

Housekeeping

- Lab access
- HW turn-in
- Jin ?
- Class preparation for next time: look at the section on CRCs 2.4.3. Be prepared to explain how/why the shift register implements the CRC
- Skip Token Rings section
- New HW assignment next time – no programming

Point-to-Point Links

Outline

Basic Performance Metrics

Encoding

Framing

Error Detection

Sliding Window Algorithm

Basic Performance Metrics

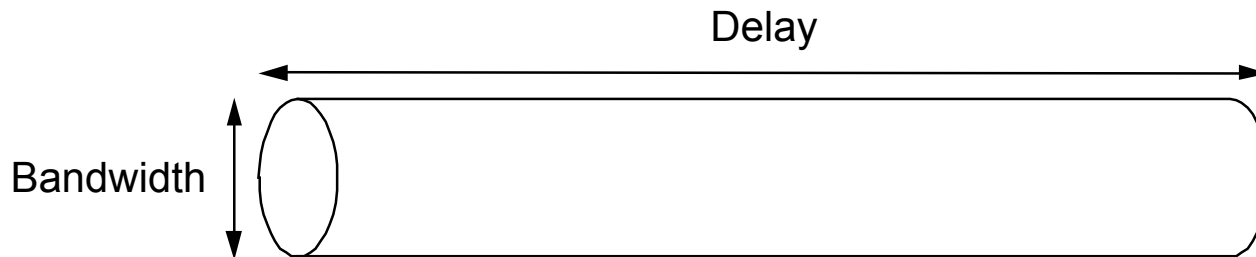
- **Bandwidth (throughput)**
 - data transmitted per time unit
 - link versus end-to-end
 - notation
 - **KB** = 2^{10} bytes
 - **Mbps** = 10^6 bits per second
- **Latency (delay)**
 - time to send message from point A to point B
 - one-way versus round-trip time (RTT)
 - components
 - Latency = Propagation + Transmit + Queue
 - Propagation = Distance / $c \cdot \text{velocityFactor}$ (Table 2.8)
 - Transmit = Size / Bandwidth

Bandwidth versus Latency

- Relative importance
 - 1-byte: 1ms vs 100ms dominates 1Mbps vs 100Mbps
 - 25MB: 1Mbps vs 100Mbps dominates 1ms vs 100ms
- Infinite bandwidth
 - RTT dominates
 - $\text{Throughput} = \text{TransferSize} / \text{TransferTime}$
 - $\text{TransferTime} = \text{RTT} + 1/\text{Bandwidth} \times \text{TransferSize}$
 - 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: $100\text{ms} \times 45\text{Mbps} = 560\text{KB}$
- Why is the delay-bandwidth product important?

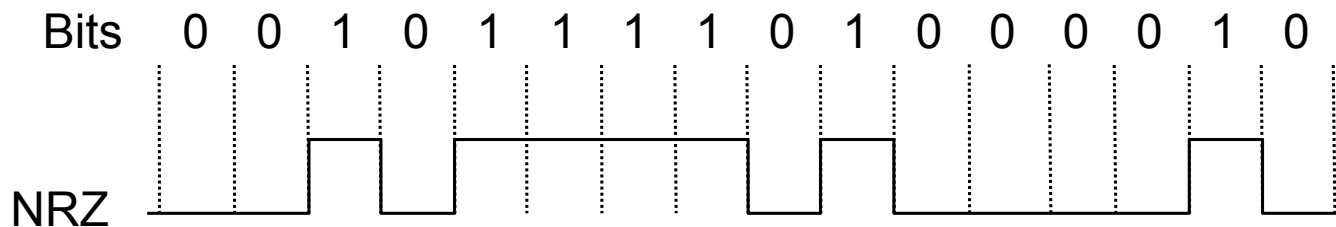


Things that go wrong

- Damaged packets – electrical/optical errors
- Dropped packets – congestion
- Duplicated packets
- Link and node failures
- Messages are delayed
- Messages are deliver out-of-order
- Third parties eavesdrop or inject traffic

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

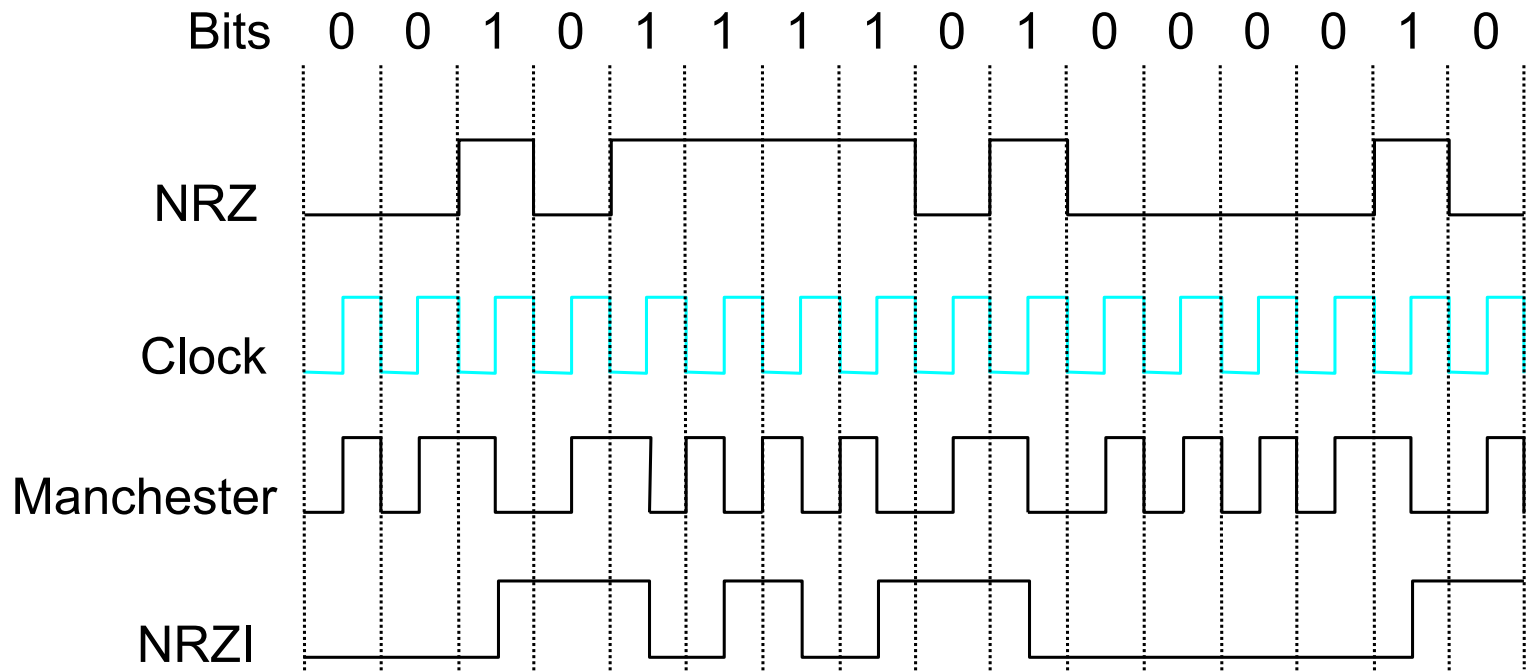
Alternative Encodings

- 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.

Encodings (cont)

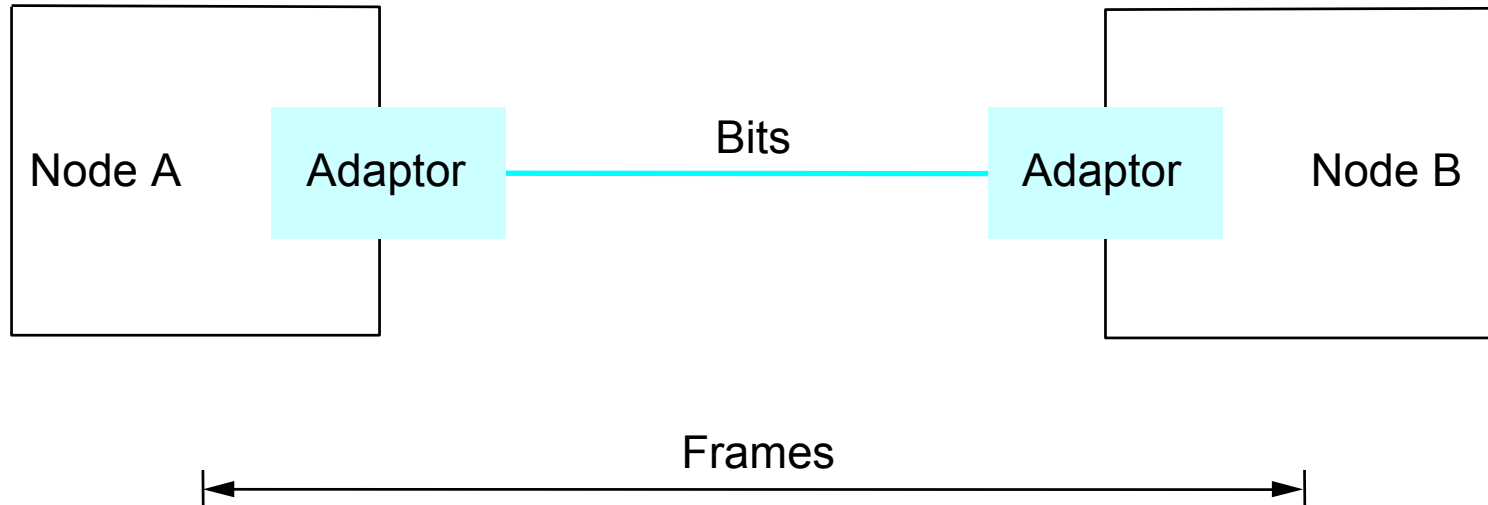
- 4B/5B
 - every 4 bits of data encoded in a 5-bit code
 - 5-bit codes selected to have no more than one leading 0 and no more than two trailing 0s
 - thus, never get more than three consecutive 0s
 - resulting 5-bit codes are transmitted using NRZI
 - achieves 80% efficiency

Encodings (cont)



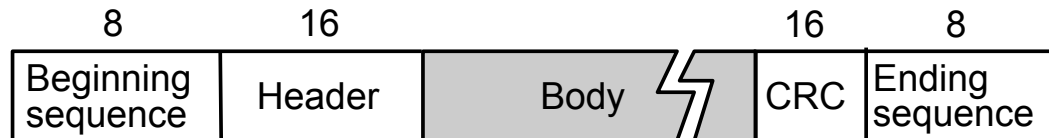
Framing

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



Approaches

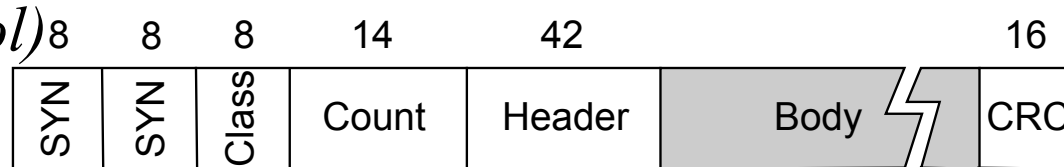
- Sentinel-based
 - delineate frame with special pattern: 01111110
 - e.g., HDLC, SDLC, PPP



- problem: special pattern appears in the payload
- solution: *bit stuffing/byte stuffing*
 - sender: insert 0 after five consecutive 1s
 - receiver: delete 0 that follows five consecutive 1s
- finite state machine implementation

Approaches (cont)

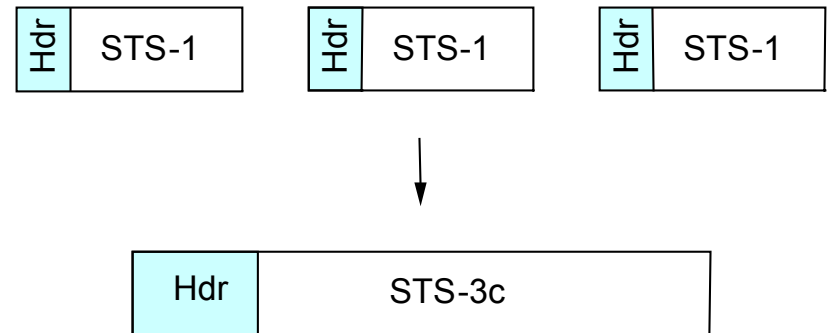
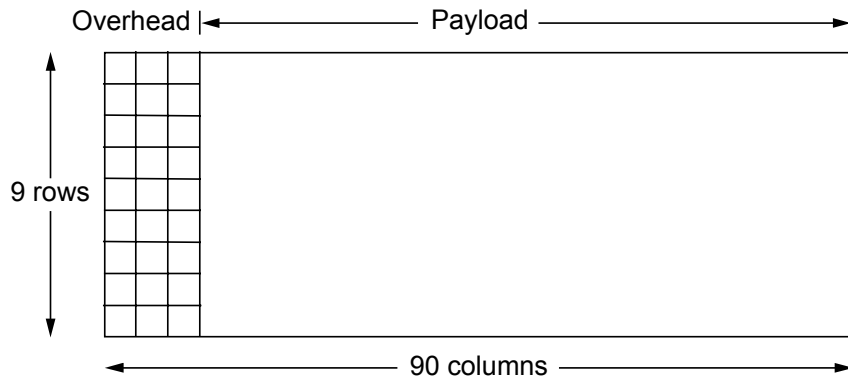
- Counter-based
 - include payload length in header
 - e.g., DDCMP (*Digital Data Communication Message Protocol*)



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

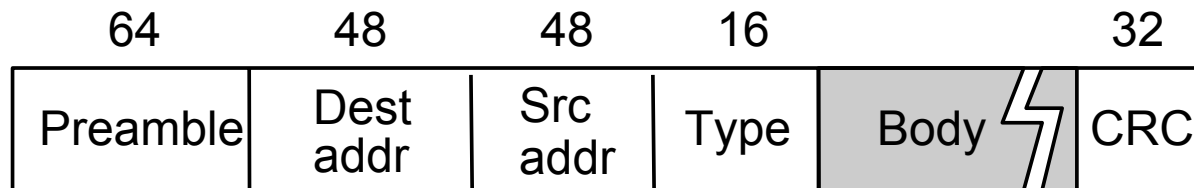
Approaches (cont)

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



Ethernet Overview

- History
 - developed by Xerox PARC in mid-1970s
 - roots in Aloha packet-radio network
 - standardized by Xerox, DEC, and Intel in 1978
 - similar to IEEE 802.3 standard
- CSMA/CD
 - carrier sense
 - multiple access
 - collision detection
- Frame Format



Ethernet (cont)

- Addresses
 - unique, 48-bit unicast address assigned to each adapter
 - example: **8 : 0 : e4 : b1 : 2**
 - broadcast: all **1**s
 - multicast: first bit is **1**
- Bandwidth: 10Mbps, 100Mbps, 1Gbps
- Length: 2500m (500m segments with 4 repeaters)
- Problem: Distributed algorithm that provides fair access

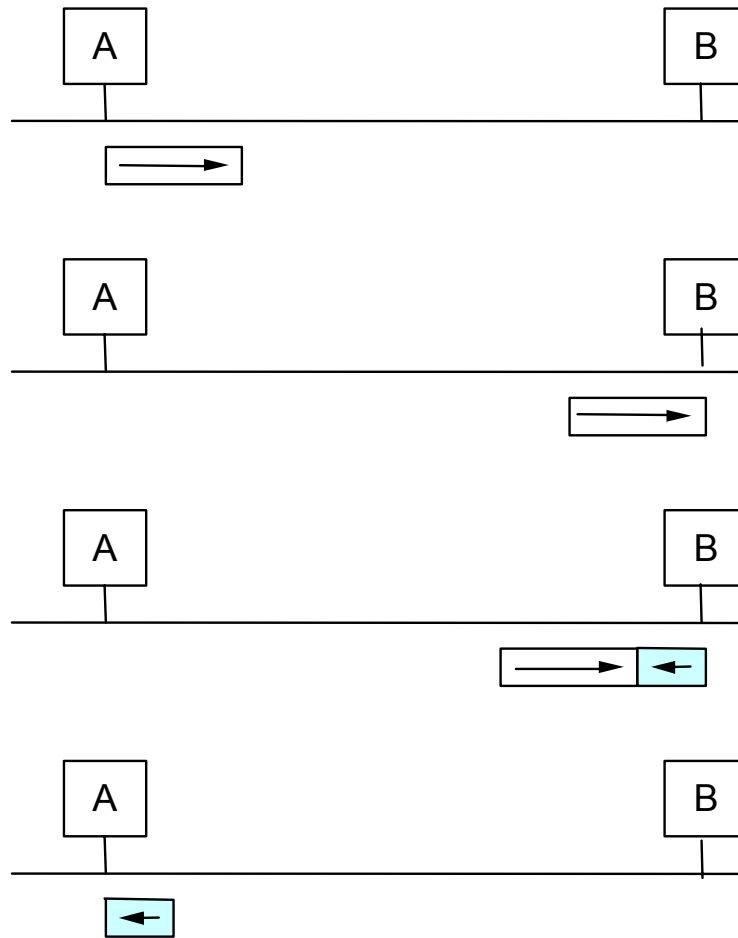
Transmit Algorithm

- If line is idle...
 - send immediately
 - upper bound message size of 1500 bytes
 - must wait 9.6 μ s between back-to-back frames
- If line is busy...
 - wait until idle and transmit immediately
 - called *1-persistent* (special case of *p-persistent*)

Algorithm (cont)

- If collision...
 - jam for 32 bits, then stop transmitting frame
 - minimum frame is 64 bytes (header + 46 bytes of data)
 - delay and try again
 - 1st time: 0 or 51.2us
 - 2nd time: 0, 51.2, or 102.4us
 - 3rd time: 51.2, 102.4, or 153.6us
 - *n*th time: $k \times 51.2\text{us}$, for randomly selected $k=0..2^n - 1$
 - give up after several tries (usually 16)
 - exponential backoff

Collisions



Review

- Physical layer and link layer
 - Performance – concepts extend to multi-hop networks
 - Encoding – primarily physical layer
 - Framing – varies – PPP it is a link layer issue, ethernet it is a physical layer issue