CSE/EE 461 – Lecture 3

Bits, Links and Frames

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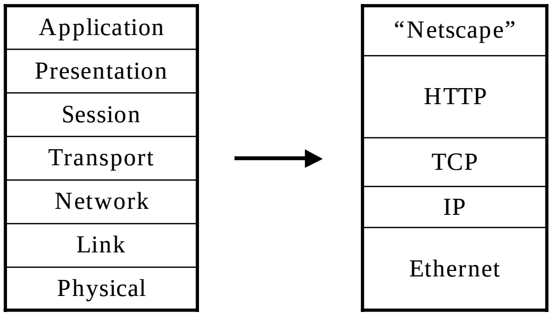
Last Time …

- Protocols, layering and reference models



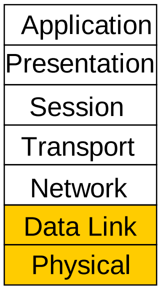
The OSI Model
Application
Presentation
Session
Transport
Network
Link
Physical

Sample Protocol Stack
“Netscape”
HTTP
TCP
IP
Ethernet

The OSI Model → Sample Protocol Stack

This Lecture

- Focus: *How do we send a message across a wire?*
- The physical/link layers:
  1. Different kinds of media
  2. Encoding bits
  3. Model of a link
  4. Framing messages



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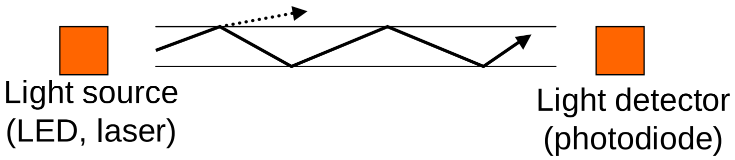
1. Different kinds of media

- Wire
  - Twisted pair, e.g., CAT5 UTP, 10 100Mbps, 100m
  - Coaxial cable, e.g, thin-net, 10 100Mbps, 200m
- Fiber
  - Multi-mode, 100Mbps, 2km
  - Single mode, 100 2400 Mbps, 40km
- Wireless
  - Infra-red, e.g., IRDA, ~1Mbps
  - RF, e.g., 802.11 wireless LANs, Bluetooth (2.4GHz)
  - Microwave, satellite, cell phones, …

Fiber

- Long, thin, pure strand of glass
  - Enormous bandwidth available (terabits)



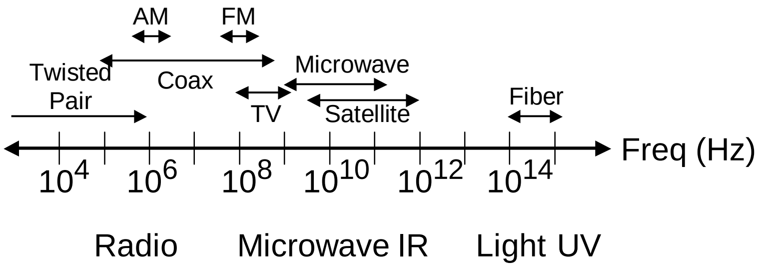
Light source
(LED, laser)

Light detector
(photodiode)

- Multi-mode allows many different paths, dispersion
- Chromatic dispersion if multiple frequencies

Wireless

- Different frequencies have different properties
- Signals subject to atmospheric/environmental effects

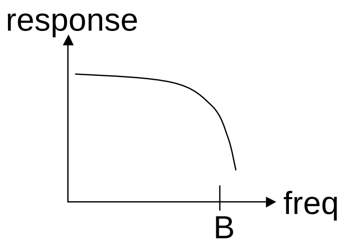


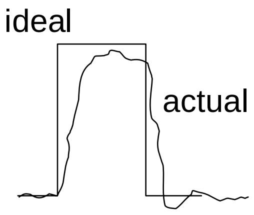
AM
FM
Twisted Pair
Coax
Microwave
TV
Satellite
Fiber
Freq (Hz)
10^4 10^6 10^8 10^{10} 10^{12} 10^{14}

Radio Microwave IR Light UV

Wires

- Signal subject to:
  - Attenuation (repeaters)
  - Distortion (frequency and delay)
  - Noise (thermal, crosstalk, impulse)





Aside: Bandwidth of a Channel

- EE: Bandwidth (B) (Hz) is the width of the pass-band in the frequency domain
- CS: “Bandwidth” (bps) is the information carrying capacity (C) of the channel

- Shannon showed how they are related by noise, which limits how many signal levels we can safely distinguish.

Model of Channel Distortion

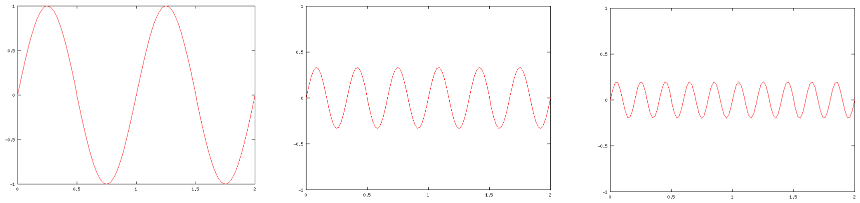
- Behavior of channel on a signal is based on behavior on each component of the signal:
  - g(signal) = g(∑(freq)) = ∑(g'(freq))
  - frequency response (amplitude attenuation)
  - phase response (phase shift)
- Measure channel on pure signals

  => predict impact on each component

  => sum to get output

Ex: Decomposing a Square Wave

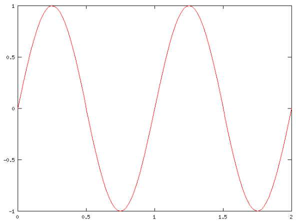
- Square wave can be decomposed into a sum of sines by a technique called Fourier analysis



sin(x) + sin(3x)/3 + sin(5x)/5 …

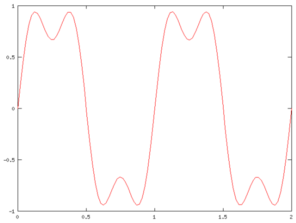
Ex: Transmitting a Square Wave

- Higher channel bandwidth passes more components that give successively better representations of the original square wave



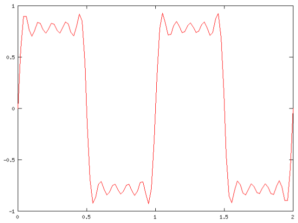
fundamental

Bandwidth = f



1st + 3rd harmonic

3f

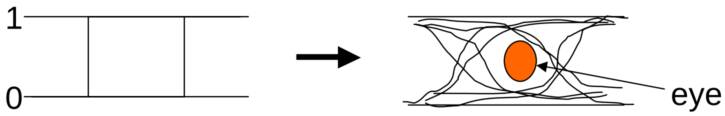


5 terms …

5f

Nyquist Limit (~1924)

- For a noiseless channel with bandwidth B
- Symbols will be distorted, and sending too fast leads to Inter-symbol Interference (ISI)



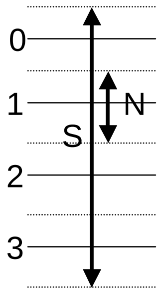
- The maximum rate at which it is possible to send:

R = 2B symbols / sec

e.g., 3KHz 6Ksym / sec

Taking Noise into Account

- Noise limits how many signal levels we can safely distinguish between
  - S = max signal amp., N = max noise amp.
- The number of bits per symbol depends on the number of signal levels
  - E.g, 4 levels implies 2 bits / symbol



The Shannon Limit (1948)

- Define Signal to Noise Ratio (SNR):

  SNR = $10\log_{10}$(signal / noise) decibels (dB)

  e.g, 30 dB means signal 1000 times noise

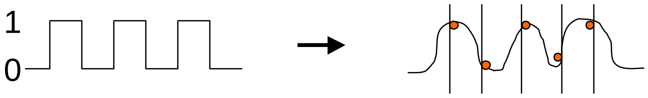
- For a noisy channel with bandwidth B (Hz) and given SNR, the maximum rate at which it is possible to send information, the channel capacity, is:

  $C = B \log_2(1 + \mathrm{SNR})$ (bits / sec)

  e.g 3KHz and 30dB SNR   30Kbps

2. Encoding Bits with Signals

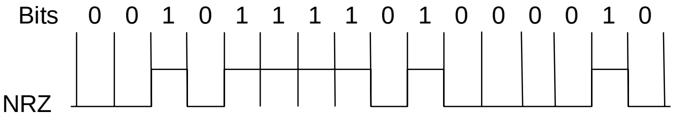
- Generate analog waveform (e.g., voltage) from digital data at transmitter and sample to recover at receiver



- We send / recover symbols that are mapped to bits
  - Signal transition rate = baud rate, versus bit rate
- This is baseband transmission … take a signals course!

NRZ and NRZI

- Simplest encoding, NRZ (Non-return to zero)
  - Use high / low voltages, e.g., high = 1, low = 0
- Variation, NRZI (NRZ, invert on 1)
  - Use transition for 1s, no transition for 0s



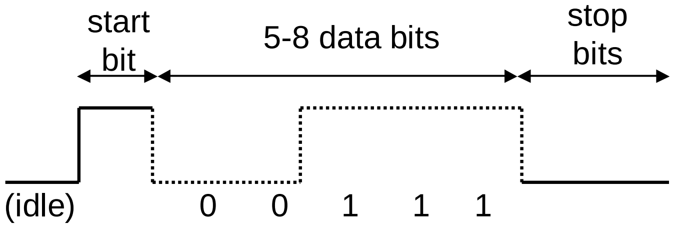
Clock Recovery

- Problem: How do we distinguish consecutive 0s or 1s?
- If we sample at the wrong time we get garbage …
- If sender and receiver have exact clocks no problem
  - But in practice they drift slowly
- This is the problem of clock recovery

- Possible solutions:
  - Send separate clock signal expensive
  - Keep messages short limits data rate
  - Embed clock signal in data signal other codes

"Asynchronous" Transmission

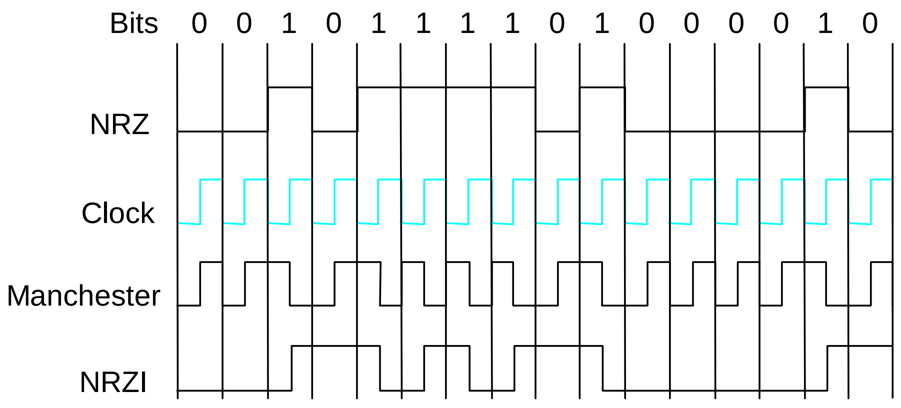
- Avoid timing problem by sending short, delimited data with a well-defined beginning
  - E.g., UARTs (typically used to connect your keyboard)



Manchester Coding

- Make transition in the middle of every bit period
  - Low-to-high is 0; high-to-low is 1
  - Signal rate is twice the bit rate
  - Used on 10 Mbps Ethernet
- Advantage: self-clocking
  - clock is embedded in signal, and we re-sync with a phase-locked loop every bit
- Disadvantage: 50% efficiency

Coding Examples



4B/5B Codes

- We want transitions *and* efficiency …
- Solution: map data bits (which may lack transitions) into code bits (which are guaranteed to have them)

- 4B / 5B code:
  - 0000 11110, 0001 01001, … 1111 11101
  - Never more than three consecutive 0s back-to-back
  - 80% efficiency

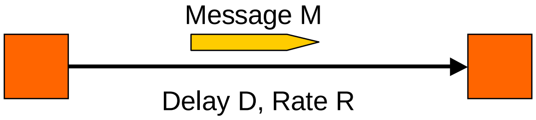
- This code is used by LANs such as FDDI

3. Model of a Link

- Abstract model is typically all we will need
  - What goes in comes out altered by the model
- Other parameters that are important:
  - The kind and frequency of errors
  - Whether the media is broadcast or not

Message Latency

- How long does it take to send a message?



- Two terms:
  - Propagation delay = distance / speed of light in media
  - Transmission delay = message (bits) / rate (bps)
- In effect, slow links stretch bits out in time/space
- Later we will see queuing delay …

One-way Latency examples

- Either a slow link or long wire makes for large latency

- Dialup with a modem:
  - D = 10ms (say), R = 56Kbps, M = 1000 bytes
  - Latency = 10ms + (1024 x 8)/(56 x 1024) sec = 153ms!

- Cross-country with T3 (45Mbps) line:
  - D = 50ms, R = 45Mbps, M = 1000 bytes
  - Latency = 50ms + (1024 x 8) / (45 x 1000000) sec = 50ms!

Terminology

- Latency is typically the one way delay over a link
  - But latency and delay are generic terms
- The round trip time (RTT) is twice the one way delay
  - Measure of how long to signal and get a response
- An important metric is the bandwidth-delay product
  - Measure of how much data can be in-flight at a time

4. Framing

- Need to send message, not just bits
  - Requires that we synchronize on the start of message reception at the far end of the link
  - Complete Link layer messages are called <u>frames</u>

- Common approach: Sentinels
  - Look for special control code that marks start of frame
  - And escape or "stuff" this code within the data region

Point-to-Point Protocol (PPP)

- IETF standard, used for dialup and leased lines

Flag 0x7E	(header)	Payload (variable)	(trailer)	Flag 0x7E

- Flag is special and indicates start / end of frame
- Occurrences of flag inside payload must be “stuffed”
  - Replace 0x7E with 0x7D, 0x5E
  - Replace 0x7D with 0x7D, 0x5D

Alternatives that avoid stuffing

- “Invalid” signal from physical layer
  - Just trust me. Used in Ethernet and FDDI (later).
- Explicit byte count after flag
- SONET: “clock”-based framing
  - Periodic sync information plus very accurate clock
  - Used extensively in the telecommunications industry

- What are the pros and cons?
  - Efficiency (in terms of bandwidth)
  - Robustness (with respect to errors)

Key Concepts

- We typically model links in terms of bandwidth and delay, from which we can calculate message latency
- Different media have different properties that affect their performance as links
- We need to encode bits into signals so that we can recover them at the other end of the channel.
- Framing allows complete messages to be recovered at the far end of the link