Lecture 5
Transmission

Hui Zhang

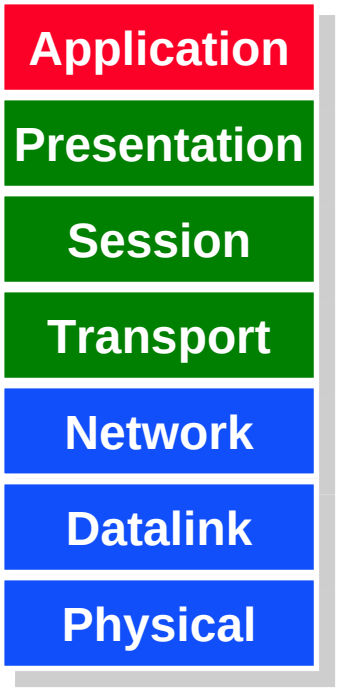
Department of Computer Science

Carnegie Mellon University

http://www.cs.cmu.edu/~srini/15-441/F07

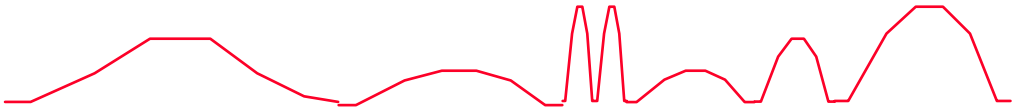
Physical and Datalink Layers: 3 Lectures

1. **Physical layer.**
2. **Datalink layer introduction, framing, error coding, switched networks.**
3. **Broadcast-networks, home networking.**



From Signals to Packets

Analog Signal

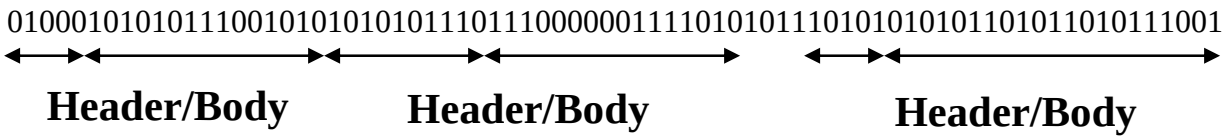


"Digital" Signal

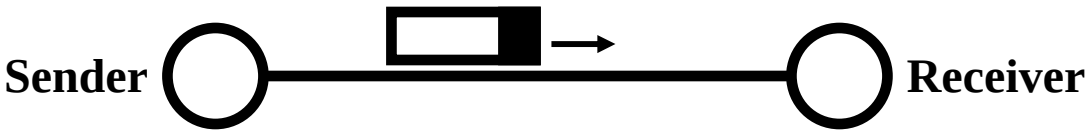
Bit Stream

0 0 1 0 1 1 1 0 0 0 1

Packets



Packet Transmission



Today's Lecture

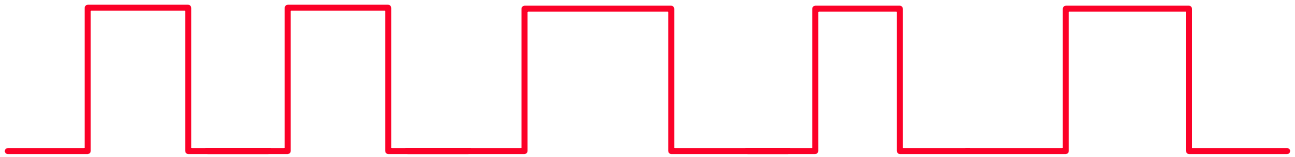
- **Modulation.**
- **Bandwidth limitations.**
- **Frequency spectrum and its use.**
- **Multiplexing.**
- **Media: Copper, Fiber, Optical, Wireless.**

- **Coding.**
- **Framing.**

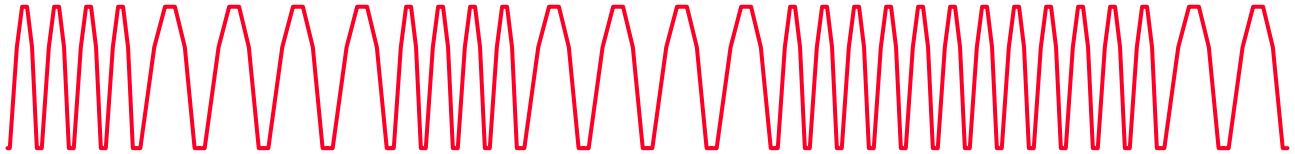
Modulation

- **Sender changes the nature of the signal in a way that the receiver can recognize.**
  - » **Similar to radio: AM or FM**
- **Digital transmission: encodes the values 0 or 1 in the signal.**
  - » **It is also possible to encode multi-valued symbols**
- **Amplitude modulation: change the strength of the signal, typically between on and off.**
  - » **Sender and receiver agree on a "rate"**
  - » **On means 1, Off means 0**
- **Similar: frequency or phase modulation.**
- **Can also combine method modulation types.**

Amplitude and Frequency Modulation



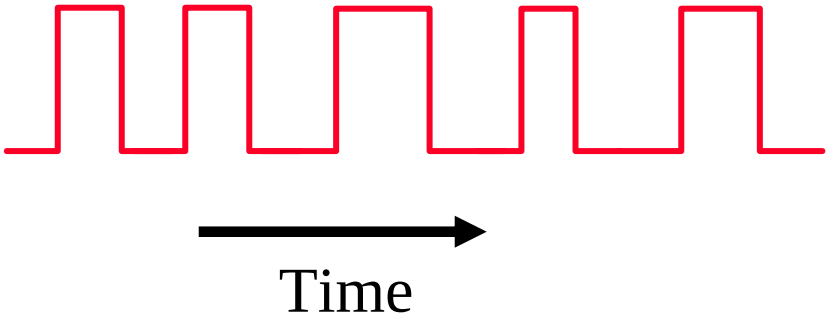
0 0 1 1 0 0 1 1 0 0 0 1 1 1 0 0 0 1 1 0 0 0 1 1 1 0

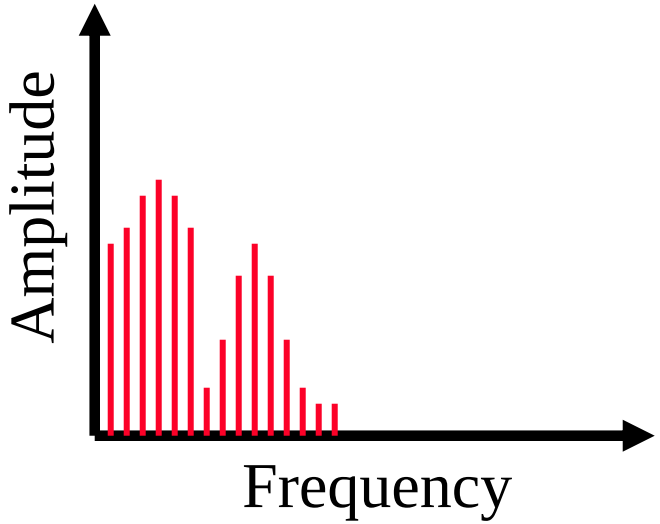


0 1 1 0 1 1 0 0 0 1

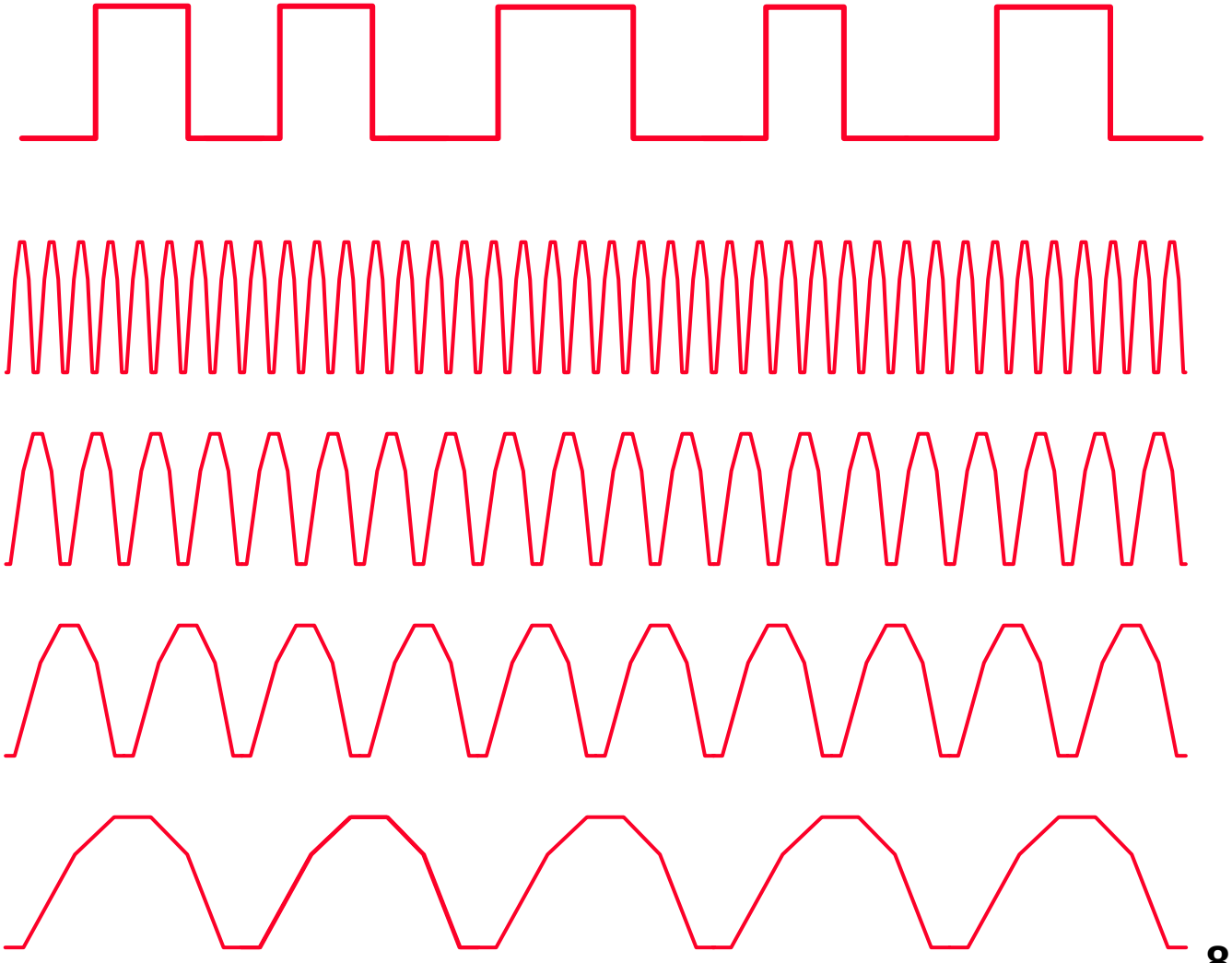
The Frequency Domain

- **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)**
- **Again: Similar to radio and TV signals.**





Signal = Sum of Waves

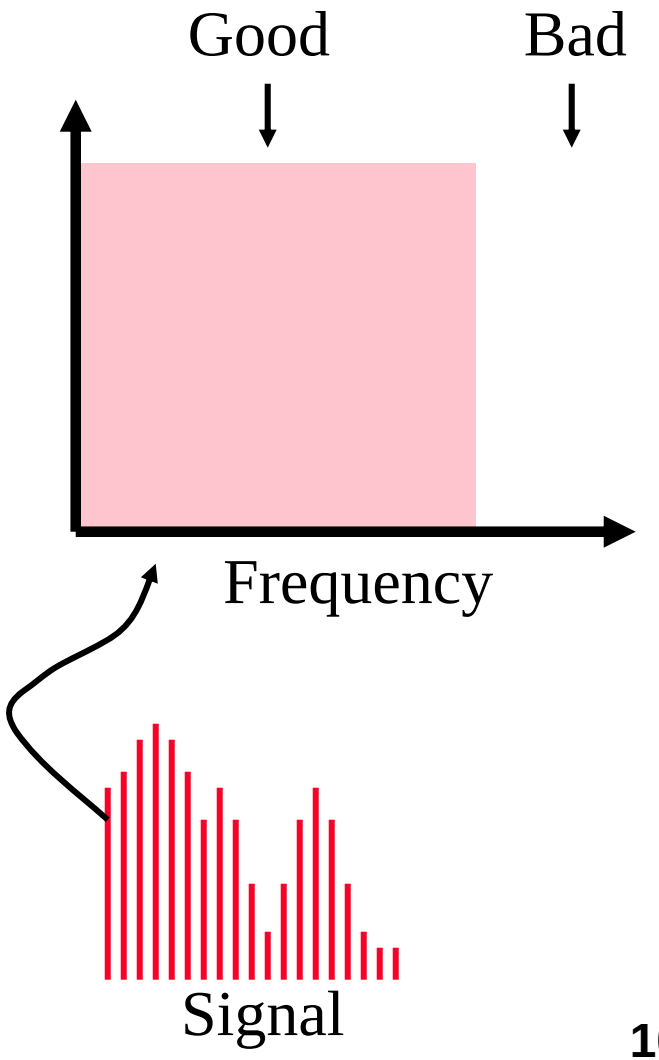


Why Do We Care?

- How much bandwidth can I get out of a specific wire (transmission medium)?
- What limits the physical size of the network?
- How can multiple hosts communicate over the same wire at the same time?
- How can I manage bandwidth on a transmission medium?
- How do the properties of copper, fiber, and wireless compare?

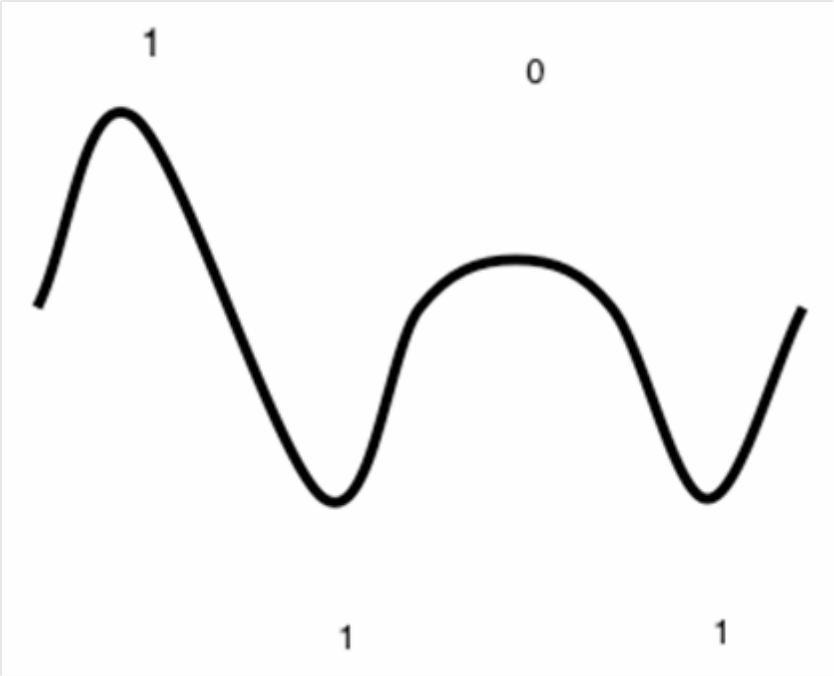
Transmission Channel Considerations

- **Every medium supports transmission in a certain frequency range.**
  - » **Outside this range, effects such as attenuation, .. degrade the signal too much**
- **Transmission and receive hardware will try to maximize the useful bandwidth in this frequency band.**
  - » **Tradeoffs between cost, distance, bit rate**
- **As technology improves, these parameters change, even for the same wire.**
  - » **Thanks to our EE friends**



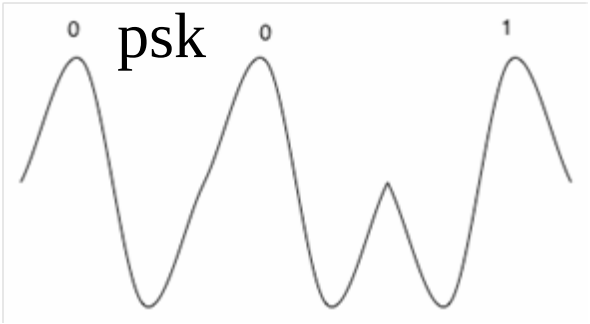
The Nyquist Limit

- **A noiseless channel of width H can at most transmit a binary signal at a rate 2 x H.**
  - » **E.g. a 3000 Hz channel can transmit data at a rate of at most 6000 bits/second**
  - » **Assumes binary amplitude encoding**

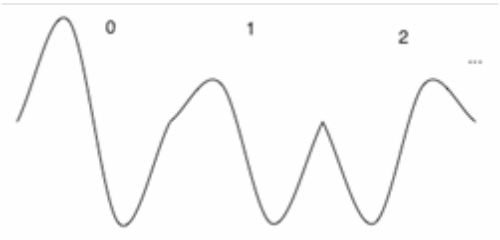


Past the Nyquist Limit

- **More aggressive encoding can increase the channel bandwidth.**
  - » **Example: modems**
    - – **Same *frequency* - number of symbols per second**
    - – **Symbols have more possible values**



Psk
+
AM



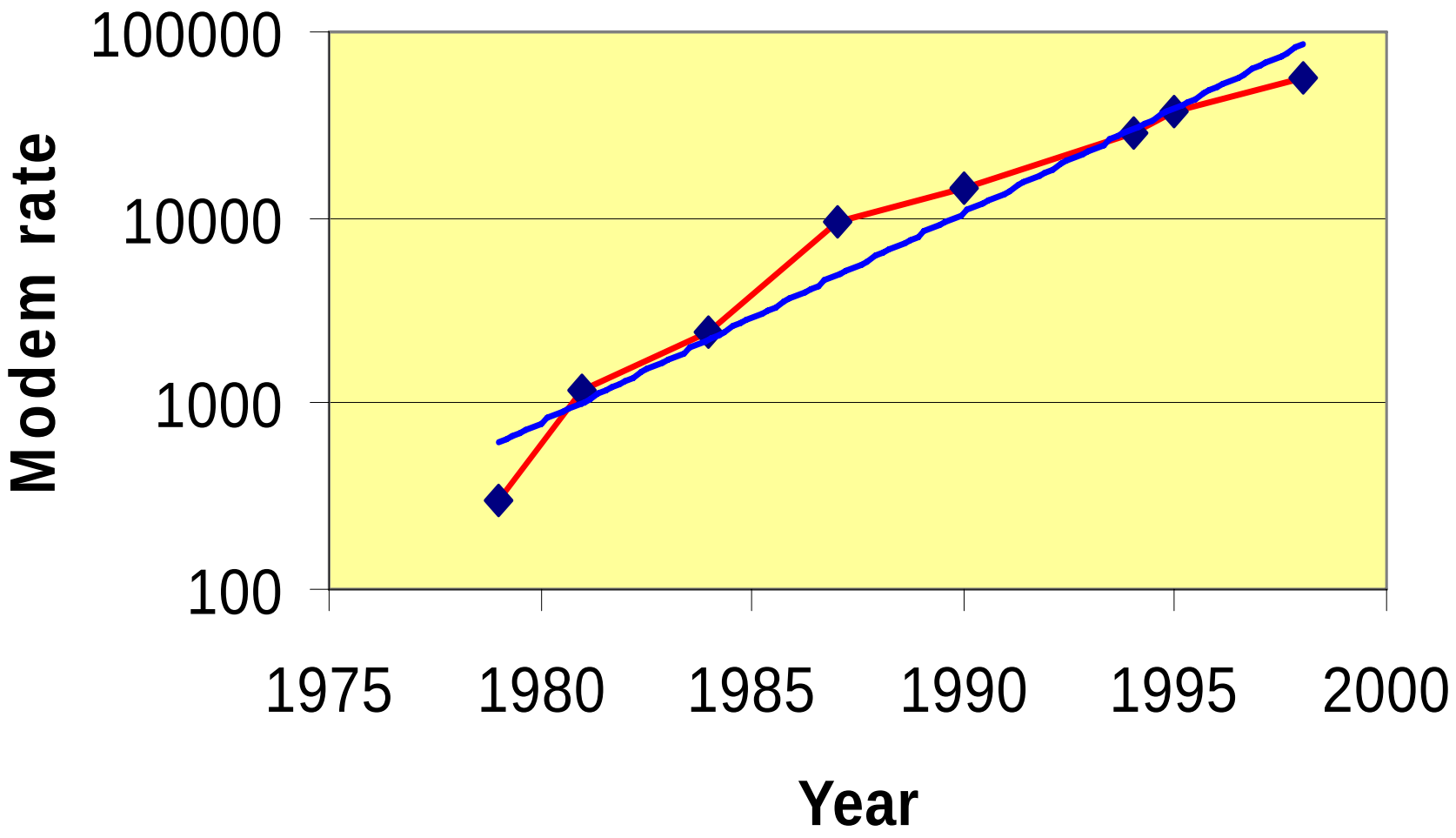
- **Every transmission medium supports transmission in a certain frequency range.**
  - » **The channel bandwidth is determined by the transmission medium and the quality of the transmitter and receivers**
  - » **Channel capacity increases over time**

Capacity of a Noisy Channel

- **Can't add infinite symbols - you have to be able to tell them apart. This is where noise comes in.**

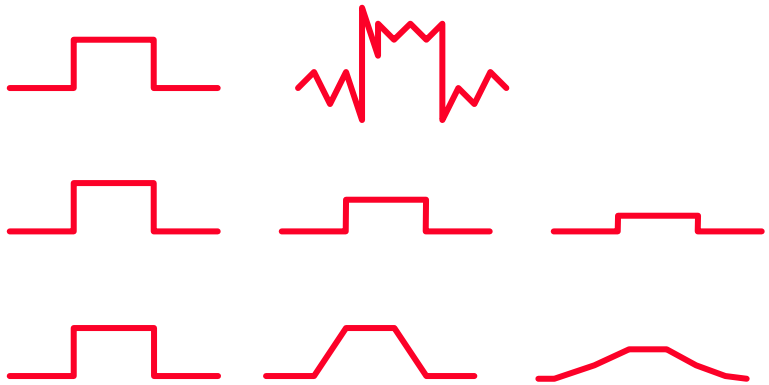
- **Shannon's theorem:**
  - **C = B x log(1 + S/N)**
  - **C: maximum capacity (bps)**
  - **B: channel bandwidth (Hz)**
  - **S/N: signal to noise ratio of the channel**
    - **Often expressed in decibels (db). 10 log(S/N).**
- **Example:**
  - **Local loop bandwidth: 3200 Hz**
  - **Typical S/N: 1000 (30db)**
  - **What is the upper limit on capacity?**
    - **Modems: Teleco internally converts to 56kbit/s digital signal, which sets a limit on B and the S/N.**

Example: Modem Rates



Limits to Speed and Distance

- Noise: “random” energy is added to the signal.
- Attenuation: some of the energy in the signal leaks away.
- Dispersion: attenuation and propagation speed are frequency dependent.
  - » Changes the shape of the signal



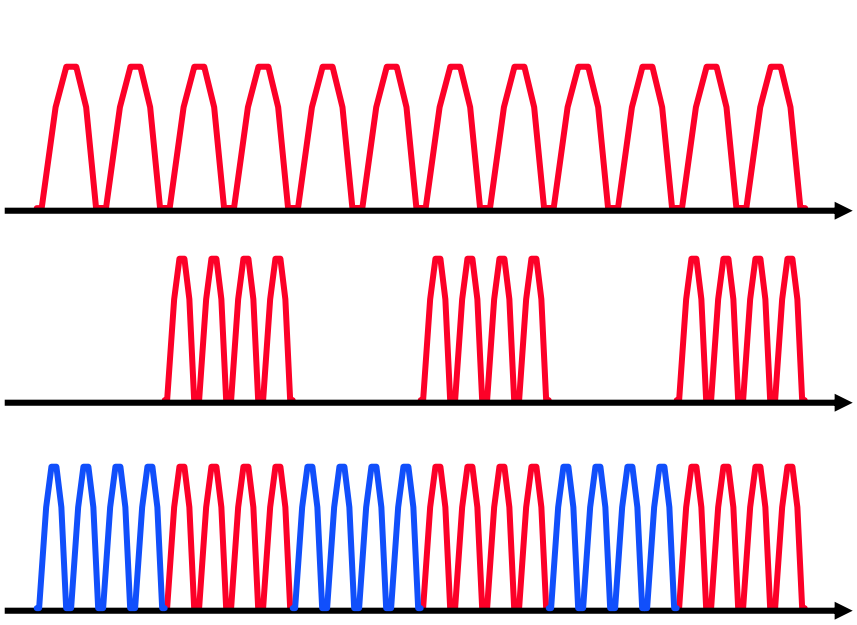
- Effects limit the data rate that a channel can sustain.
  - » But affects different technologies in different ways
- Effects become worse with distance.
  - » Tradeoff between data rate and distance

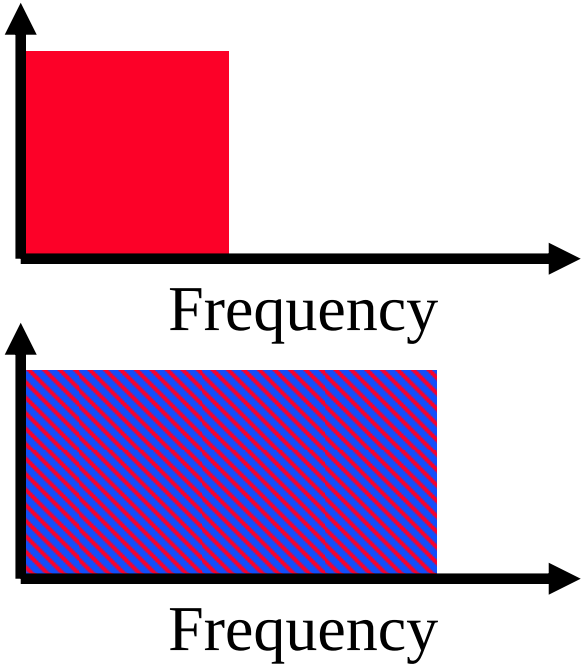
Supporting Multiple Channels

- **Multiple channels can coexist if they transmit at a different frequency, or at a different time, or in a different part of the space.**
  - » **Three dimensional space: frequency, space, time**
- **Space can be limited using wires or using transmit power of wireless transmitters.**
- **Frequency multiplexing means that different users use a different part of the spectrum.**
  - » **Again, similar to radio: 95.5 versus 102.5 station**
- **Controlling time is a datalink protocol issue.**
  - » **Media Access Control (MAC): who gets to send when?**

Time Division Multiplexing

- **Different users use the wire at different points in time.**
- **Aggregate bandwidth also requires more spectrum.**

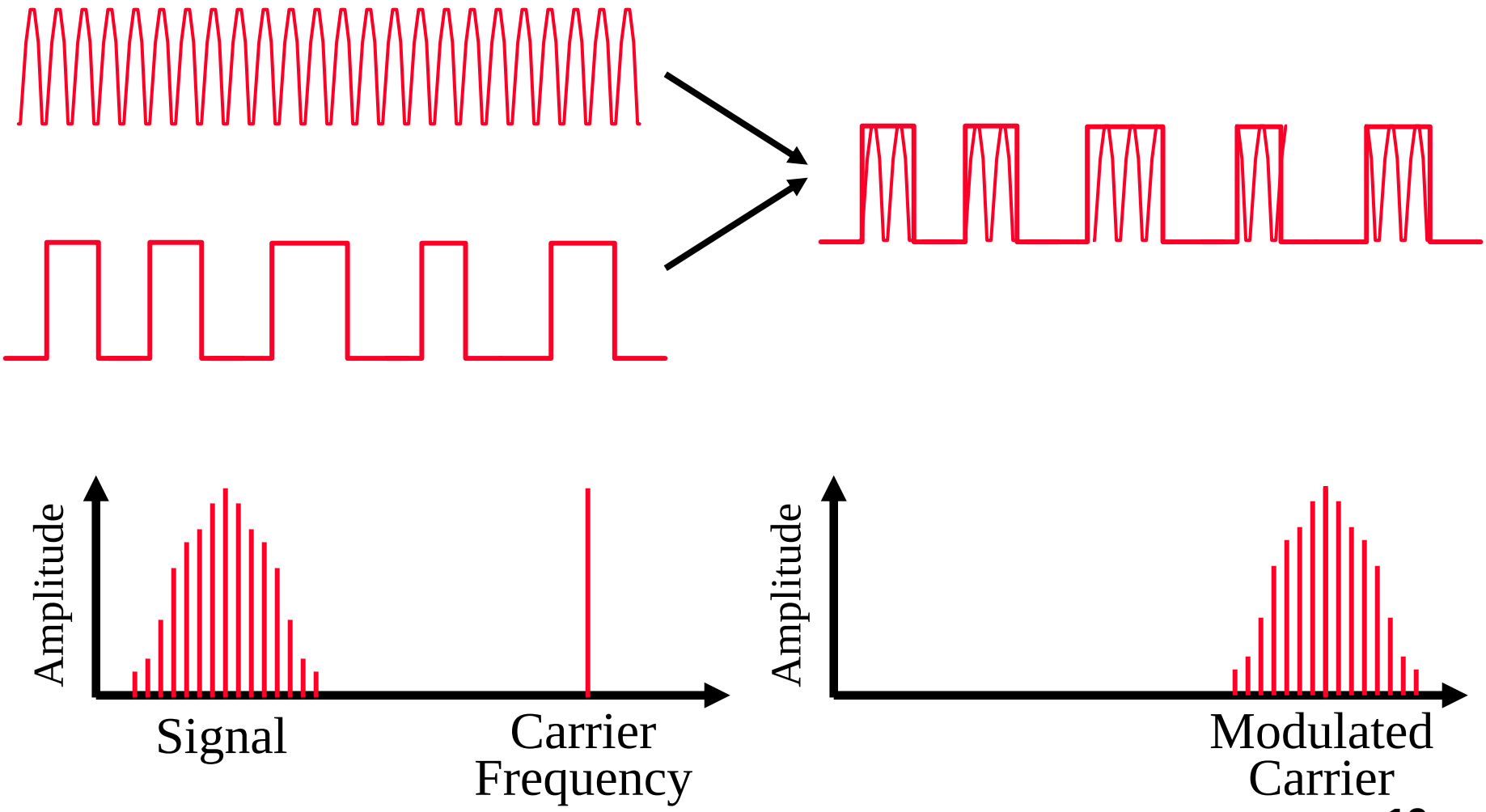




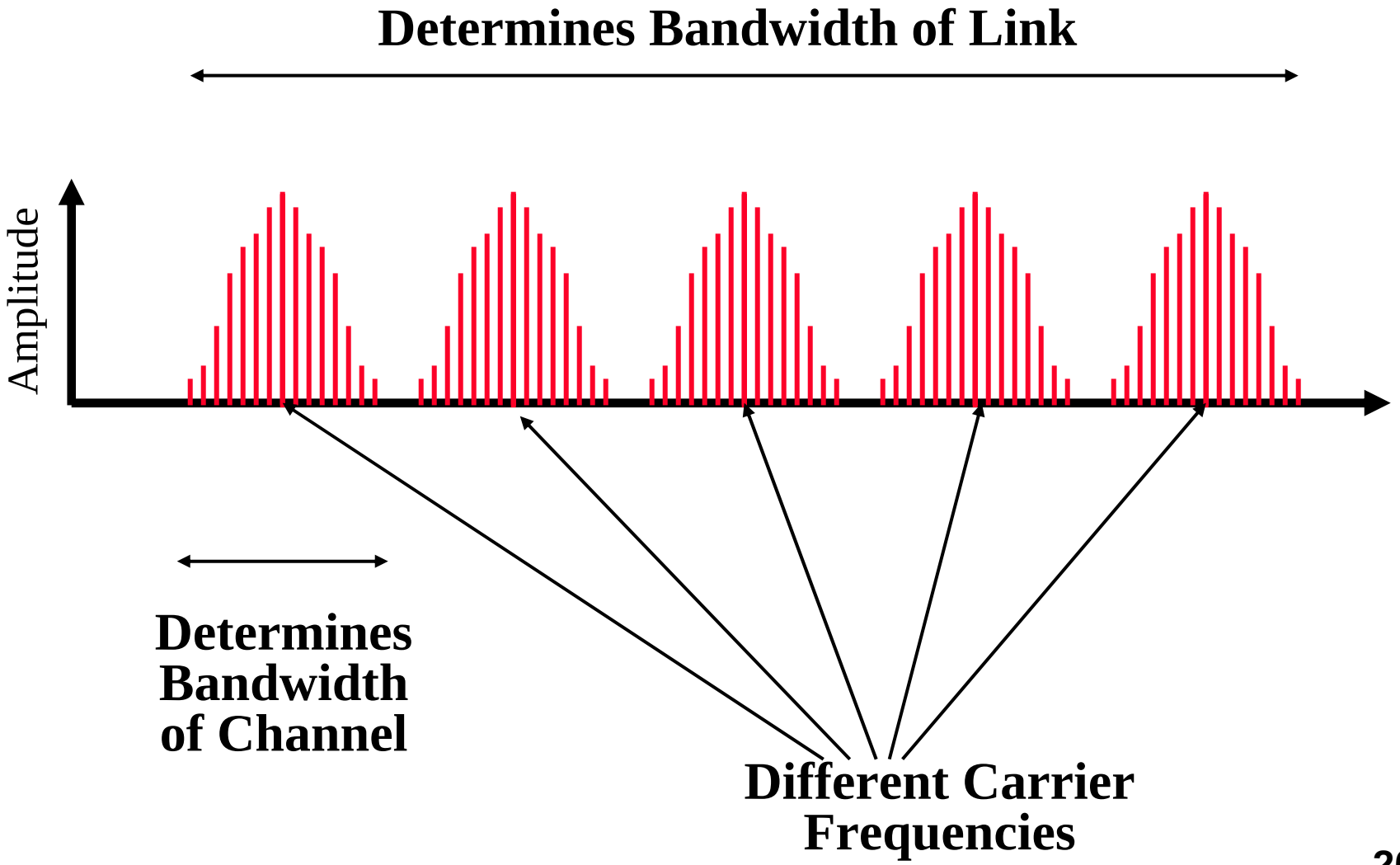
Baseband versus Carrier Modulation

- **Baseband modulation: send the “bare” signal.**
- **Carrier modulation: use the signal to modulate a higher frequency signal (carrier).**
  - » **Can be viewed as the product of the two signals**
  - » **Corresponds to a shift in the frequency domain**
- **Same idea applies to frequency and phase modulation.**
  - » **E.g. change frequency of the carrier instead of its amplitude**

Amplitude Carrier Modulation

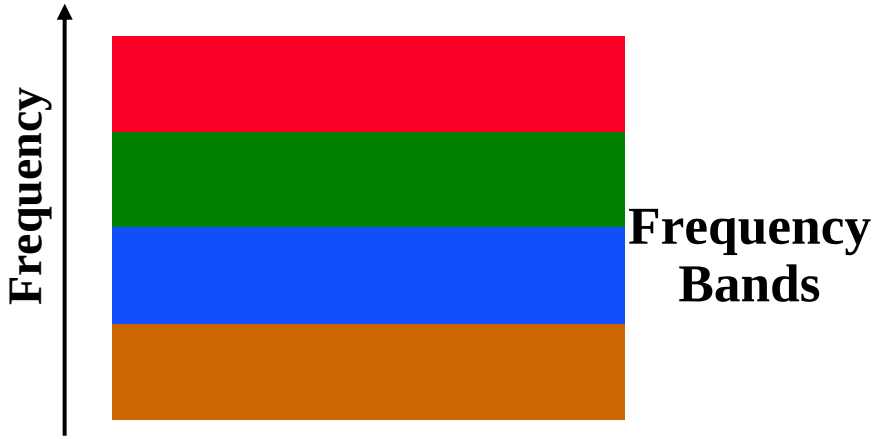


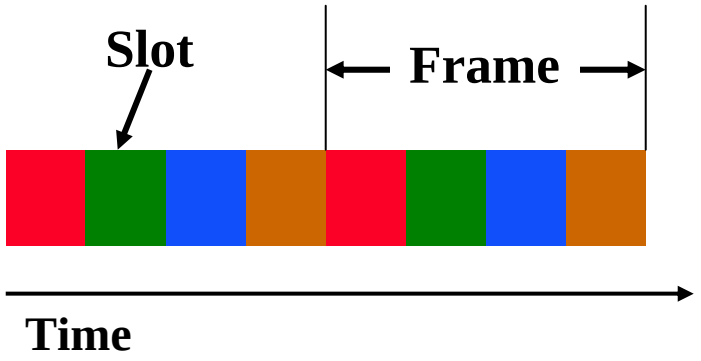
Frequency Division Multiplexing: Multiple Channels



Frequency versus Time-division Multiplexing

- With frequency-division multiplexing different users use different parts of the frequency spectrum.
  - » I.e. each user can send all the time at reduced rate
  - » Example: roommates
- With time-division multiplexing different users send at different times.
  - » I.e. each user can sent at full speed some of the time
  - » Example: a time-share condo
- The two solutions can be combined.

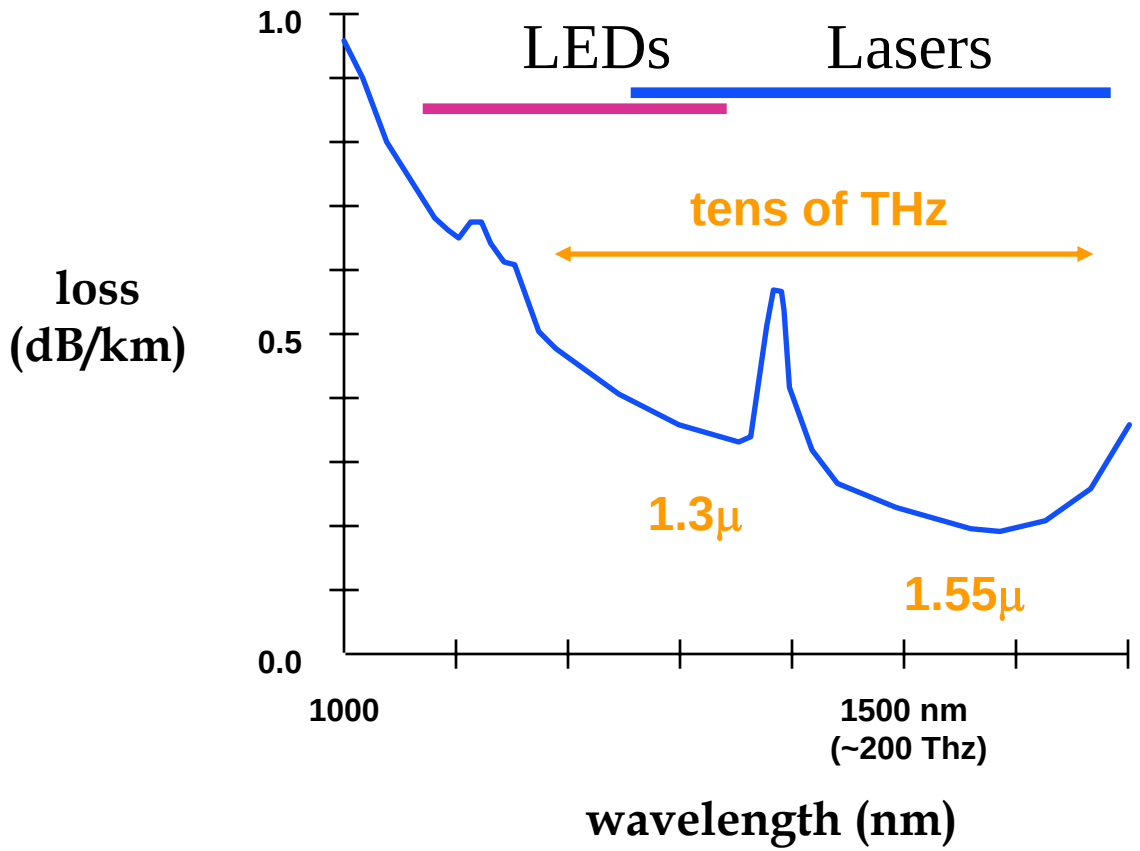




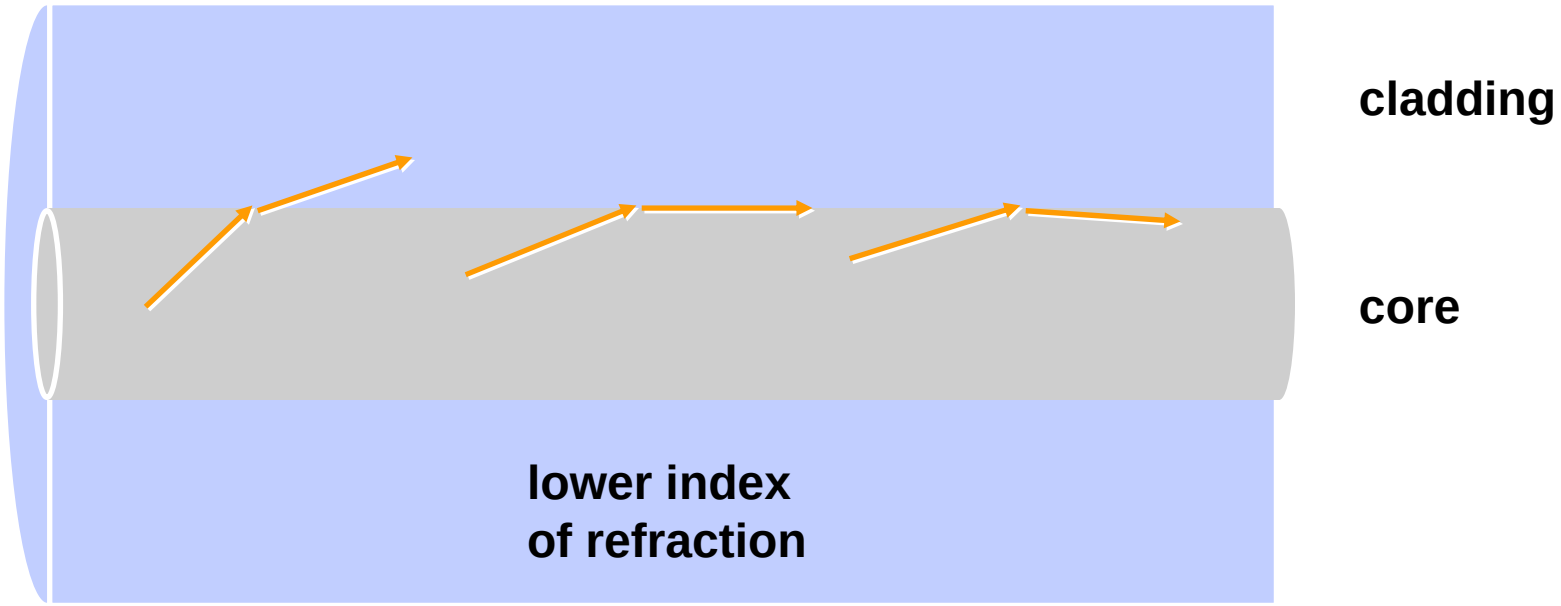
Copper Wire

- **Unshielded twisted pair**
  - Two copper wires twisted - avoid antenna effect
  - Grouped into cables: multiple pairs with common sheath
  - Category 3 (voice grade) versus category 5
  - 100 Mbit/s up to 100 m, 1 Mbit/s up to a few km
  - Cost: ~ 10cents/foot
- **Coax cables.**
  - One connector is placed inside the other connector
  - Holds the signal in place and keeps out noise
  - Gigabit up to a km
- **Signaling processing research pushes the capabilities of a specific technology.**
  - E.g. modems, use of cat 5

Light Transmission in Fiber



Ray Propagation



(note: minimum bend radius of a few cm)

Fiber Types

- **Multimode fiber.**
  - 62.5 or 50 micron core carries multiple “modes”
  - used at 1.3 microns, usually LED source
  - subject to mode dispersion: different propagation modes travel at different speeds
  - typical limit: 1 Gbps at 100m
- **Single mode**
  - 8 micron core carries a single mode
  - used at 1.3 or 1.55 microns, usually laser diode source
  - typical limit: 1 Gbps at 10 km or more
  - still subject to chromatic dispersion

Gigabit Ethernet: Physical Layer Comparison

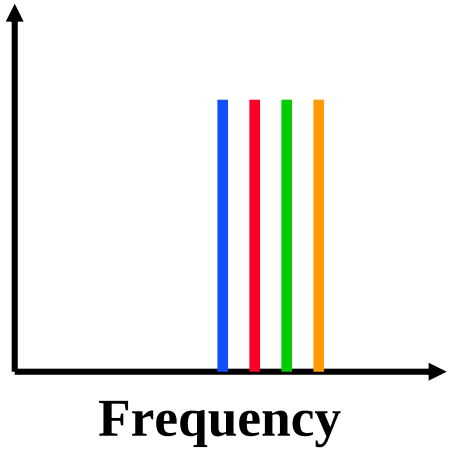
Medium	Transmit/receive	Distance	Comment
Copper	1000BASE-CX	25 m	machine room use
Twisted pair	1000BASE-T	100 m	not yet defined; cost? Goal:4 pairs of UTP5
MM fiber 62 μm	1000BASE-SX	260 m	
	1000BASE-LX	500 m	
MM fiber 50 μm	1000BASE-SX	525 m	
	1000BASE-LX	550 m	
SM fiber	1000BASE-LX	5000 m	
Twisted pair	100BASE-T	100 m	2p of UTP5/2-4p of UTP3
MM fiber	100BASE-SX	2000m	

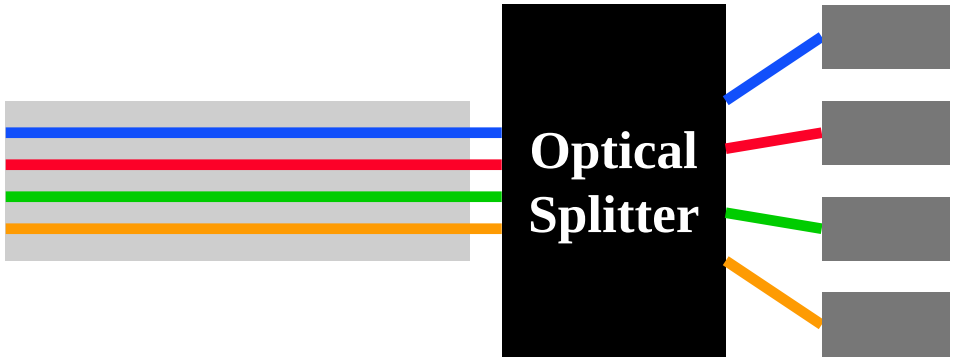
Regeneration and Amplification

- At end of span, either regenerate electronically or amplify.
- Electronic repeaters are potentially slow, but can eliminate noise.
- Amplification over long distances made practical by erbium doped fiber amplifiers offering up to 40 dB gain, linear response over a broad spectrum. Ex: 10 Gbps at 500 km.

Wavelength Division Multiplexing

- **Send multiple wavelengths through the same fiber.**
  - » **Multiplex and demultiplex the optical signal on the fiber**
- **Each wavelength represents an optical carrier that can carry a separate signal.**
  - » **E.g., 16 colors of 2.4 Gbit/second**
- **Like radio, but optical and much faster**





Wireless Technologies

- **Great technology: no wires to install, convenient mobility, ..**
- **High attenuation limits distances.**
  - **Wave propagates out as a sphere**
  - **Signal strength reduces quickly $(1/\text{distance})^3$**
- **High noise due to interference from other transmitters.**
  - **Use MAC and other rules to limit interference**
  - **Aggressive encoding techniques to make signal less sensitive to noise**
- **Other effects: multipath fading, security, ..**
- **Ether has limited bandwidth.**
  - **Try to maximize its use**
  - **Government oversight to control use**

Things to Remember

- **Bandwidth and distance of networks is limited by physical properties of media.**
  - » **Attenuation, noise, …**
- **Network properties are determined by transmission medium and transmit/receive hardware.**
  - » **Nyquist gives a rough idea of idealized throughput**
  - » **Can do much better with better encoding**
    - – **Low b/w channels: Sophisticated encoding, multiple bits per wavelength.**
    - – **High b/w channels: Simpler encoding (FM, PCM, etc.), many wavelengths per bit.**
- **Multiple users can be supported using space, time, or frequency division multiplexing.**
- **Properties of different transmission media.**