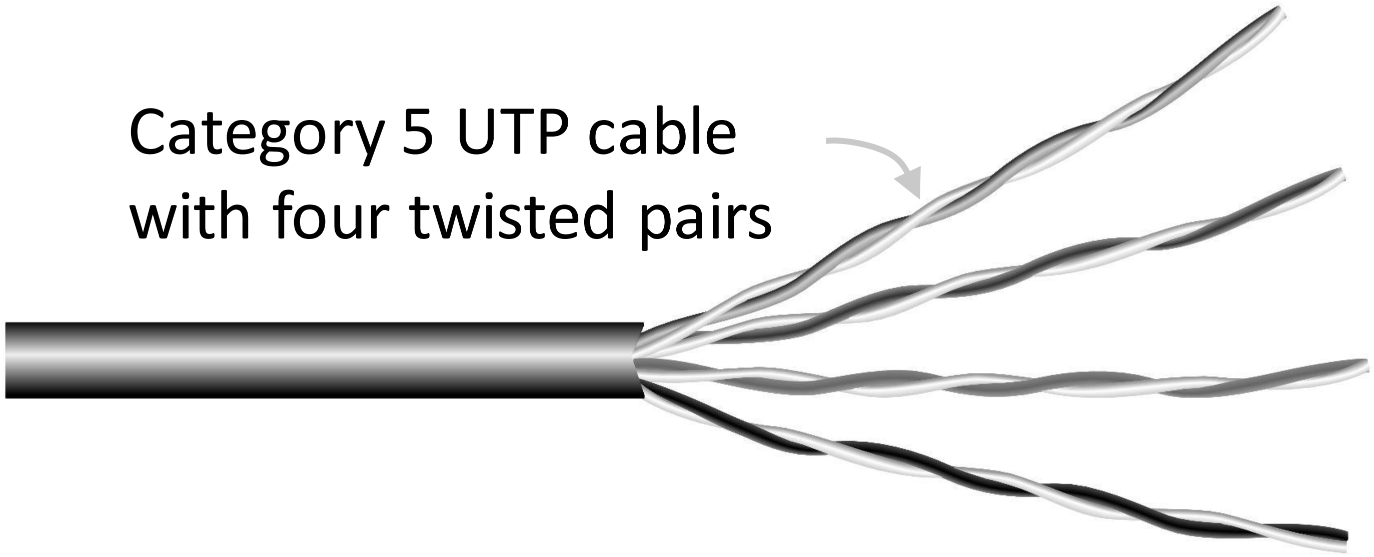
Media

Types of Media

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

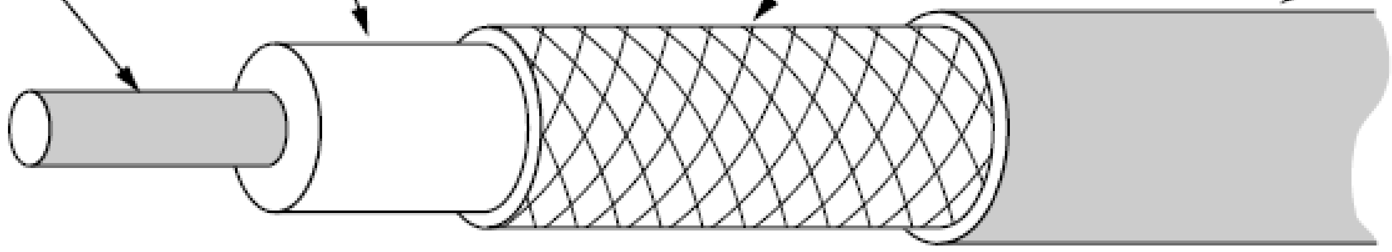
Wires – Twisted Pair

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



Wires – Coaxial Cable

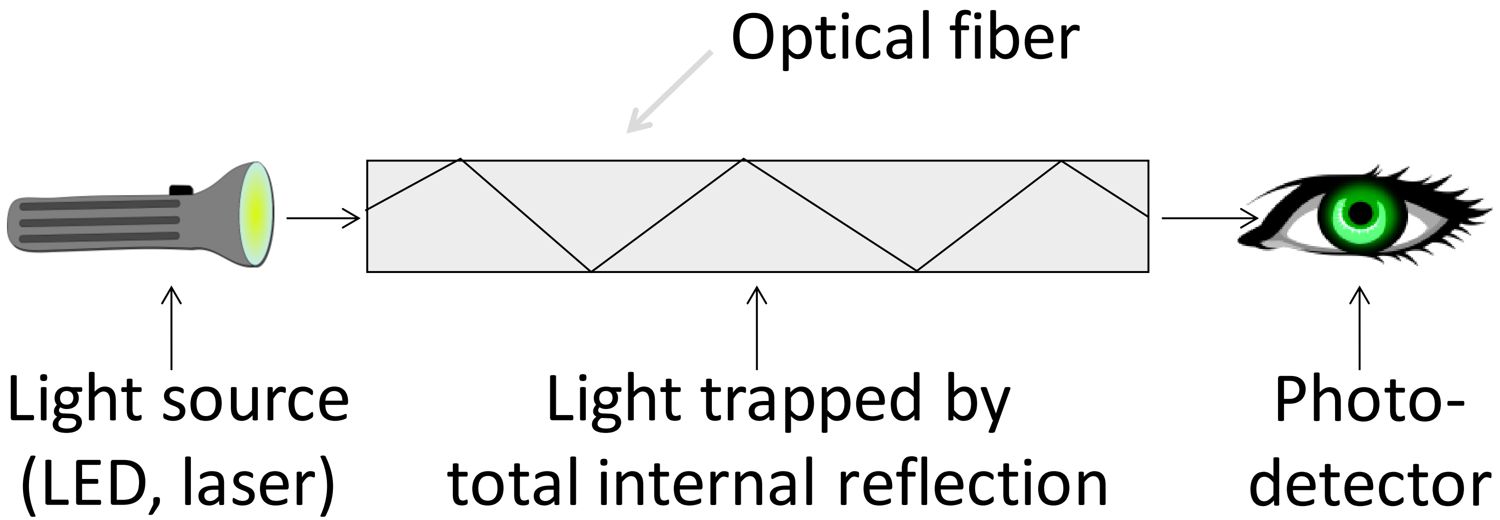
- Also common. Better shielding for better performance



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

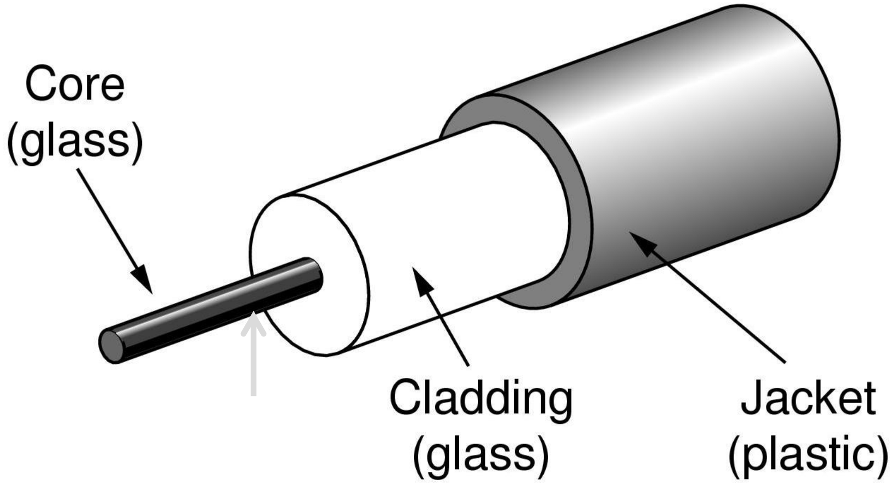
Fiber

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

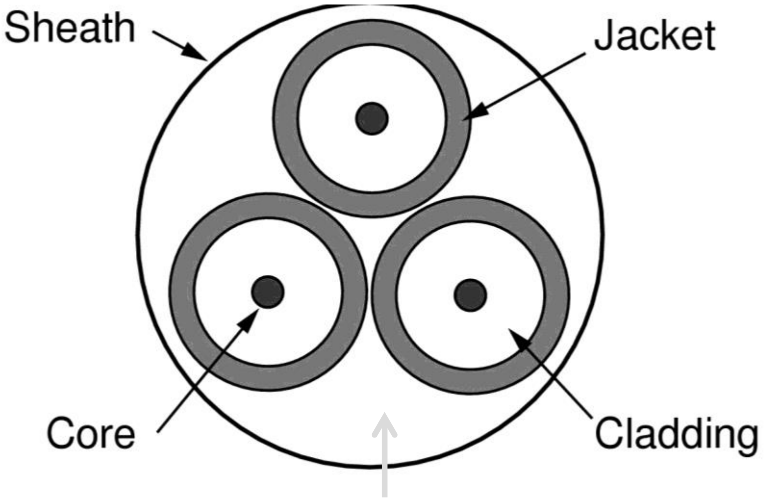


Fiber

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



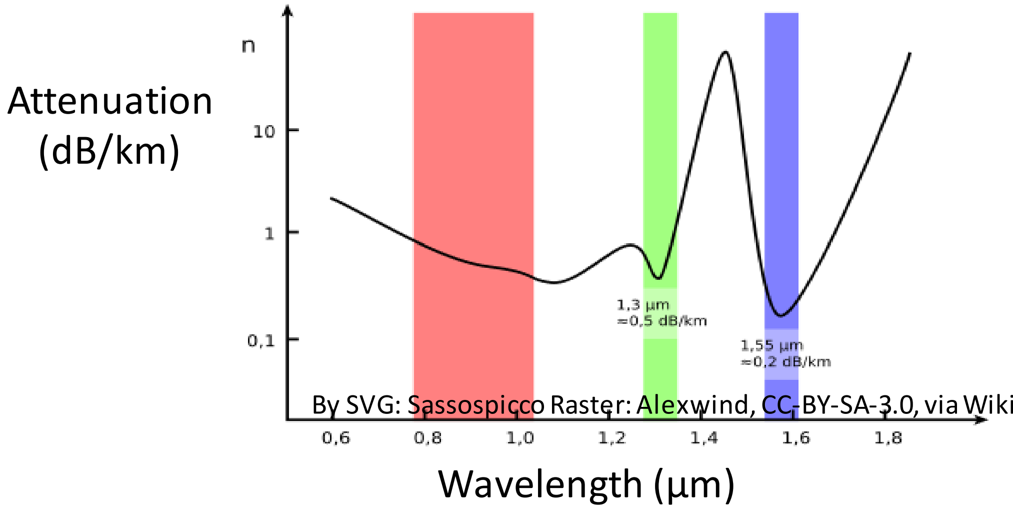
One fiber



Fiber bundle in a cable

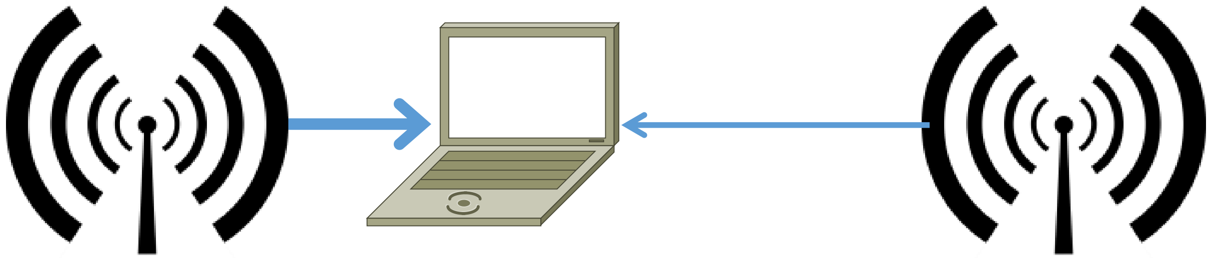
Signals over Fiber

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

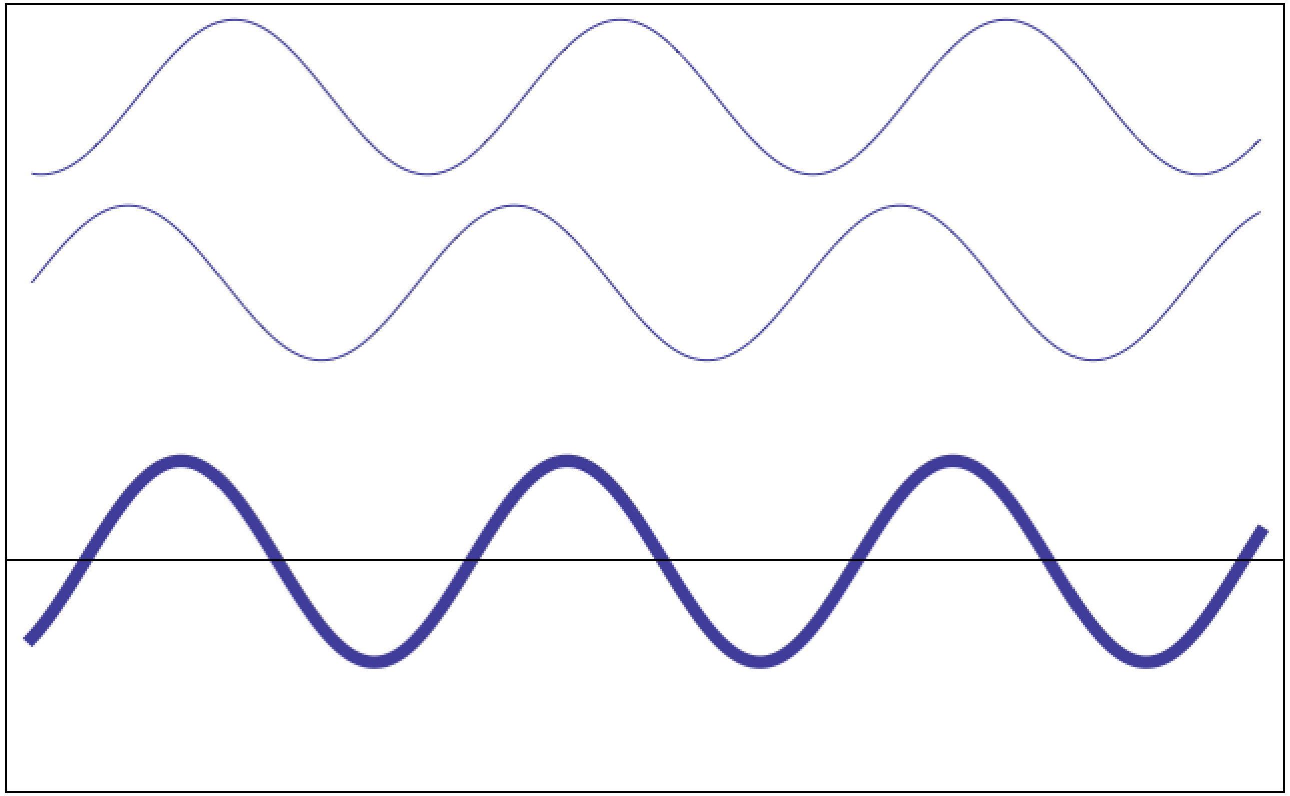


Wireless

- 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

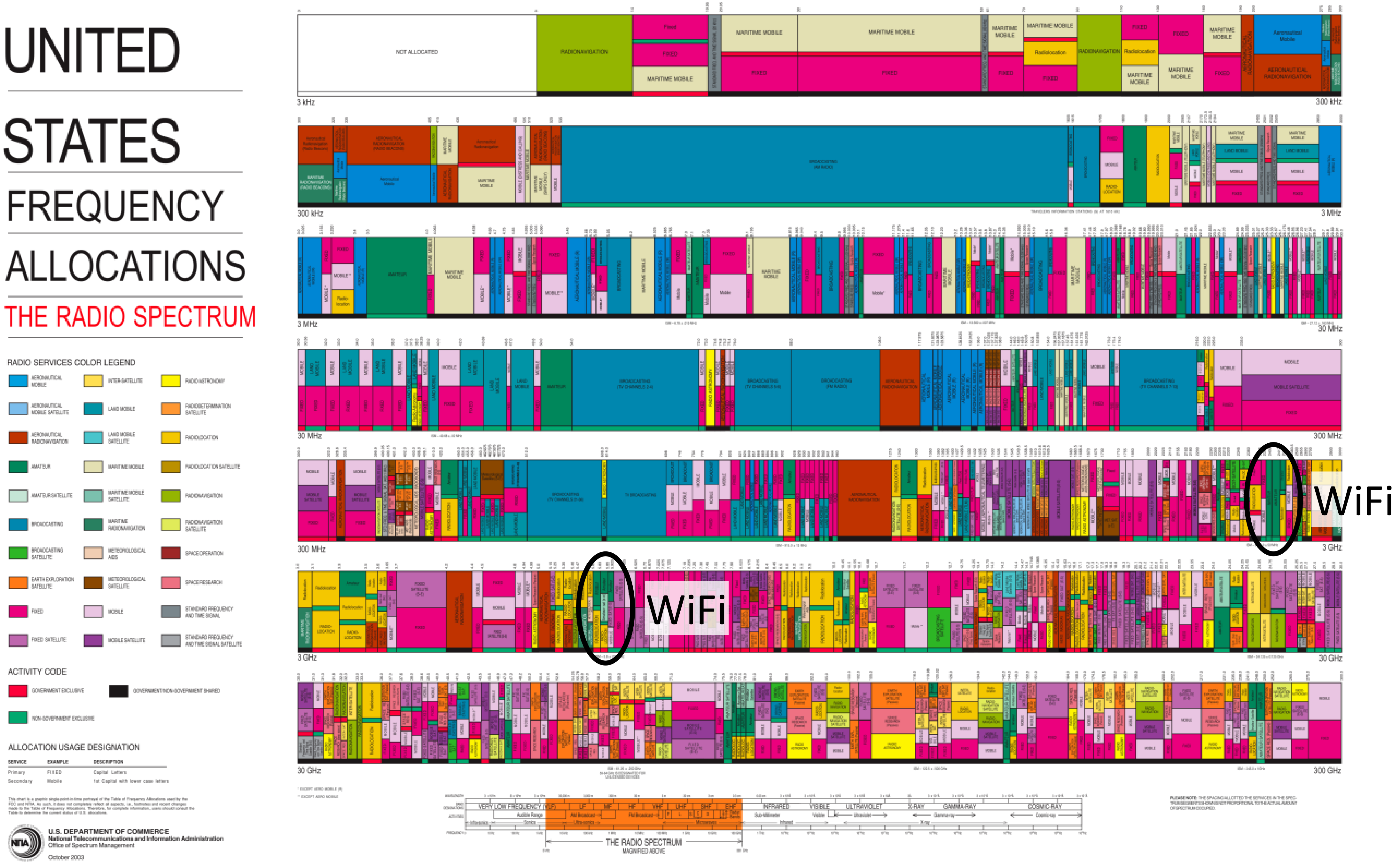


Wireless Interference



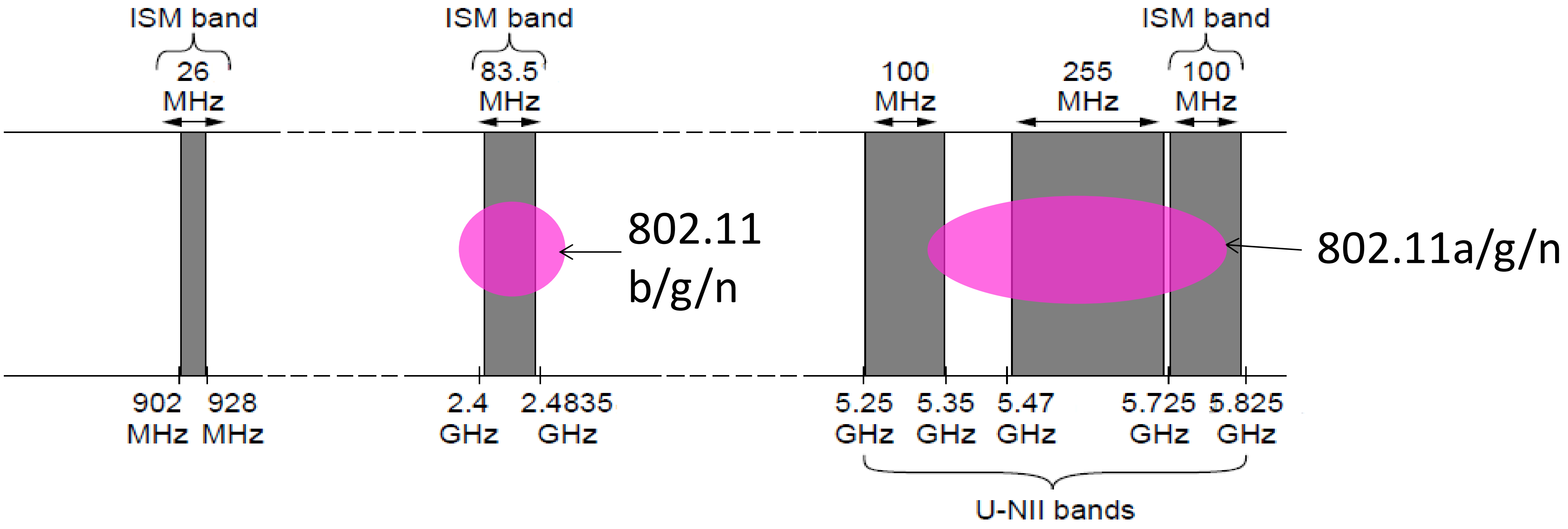
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



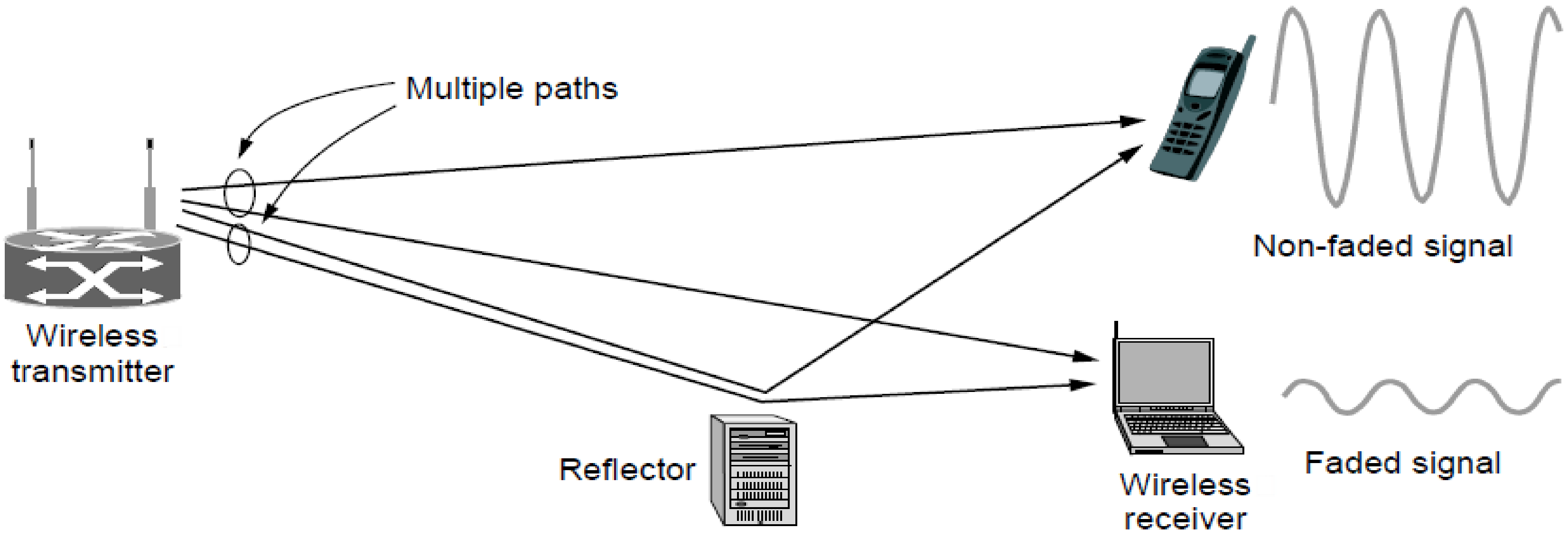
Wireless

- Unlicensed (ISM) frequencies, e.g., WiFi, are widely used for computer networking

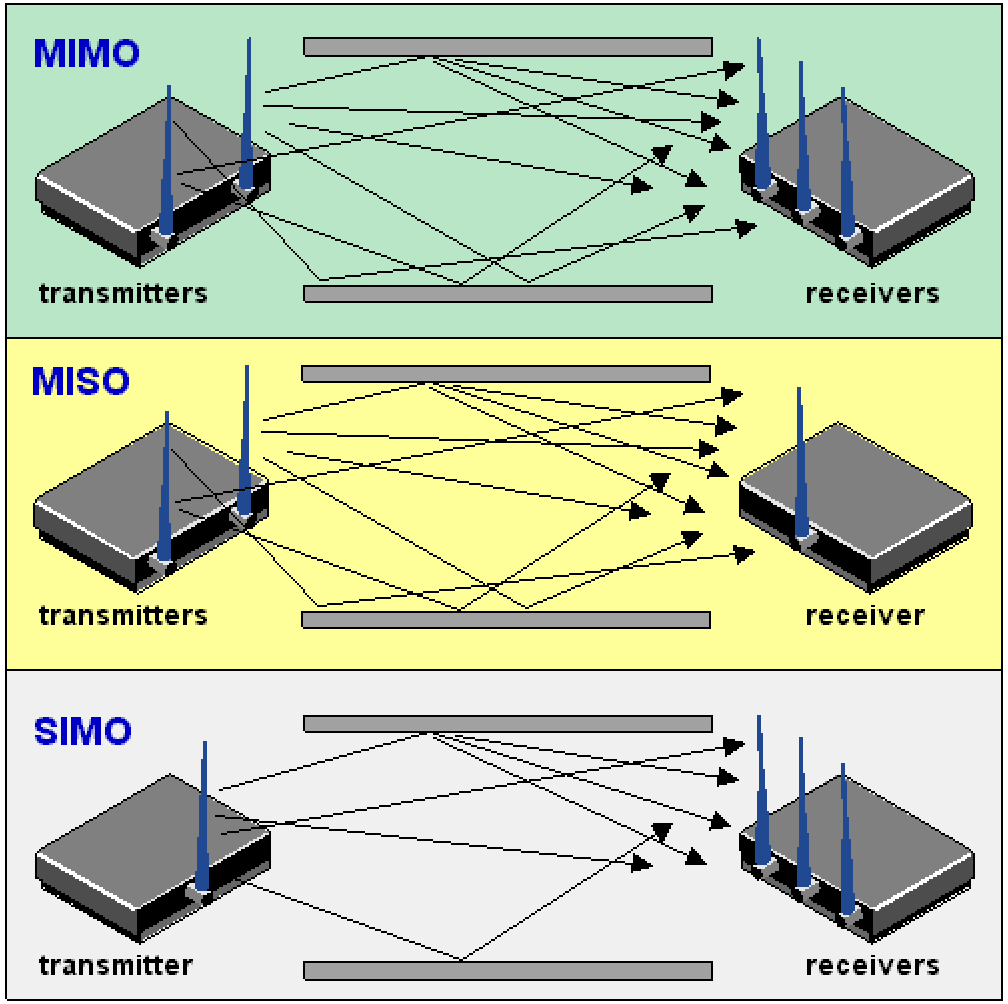


Multipath

- Signals bounce off objects and take multiple paths
  - Some frequencies attenuated at receiver, varies with location



MIMO (Multiple input and multiple output)



https://www.pcmag.com/encyclopedia/term/47052/mimo

Limits

Topic

- How rapidly can we send information over a link?
  - Nyquist limit (~1924)
  - Shannon capacity (1948)

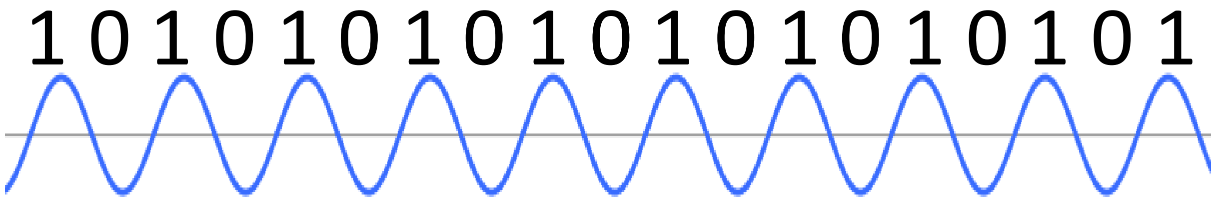
- Practical systems are devised to approach these limits

Key Channel Properties

- The bandwidth (B), signal strength (S), and noise (N)
  - B (in hertz) limits the rate of transitions
  - S and N limit how many signal levels we can distinguish

Nyquist Limit

- The maximum symbol rate is 2B

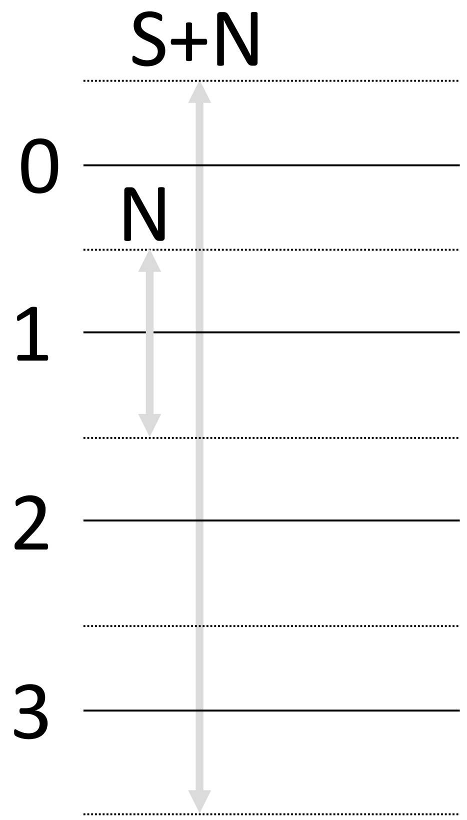


- Thus if there are V signal levels, ignoring noise, the maximum bit rate is:

$$R = 2B \log_2 V \text{ bits/sec}$$

Shannon Capacity

- How many levels we can distinguish depends on S/N
  - Or SNR, the Signal-to-Noise Ratio
  - Note noise is random, hence some errors
- SNR given on a log-scale in deciBels:
  - $SNR_{dB} = 10\log_{10}(S/N)$



Shannon Capacity

- Shannon limit is for capacity (C), the maximum information carrying rate of the channel:

$$C = B \log_2(1 + S/N) \text{ bits/sec}$$

Wired/Wireless Perspective

- Wires, and Fiber
  - Engineer link to have requisite SNR and B

→Can fix data rate

Engineer SNR for data rate

- Wireless
  - Given B, but SNR varies greatly

→Can't design for worst case, must adapt data rate

Adapt data rate to SNR