Overview

- Performance metrics - Section 1.5
- Direct link networks
  - Hardware building blocks - Section 2.1
  - Encoding - Section 2.2
  - Framing - Section 2.3

Performance Metrics

- Bandwidth
  - Amount of data that can be transmitted per time unit
- Throughput
  - Measured performance of the system
  - link versus end-to-end measurement
- Notation - Mbps = 10^6 bits per second

Performance metrics

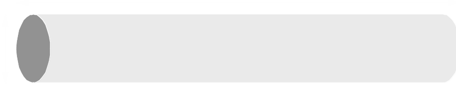
- Latency (delay)
  - time to send message from point A to point B
  - one-way versus round-trip time (RTT)
  - components
    - Latency = Propagation + Transmit + Queue
    - Propagation = Distance / c; c - speed of light
    - Transmit = Size / Bandwidth

Bandwidth versus Latency

- For interactive performance, is it better to login through a 1 Gbps satellite link or 56 kbps dialup link?
  - For ssh’ing to darwin.cc.nd.edu, is DSL better than dialup?
- Relative importance
  - 1-byte: 1ms vs 100ms dominates 1Mbps vs 100Mbps
  - 25MB: 1Mbps vs 100Mbps dominates 1ms vs 100ms
- Infinite bandwidth
  - RTT dominates
    - Throughput = TransferSize / TransferTime
    - TransferTime = RTT + 1/Bandwidth x TransferSize
  - 1-MB file to 1-Gbps link as 1-KB packet to 1-Mbps link

Delay x Bandwidth Product

- Amount of data “in flight” or “in the pipe”
- Example: 100ms x 45Mbps = 560KB
- Affects how much data should be put on the wire



Direct Link Networks

- Hosts are directly connected by some medium
  - Twisted pair: telephone cable, Ethernet (Category 5: Cat5)
  - Coaxial pair: TV
  - Optical Fiber
  - Wireless: Infrared, Radio, Microwave
- Common bandwidth designators:
  - DS1 (or T1): 1.544 Mbps
  - DS3 (or T3): 44.736 Mbps (for example, ND has 2 DS3 links now)
  - STS-1 (OC1): 51.840 Mbps
  - STS-12: 622.080 Mbps …

Last Mile

- Plain Old Telephone Service (POTS):
  - 28.8 Kbps to 56 Kbps
- ISDN
- Cellular - GPRS
- xDSL 1.544 Mbps to 8.448 Mbps
- Cable (40 Mbps down, 20 Mbps up) – Shared
  - wish we can get that much huh?
- Canopy wireless (canopy.nd.edu)

Relevant technologies

- Encoding - (how are we talking - language)
- Framing - (how do know the beginning and end of a conversation)
- Error
- Reliable transmission (over unreliable links)

Encoding

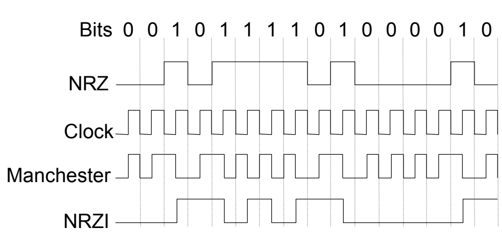
Encoding

- Signals propagate over a physical medium
  - modulate electromagnetic waves
  - e.g., vary voltage
- Encode binary data onto signals
  - e.g., 0 as low signal and 1 as high signal
  - known as Non-Return to zero (NRZ)
- Problem: Consecutive 1s or 0s
  - Low signal (0) may be interpreted as no signal
  - High signal (1) leads to baseline wander
  - Unable to recover clock

Alternative Encodings

- Non-return to Zero Inverted (NRZI)
  - make a transition from current signal to encode a one; stay at current signal to encode a zero
  - solves the problem of consecutive ones
- Manchester
  - transmit XOR of the NRZ encoded data and the clock
  - only 50% efficient
- 4B/5B
  - every 4 bits of data encoded in a 5-bit code
  - 5-bit codes selected to have no more than one leading 0 and no more than two trailing 0s (thus, never get more than three consecutive 0s)
  - resulting 5-bit codes are transmitted using NRZI
  - achieves 80% efficiency

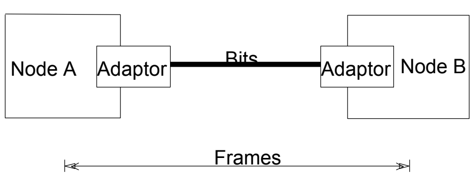
Encodings (cont)



Framing

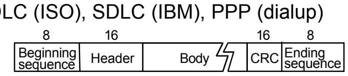
Framing

- Break sequence of bits into a frame
- Typically implemented by network adaptor



Approaches

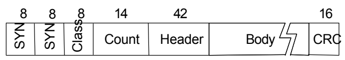
- Sentinel-based
  - delineate frame with special pattern: 01111110
  - e.g., HDLC (ISO), SDLC (IBM), PPP (dialup)



  - problem: what if the special pattern appears in the payload itself?
  - solution: bit stuffing
    - sender: insert 0 after five consecutive 1s
    - receiver: delete 0 that follows five consecutive 1s

Approaches (cont)

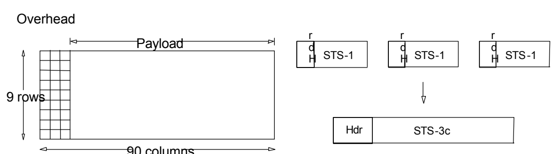
- Counter-based
  - include payload length in header
  - e.g., DDCMP (DECNET)



  - problem: count field itself corrupted
  - solution: catch when CRC fails

Approaches (cont)

- Clock-based
  - each frame is 125µs long
  - e.g., SONET: Synchronous Optical Network
  - STS-n (STS-1 = 51.84 Mbps)



Three STS-1 frames multiplexed onto one STS-3c