

15-441 Lecture 4

Physical Layer &
Link Layer Basics

Peter Steenkiste
Fall 2010

www.cs.cmu.edu/~prs/15-441-F10

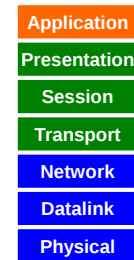
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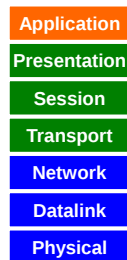
Last Time

- Application Layer
- Example Protocols
 - ftp
 - http
- Performance



Today (& Tomorrow (& Tmrw))

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



Transferring Information

- Information transfer is a physical process
- In this class, we generally care about
 - Electrical signals (on a wire)
 - Optical signals (in a fiber)
 - More broadly, EM waves
- Information carrier can also be ?

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Transferring Information

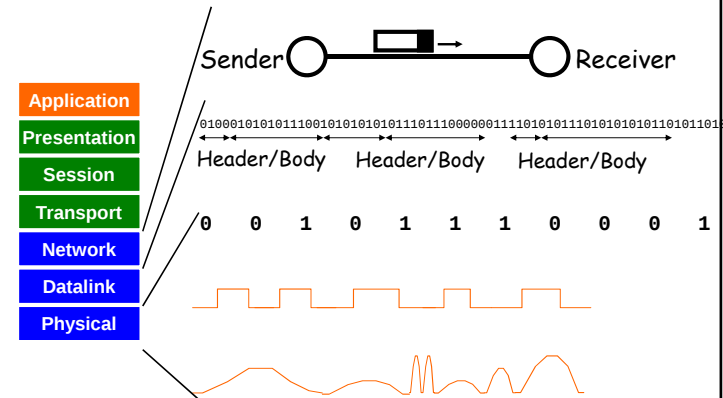
- Information transfer is a physical process
- In this class, we generally care about
 - Electrical signals (on a wire)
 - Optical signals (in a fiber)
 - More broadly, EM waves
- Information carriers can also be
 - Sound waves
 - Quantum states
 - Proteins
 - Ink & paper, etc.

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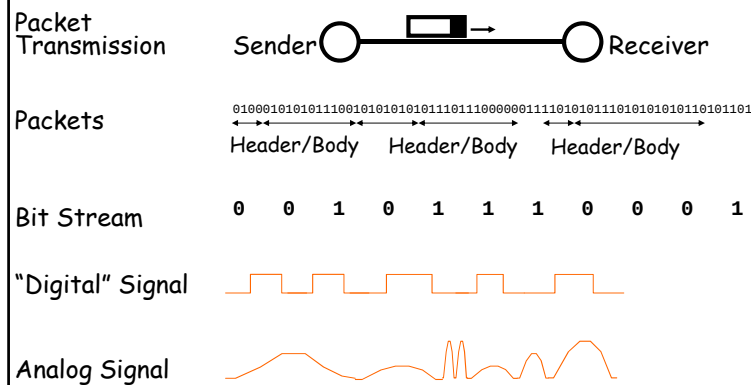
From Signals to Packets



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From Signals to Packets



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Today's Lecture

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

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Why Do We Care?

- I am not an electrical engineer?
 - Well, most of you aren't
- Physical layer places constraints on what the network infrastructure can deliver
 - Reality check
 - Impact on system performance
 - Impact on the higher protocol layers
 - Some examples:
 - Fiber or copper?
 - Do we need wires?
 - Error characteristic and failure modes
 - Effects of distance - remember last lecture?

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Modulation

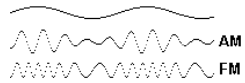
- Changing a signal to convey information
- From Music:
 - Volume
 - Pitch
 - Timing

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Modulation

- Changing a signal to convey information
 - Ways to modulate a sinusoidal wave
 - Volume: Amplitude Modulation (AM)
 - Pitch: Frequency Modulation (FM)
 - Timing: Phase Modulation (PM)
- 
- In our case, modulate signal to encode a 0 or a 1.
(multi-valued signals sometimes)

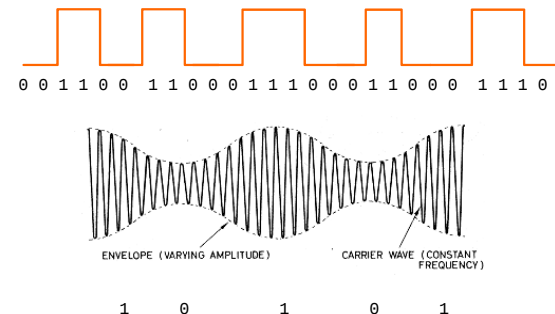
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Amplitude Modulation

- AM: change the strength of the signal.
- Example: High voltage for a 1, low voltage for a 0



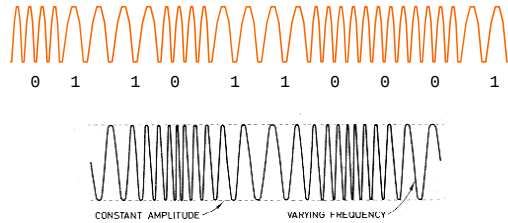
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Frequency Modulation

- FM: change the frequency



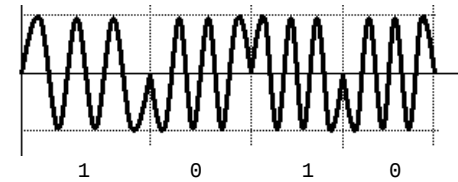
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Phase Modulation

- PM: Change the phase of the signal



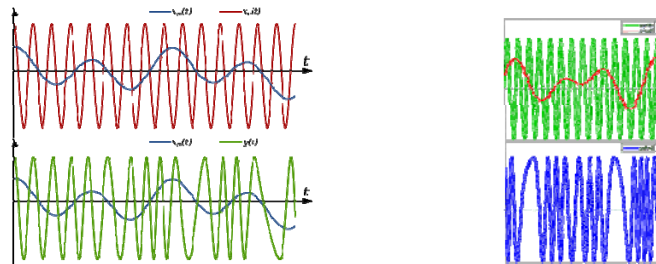
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Baseband vs Carrier Modulation

- 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

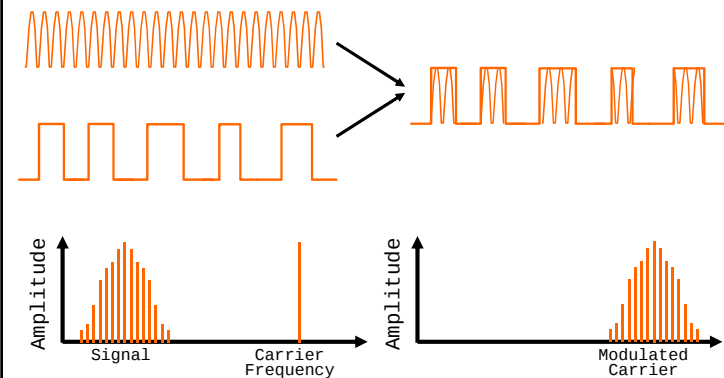


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Amplitude Carrier Modulation



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Why Different Modulation Methods?

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Why Different Modulation Methods?

- Transmitter/Receiver complexity
- Power requirements
- Bandwidth
- Medium (air, copper, fiber, ...)
- Noise immunity
- Range
- Multiplexing

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What Do We Care About?

- 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?

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Bandwidth

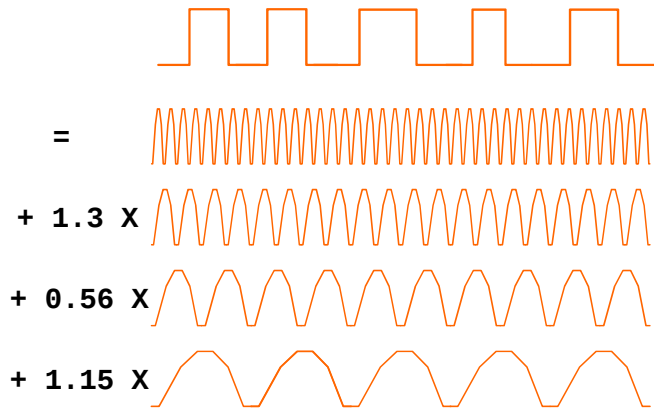
- Bandwidth is width of the frequency range in which the fourier transform of the signal is non-zero.
- Sometimes referred to as the channel width
- Or, where it is above some threshold value (Usually, the half power threshold, e.g., -3dB)
- dB
 - Short for decibel
 - Defined as $10 * \log_{10}(P_1/P_2)$
 - When used for signal to noise: $10 * \log_{10}(S/N)$

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Signal = Sum of Waves



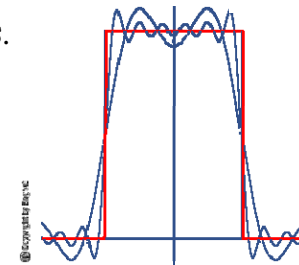
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The Frequency Domain

- 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)
- E.g., radio and TV signals.



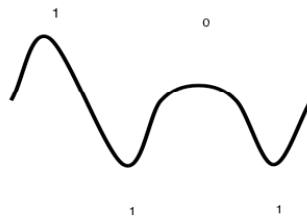
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The Nyquist Limit

- A noiseless channel of width H can at most transmit a binary signal at a rate $2 \times H$.
 - Assumes binary amplitude encoding



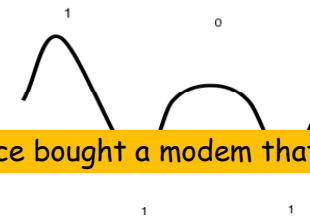
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The Nyquist Limit

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



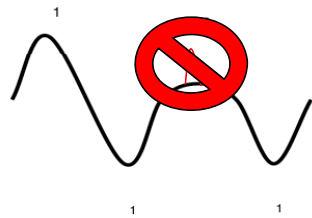
Hmm, I once bought a modem that did 54K????

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How to Get Past the Nyquist Limit



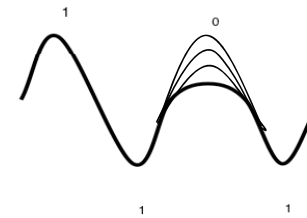
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How to Get Past the Nyquist Limit

- Instead of 0/1, use lots of different values.
- (Remember, the channel is noiseless.)
- Can we really send an infinite amount of info/sec?



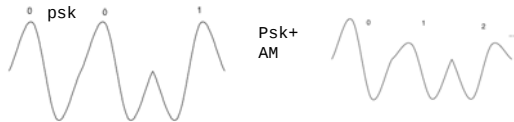
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Past the Nyquist Limit

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



- 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

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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.

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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:

$$C = B \times \log_2(1 + S/N)$$
 - 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)

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Capacity of a Noisy Channel

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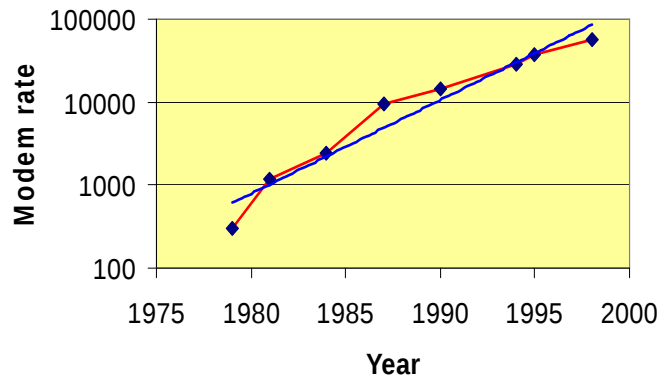
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 - C: maximum capacity (bps)
 - B: channel bandwidth (Hz)
 - S/N: signal to noise ratio of the channel
Often expressed in decibels (db) ::= 10 log(S/N)
- Example:
 - Local loop bandwidth: 3200 Hz
 - Typical S/N: 1000 (30db)
 - What is the upper limit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

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Example: Modem Rates



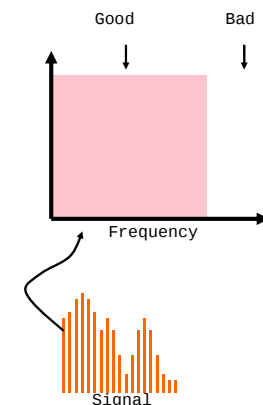
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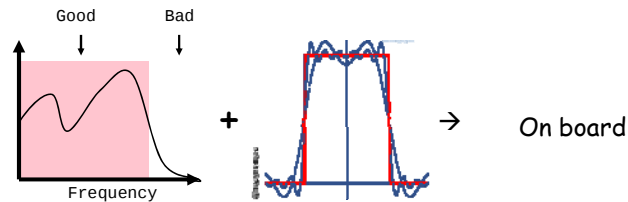
Transmission Channel Considerations

- 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.



Attenuation & Dispersion

- Real signal may be a combination of many waves at different frequencies
- Why do we care?



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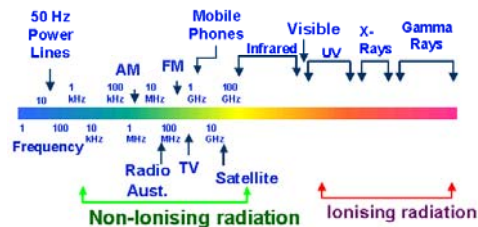
Limits to Speed and Distance

- 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

Today's Lecture

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

- Coding.
- Framing.



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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.
 - Similar to radio: 95.5 versus 102.5 station
- Controlling time (for us) is a datalink protocol issue.
 - Media Access Control (MAC): who gets to send when?

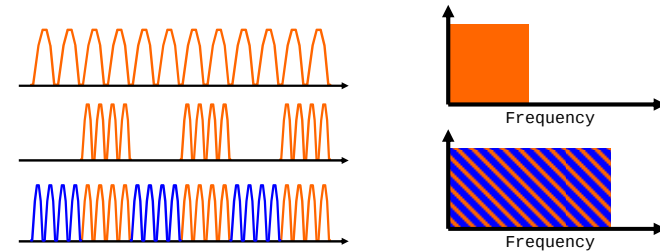
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Time Division Multiplexing

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

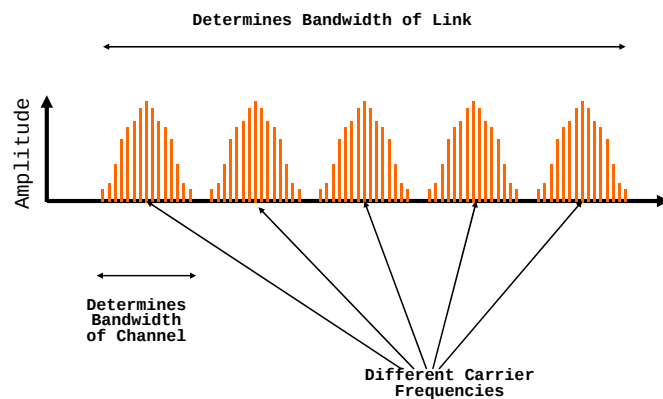


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FDM: Multiple Channels



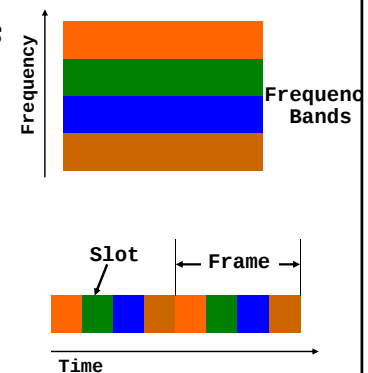
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Frequency versus Time-division Multiplexing

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



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Copper Wire

- Unshielded twisted pair (UTP)
 - 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

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UTP

- Why twist wires?



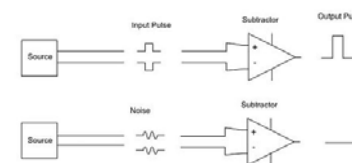
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UTP

- Why twist wires?
 - Provide noise immunity
- Combine with Differential Signaling

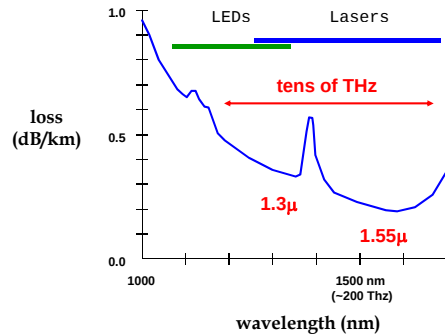


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Light Transmission in Fiber

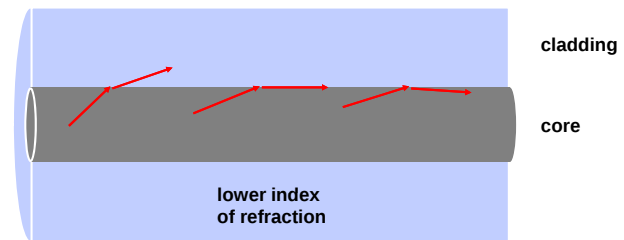


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Ray Propagation



(note: minimum bend radius of a few cm)

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Fiber Types

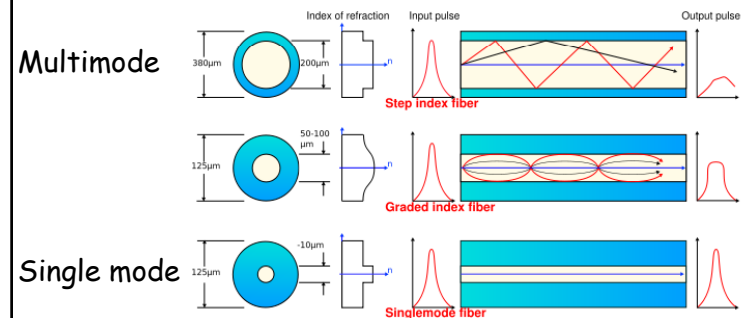
- **Multimode fiber.**
 - 62.5 or 50 micron core carries multiple "modes"
 - used at 1.3 microns, usually LED source
 - subject to mode dispersion: different propagation modes travel at different speeds
 - typical limit: 1 Gbps at 100m
- **Single mode**
 - 8 micron core carries a single mode
 - used at 1.3 or 1.55 microns, usually laser diode source
 - typical limit: 10 Gbps at 60 km or more
 - still subject to chromatic dispersion

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Fiber Types



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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 mm	1000BASE-SX	260 m	
	1000BASE-LX	500 m	
MM fiber 50 mm	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 UTP
MM fiber	100BASE-SX	2000m	

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How to increase distance?

- Even with single mode, there is a distance limit.
- I.e.: How do you get it across the ocean?

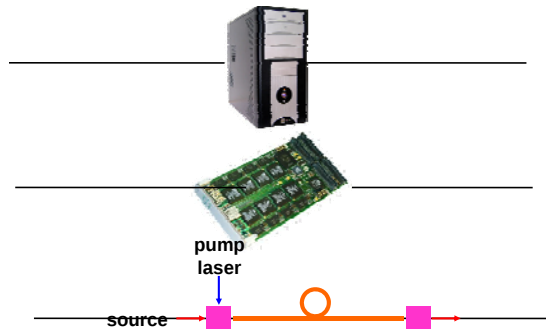
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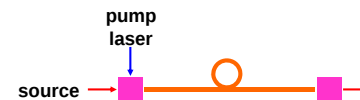
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Regeneration and Amplification

- 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: 40 Gbps at 500 km.



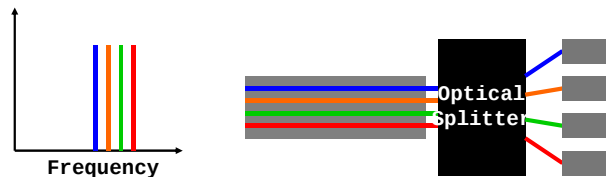
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Wavelength Division Multiplexing

- 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



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Wireless Technologies

- Great technology: no wires to install, convenient mobility, ...
- High attenuation limits distances.
 - Wave propagates out as a sphere
 - Signal strength attenuates quickly $\rightarrow 1/d^3$
- 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

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Things to Remember

- Bandwidth and distance of networks is limited by physical properties of media.
 - Attenuation, noise, dispersion, ...
- 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.
 - Shannon: $C = B \times \log_2(1 + S/N)$
- Multiple users can be supported using space, time, or frequency division multiplexing.
- Properties of different transmission media.

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