CS 640: Introduction to Computer Networks

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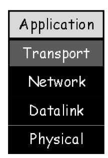
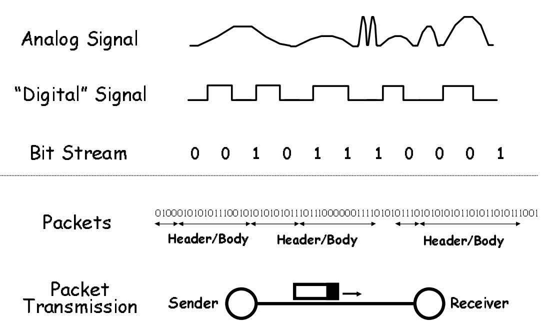
Lecture 4 -
Physical Layer Transmission
and Link Layer Basics

The Road Ahead…

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



Signals, Data and Packets



Binary data to Signals

- Encoding
  - How to convert bits to "digital" signals
  - Very complex, actually
  - Error recovery, clock recovery,…
- Modulation: changing attributes of signal to effect information transmissions

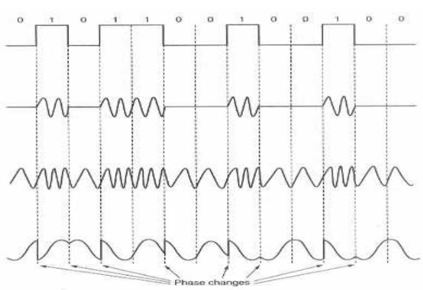
Modulation Schemes

Data

Amplitude Modulation

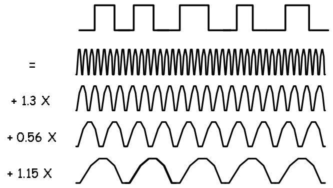
Frequency Modulation

Phase Modulation



The Frequency Domain

- A signal can be viewed as a sum of sine waves of different strengths.
- Every signal has an equivalent representation in the frequency domain.
  - What frequencies are present and their relative strength

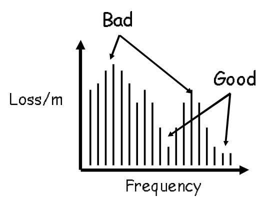


Why Do We Care?

- 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?
- How much bandwidth can I get out of a specific wire (transmission medium)?

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 reception hardware will try to maximize the useful capacity 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 constant frequency
  - Assumes AM
  - Assumes binary information transfer
  - Assumes no noise

Past the Nyquist Limit

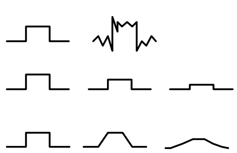
- More aggressive encoding can increase the channel bandwidth
  - Example: modems
    - Same *frequency* - number of symbols per second
    - Symbols have more possible values
    - Use multiple modulation schemes together
- The channel bandwidth is determined by the transmission medium and the quality 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:
  - $C = B \times \log(1 + S/N)$
  - C: maximum capacity (bps)
  - B: channel frequency range or 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?

Limits to Capacity

- 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



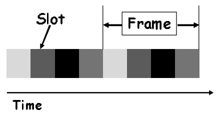
- Effects limit the data rate that a channel can sustain.
  - But affects different technologies in different ways
- Effects become worse with distance.
  - Tradeoff between data rate and distance

Supporting Multiple Channels

- Can multiple transmission channels coexist?
  - Yes, if they transmit at a different frequency, or at a different time, or in a different part of the space.
- Space can limit use of wires or of transmit power of wireless transmitters.
- Multiplexing
  - 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 → Time-division multiplexing: divide time into quanta

Frequency versus Time-division Multiplexing

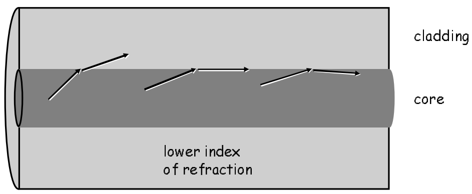
- With frequency-division multiplexing different users use different parts of the frequency spectrum.
  - I.e. each user can send all the time at reduced rate
  - Example: roommates
- With time-division multiplexing different users send at different times.
  - I.e. each user can sent at full speed some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



Copper Wire

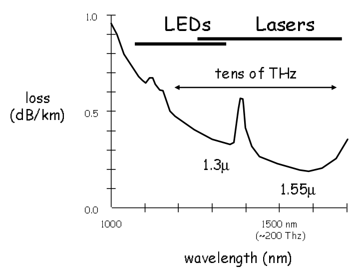
- Unshielded twisted pair
  - Two copper wires twisted - avoid antenna effect; differential
  - Grouped into cables: multiple pairs with common sheath
  - Category 3 (voice grade) versus Category 5 (Ethernet)
  - 100 Mbit/s up to 100 m, 1 Mbit/s up to a few km
  - Cost: ~ 10cents/foot; cheap
- Coax cables.
  - One connector is placed inside the other connector
  - Holds the signal in place and keeps out noise
  - Gigabit up to a km

Optical Fiber: Ray Propagation



(note: minimum bend radius of a few cm)

Optical Fiber Physical Constraints

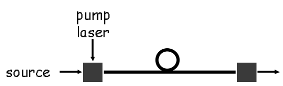


Fiber Types

- Multimode fiber
  - Designed to carry multiple modes/rays each at slightly different angle
  - 62.5 or 50 micron core carries the multiple
  - used at 1.3 micron wavelength, 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

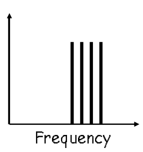
Regeneration and Amplification

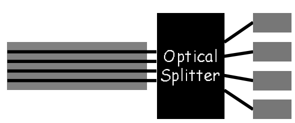
- At end of span, either regenerate electronically or amplify.
- Electronic repeaters are potentially slow, but can eliminate noise.
- Amplification over long distances made practical by erbium doped fiber amplifiers offering up to 40 dB gain.
- Ex: 10 Gbps at 500 km.



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





Gigabit Ethernet: Physical Layer Comparison

Medium	Transmit/receive	Distance
Copper	1000BASE-CX	25 m
Twisted pair	1000BASE-T	100 m
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

Wireless Technologies

- Great technology: easy to use, no wires to install, convenient mobility, ..
- High attenuation limits distances.
  - Wave propagates out as a sphere (approximately)
  - Signal strength reduces quickly $(1/\text{distance})^3$
- High noise due to interference from other transmitters.
  - Use MAC and other rules to limit interference
    - E.g transmit power control
  - Aggressive encoding techniques to make signal less sensitive to noise
    - Don't always work
- Other effects: multipath fading, security, ..
- Government tightly regulates spectrum usage

Summary So Far

- 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
- Multiple users can be supported using space, time, or frequency division multiplexing.
- Properties of different transmission media.

Analog versus Digital

- Digital transmissions.
  - Interpret the signal as a series of 1's and 0's
  - Hand over interpreted information to higher layers
  - E.g. data transmission over the Internet
- Analog transmission
  - Do not interpret the contents
  - Just play out the signal
  - E.g broadcast radio
- Why digital transmission?

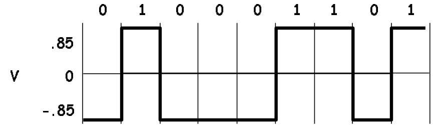
Why Do We Need Encoding?

- Meet certain electrical constraints.
  - Receiver needs enough "transitions" to keep track of the transmit clock
  - Avoid receiver saturation
- Create control symbols, besides regular data symbols.
  - E.g. start or end of frame, escape, ...
  - Important in packet switching
- Error detection or error corrections.
  - Some codes are illegal so receiver can detect certain classes of errors
  - Minor errors can be corrected by having multiple adjacent signals mapped to the same data symbol
- Encoding can be very complex, e.g. wireless.

Encoding

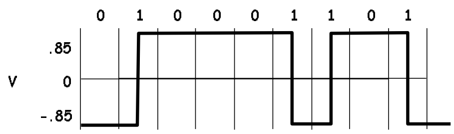
- Use two signals, high and low, to encode 0 and 1.
- Transmission is synchronous, i.e., a clock is used to sample the signal.
  - In general, the duration of one bit is equal to one or two clock ticks
  - Receiver's clock must be synchronized with the sender's clock
- Encoding can be done one bit at a time or in blocks of, e.g., 4 or 8 bits.

Non-Return to Zero (NRZ)



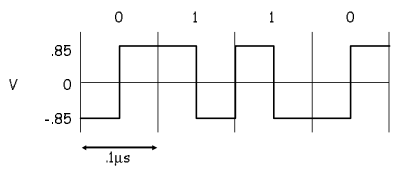
- 1 -> high signal; 0 -> low signal
- Long sequences of 1's or 0's can cause problems:
  - Hard to recover clock
  - Difficult to interpret 0's and 1's

Non-Return to Zero Inverted (NRZI)



- 1 -> make transition; 0 -> signal stays the same
- Solves the problem for long sequences of 1's, but not for 0's.

Ethernet Manchester Encoding



- Positive transition for 0, negative for 1
- XOR of NRZ with clock
- Transition every cycle communicates clock (but need 2 transition times per bit)
- Problem: doubles the rate at which signal transitions are made
  - Less efficient
  - Receiver has half the time to detect the pulse

4B/5B Encoding

- Data coded as *symbols* of 5 line bits => 4 data bits, so 100 Mbps uses 125 MHz.
  - Uses less frequency space than Manchester encoding
- Each valid symbol has no more than one leading zero and no more than two trailing zeros
  - At least two 1s ➔ Get dense transitions
- Uses NRZI to encode the 5 code bits
  - What happens if there are consecutive 1s?
- Example: FDDI.

4B/5B Encoding

- 16 data symbols, 8 control symbols
  - Control symbols: idle, begin frame, etc.
  - Remaining 8 are invalid

Data	Code	Data	Code
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

Other Encodings

- 8B/10B: Fiber Channel and Gigabit Ethernet
  - DC balance
- 64B/66B: 10 Gbit Ethernet
- B8ZS: T1 signaling (bit stuffing)

Next Lecture

- Data Link Overview
  - Framing
  - Error coding
  - Switching
  - Flow Control