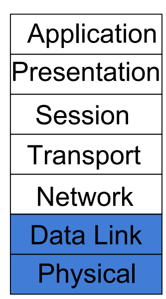
CSE 461: Bits and Bandwidth

Next Topic

- Focus: *How do we send a message across a wire?*

- The physical / link layers:
  1. Different kinds of media
  2. Encoding bits, messages
  3. Model of a link

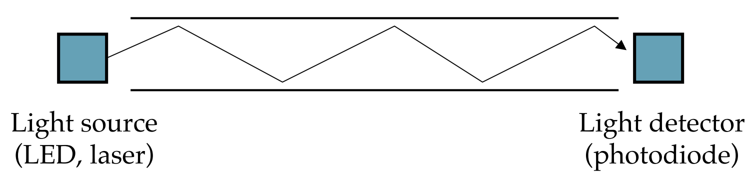


1. Different kinds of media

- 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
  - light propagated with total internal reflection
  - enormous bandwidth available (terabits)



- Multi-mode allows many different paths, limited by dispersion

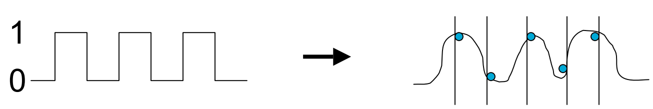
Aside: bandwidth of a channel

- EE: bandwidth (B, in 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
  - noise limits how many signal levels we can safely distinguish
  - geekspeak: "cannot distinguish the signal from the noise"

2. Encoding Bits with Signals

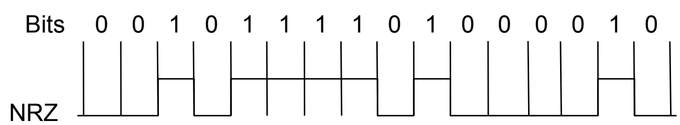
- Generate analog waveform (e.g., voltage) from digital data at transmitter and sample to recover at receiver



- We send/recover symbols that are mapped to bits
  - Signal transition rate = baud rate, versus bit rate

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

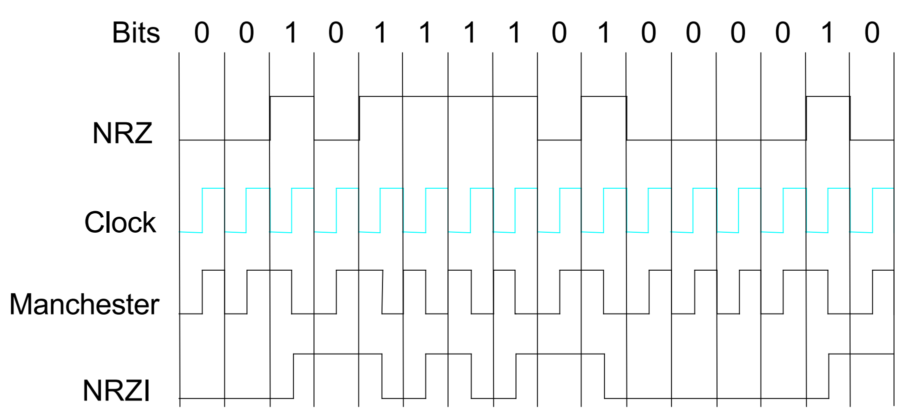
- Problem: How do we distinguish consecutive 0s or 1s?
- If we sample at the wrong time we get garbage …
- If sender and receiver have exact clocks no problem
  - But in practice they drift slowly
- This is the problem of clock recovery

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

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

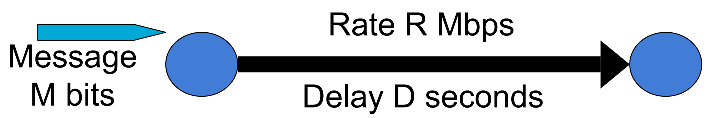
Example: Point-to-Point Protocol (PPP)

- 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”
  - Like an “escape” character:
    - \.\.\”\\ --> ..”\
  - Replace 0x7E with 0x7D, 0x5E
  - Replace 0x7D with 0x7D, 0x5D

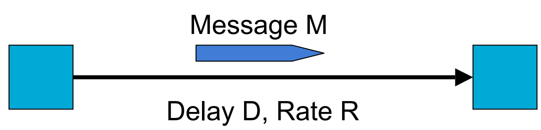
4. Model of a Link



- Abstract model is typically all we will need
- 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
    - How quickly a message travels over the wire
  - Transmission delay = message (bits) / rate (bps)
    - How quickly you can inject the message onto the wire
- Later we will see queuing delay …

Relationships

- Latency = Propagation + Transmit + Queue
- Propagation Delay = Distance/SpeedOfLight
- Transmit Time = MessageSize/Bandwidth

One-way Latency

Dialup with a modem:

- D = 10ms, R = 56Kbps, M = 1024 bytes
- Latency = 10ms + (1024 x 8)/(56 x 1024) sec = 153ms!

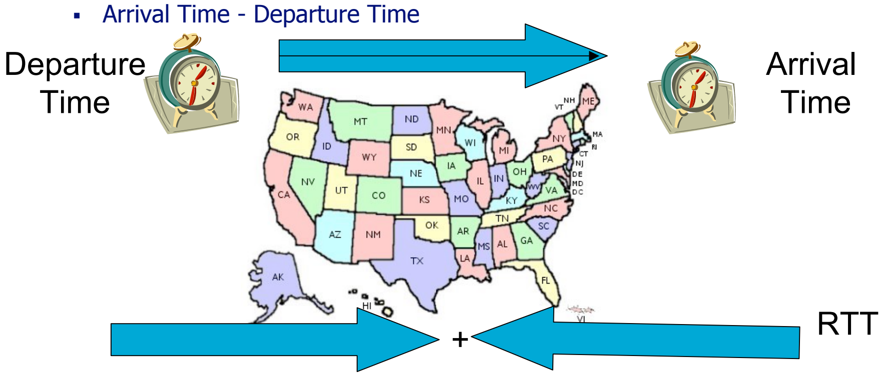
Cross-country with T3 (45Mbps) line:

- D = 50ms, R = 45Mbps, M = 1024 bytes
- Latency = 50ms + (1024 x 8) / (45 x 1024*1024) sec = 50ms!

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

Latency and RTT

- Latency is typically the one way delay over a link
  - Arrival Time - Departure Time



- The round trip time (RTT) is twice the one way delay
  - Measure of how long to signal and get a response

Throughput

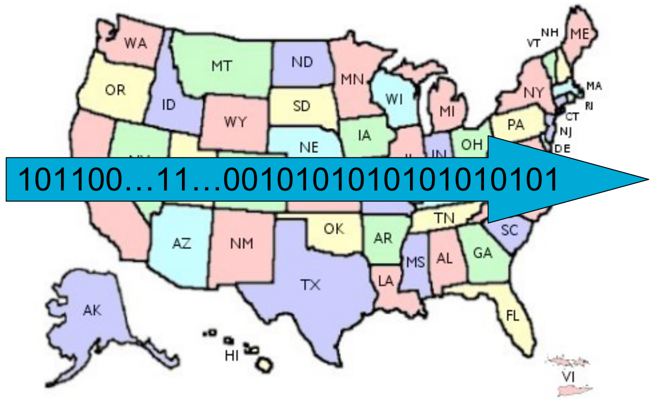
- Measure of system's ability to "pump out" data
  - NOT the same as bandwidth
- Throughput = Transfer Size / Transfer Time
  - E.g., "I transferred 1000 bytes in 1 second on a 100Mb/s link"
    - BW?
    - Throughput?
- Transfer Time = SUM OF
  - Time to get started shipping the bits
  - Time to ship the bits
  - Time to get a response if necessary

Messages Occupy "Space" On the Wire

- Consider a 1b/s network.
- Suppose latency is 16 seconds.
  - How many bits can the network "store"
  - This is the BANDWIDTH-DELAY product
  - Measure of "data in flight."
  - 1b/s * 16s = 16b
- Tells us how much data can be sent before a receiver sees any of it.
  - Twice B.D. tells us how much data we could send before hearing back from the receiver something related to the first bit sent.
  - What are the implications of high B.D.?

A More Realistic Example

BD = 50ms * 45Mbps = 2.25 * 10^6 = 280KB



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