ECE/COMPSCI 356 Computer Network Architecture

Lecture 5: Performance Metrics, Encoding, and Framing

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Overview

- Performance metrics
- Link layer functions
  - Encoding
    - NRZ, NRZI, Manchester, 4B/5B
  - Framing
    - Byte-oriented, bit-oriented, clock-based
  - Error detection
    - Parity, checksum, CRC
  - Reliable transmission
    - Error correction, stop-and-wait, sliding window

Performance metrics

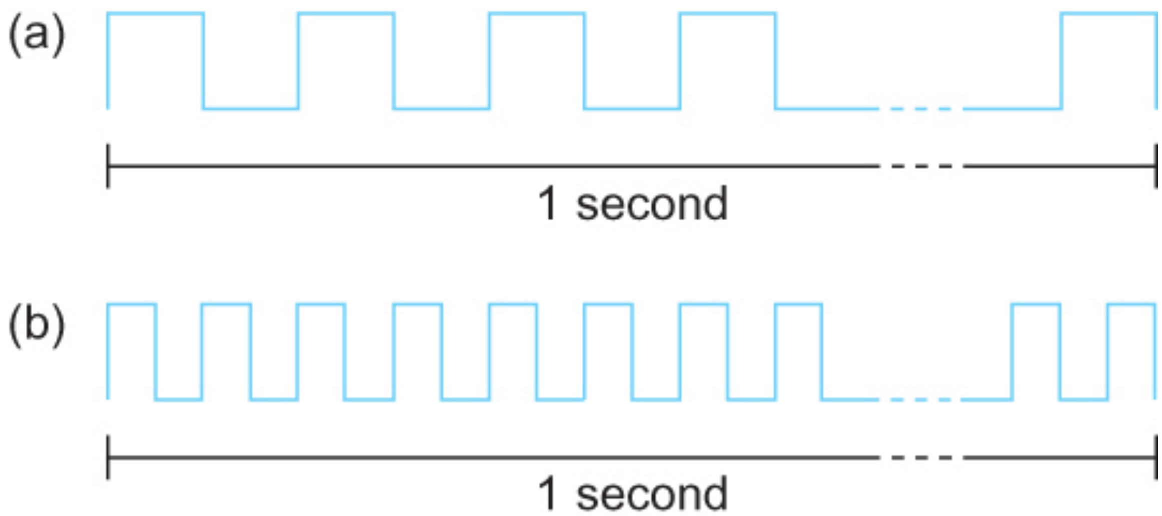
- Bandwidth
- Delay
- Delay x bandwidth
- Transfer time
- Throughput

Bandwidth

- Bandwidth is a measure of the width of a frequency band.
  - E.g., a telephone line supports a frequency band 300-3300hz has a bandwidth of 3000 hz

- Bandwidth of a link normally refers to the number of bits it can transmit in a unit time

Bandwidth



Bits transmitted at a particular bandwidth can be regarded as having some width:

(a) bits transmitted at 1Mbps (each bit 1 μs wide);

(b) bits transmitted at 2Mbps (each bit 0.5 μs wide).

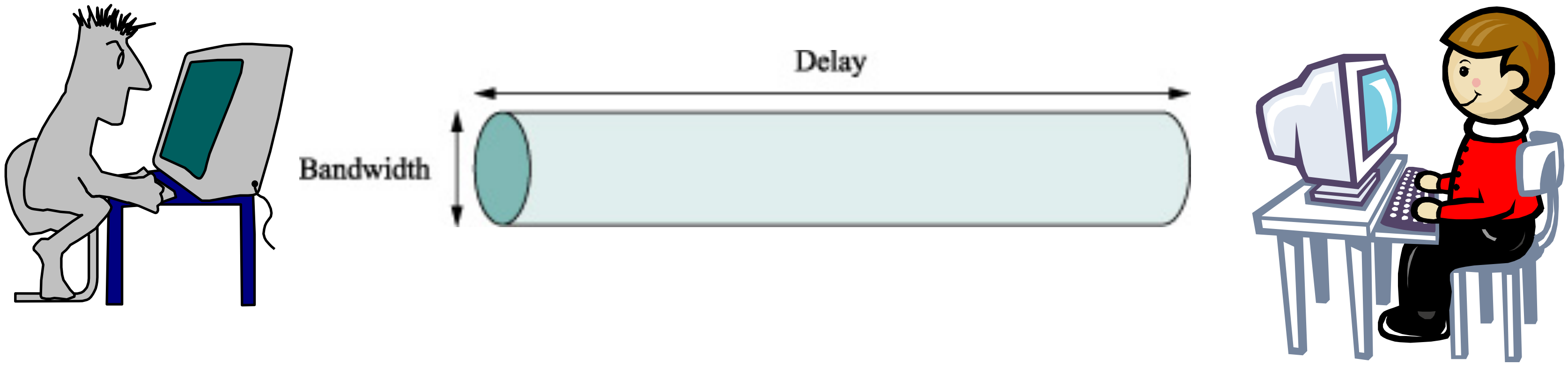
Bandwidth for last-mile links

Service	Bandwidth (typical)
Dial-up	28–56 kbps
ISDN	64–128 kbps
DSL	128 kbps–100 Mbps
CATV (cable TV)	1–40 Mbps
FTTH (fibre to the home)	50 Mbps–1 Gbps

Delay

- How long does it take for one bit to travel from one end of link to the other?
- Length Of Link / Speed Of WaveInMedium
- 2500m of copper: $2500/(2/3 * 3*10^8) = 12.5\mu s$
- Round-trip time (RTT): 2 x delay

Delay x bandwidth product



- We think the link between two nodes as a hollow pipe
- Delay length of the pipe and bandwidth the width of the pipe
- Volume of the pipe: #bits the sender sends before the receiver receives the first bit
- When the pipe is full, no more bits can be pumped into it

Delay x Bandwidth

- Relative importance of bandwidth and delay depends on application
  - For large file transfer, bandwidth is critical
  - For small messages (HTTP, NFS, etc.), delay is critical

Transfer time and Throughput

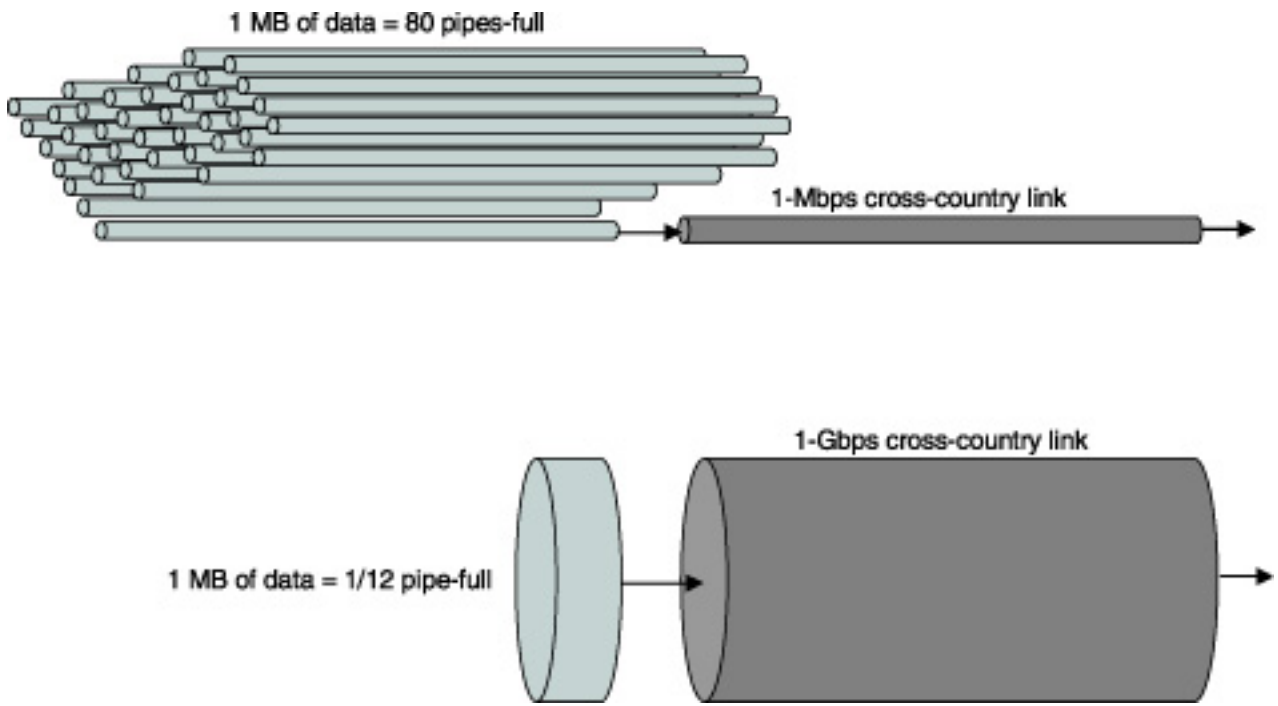
- Transfer time = delay+ transmission time + queuing time

  transmission time = Transfer Size/bandwidth

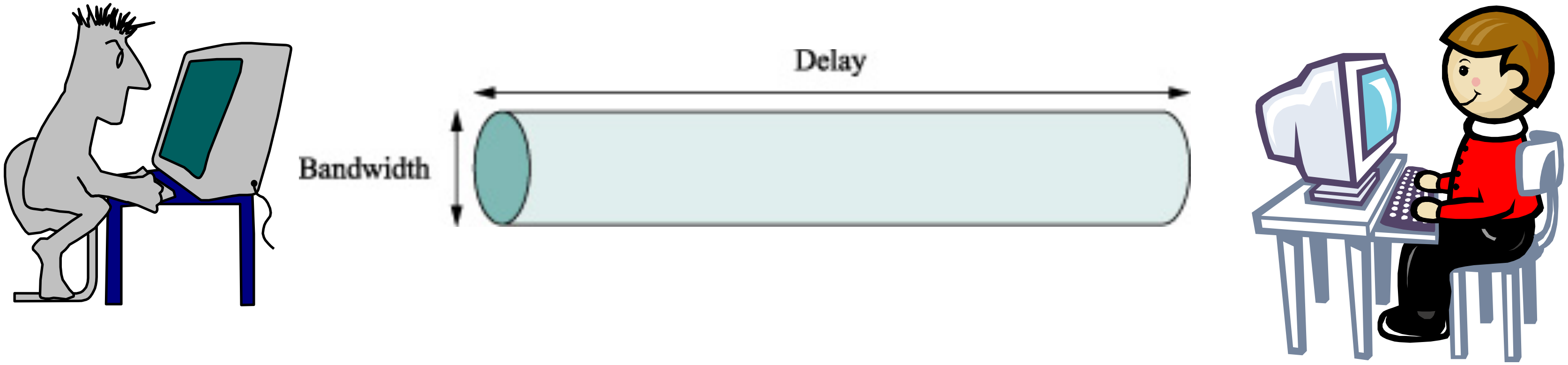
- Transfer time: also called latency/delay

- Throughput = Transfer Size/Transfer Time

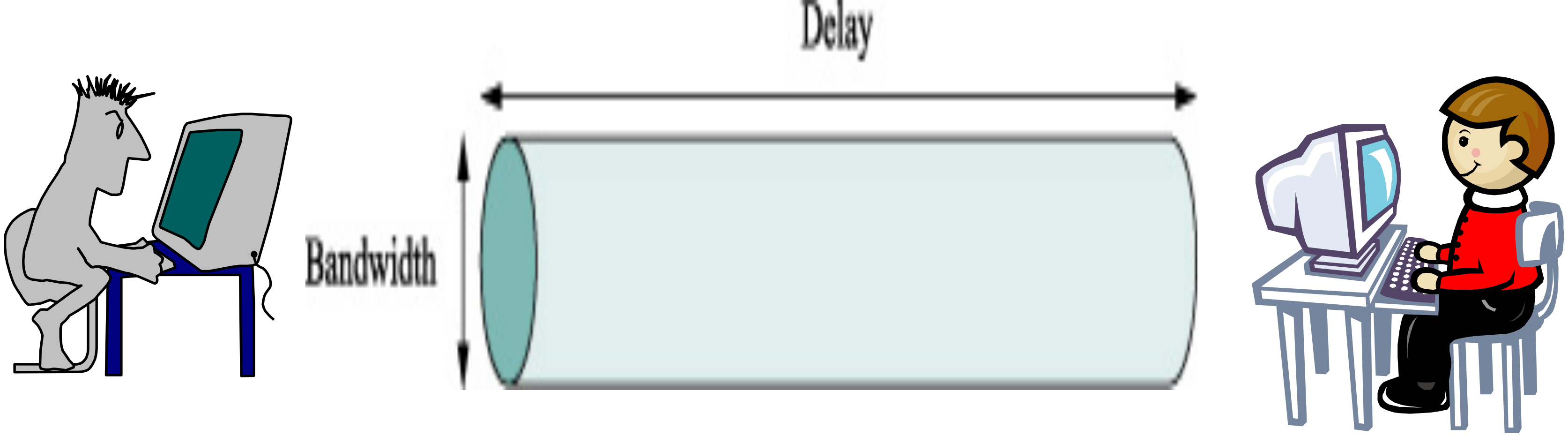
High speed versus low speed links



- A high speed link can send more bits in a unit time than a low speed link
- 1MB of data, 100ms one-way delay
- How long will it take to send over different speed of links?



- 1Mbps, 100ms, 1MB data
- Delay * Bandwidth = 100Kb
- 1MB/100Kb = 80 pipes of data
- Transfer time=80 * 100ms + 100ms = 8.1s



- 1Gbps, 100ms, 1MB data
- Delay * Bandwidth = 100Mb
- 1MB/100Mb = 0.08 pipe of data
- Transfer time = 0.08 * 100ms + 100ms = 108ms
- Throughput = Transfer Size/Transfer Time = 1MB/108ms = 74.1Mbps
  - Why is it less than 1Gbps?

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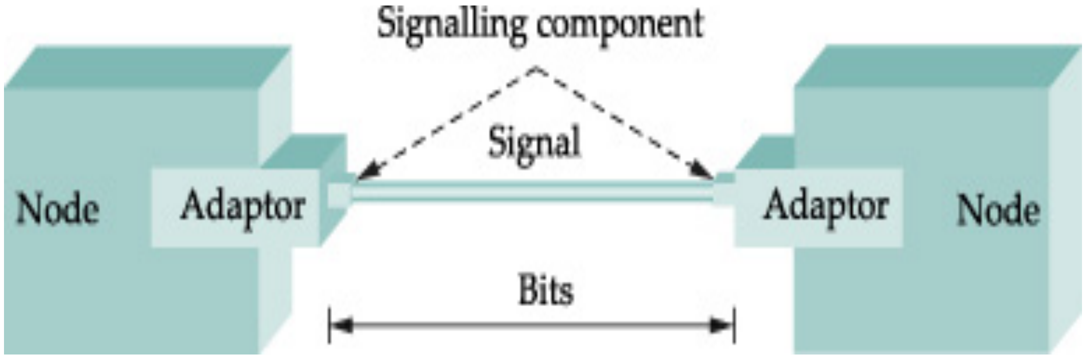
Link-layer functions



- Completed by adapters
  - **Encoding**
  - Framing
  - Error detection
  - Reliable transmission

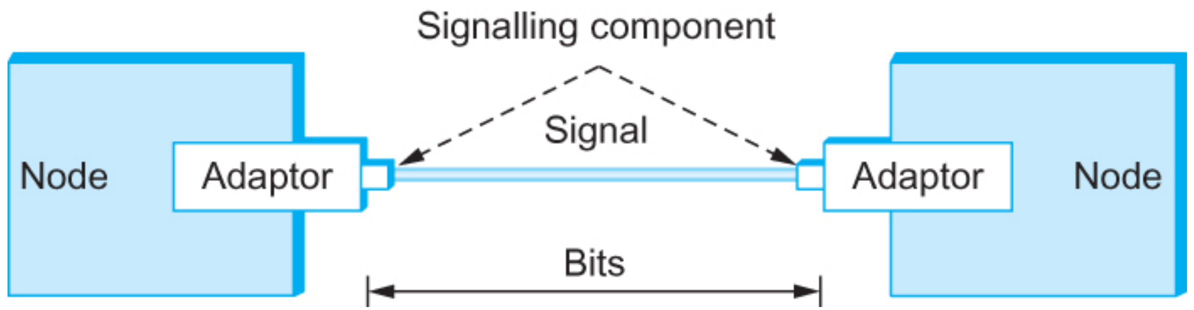
Encoding

- Non-return to zero (NRZ)
- Nonreturn to zero inverted (NRZI)
- Manchester encoding
- 4B/5B

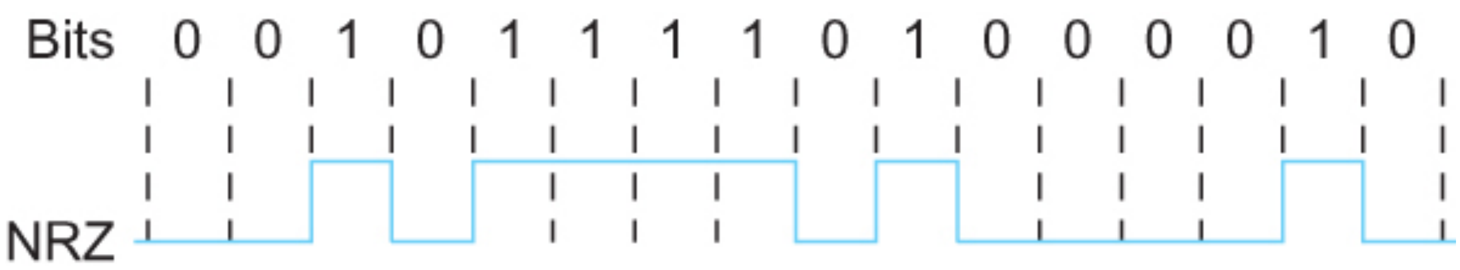
Review: Modulation

- Modulation: modifying the signals in terms of their frequency, amplitude, and phase.
  - A pair of distinguishable signals
    - “High” signal
    - “low” signal
  - Enable transmission of bit streams

Non-return to zero (NRZ)



Signals travel between signaling components; bits flow between adaptors



NRZ encoding of a bit stream

Problem with NRZ

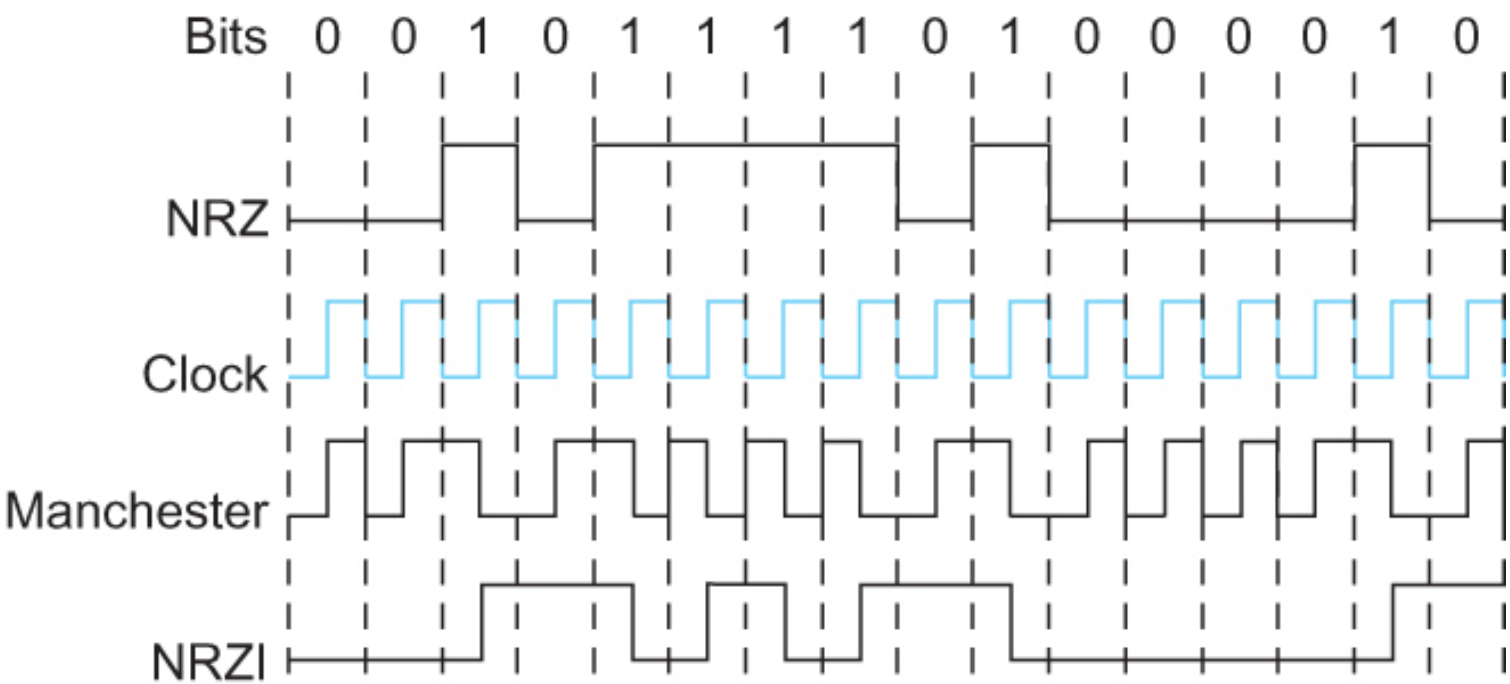
- Baseline wander
  - The receiver keeps an average of the signals it has seen so far
  - Uses the average to distinguish between low and high signal
  - When a signal is significantly low than the average, it is 0, else it is 1
  - Too many consecutive 0’s and 1’s cause this average to change, making it difficult to detect

Problem with NRZ

- Clock recovery
  - Frequent transition from high to low or vice versa are necessary to enable clock recovery
  - Both the sending and decoding process is driven by a clock
  - Every clock cycle, the sender transmits a bit and the receiver recovers a bit
  - The sender and receiver have to be precisely synchronized

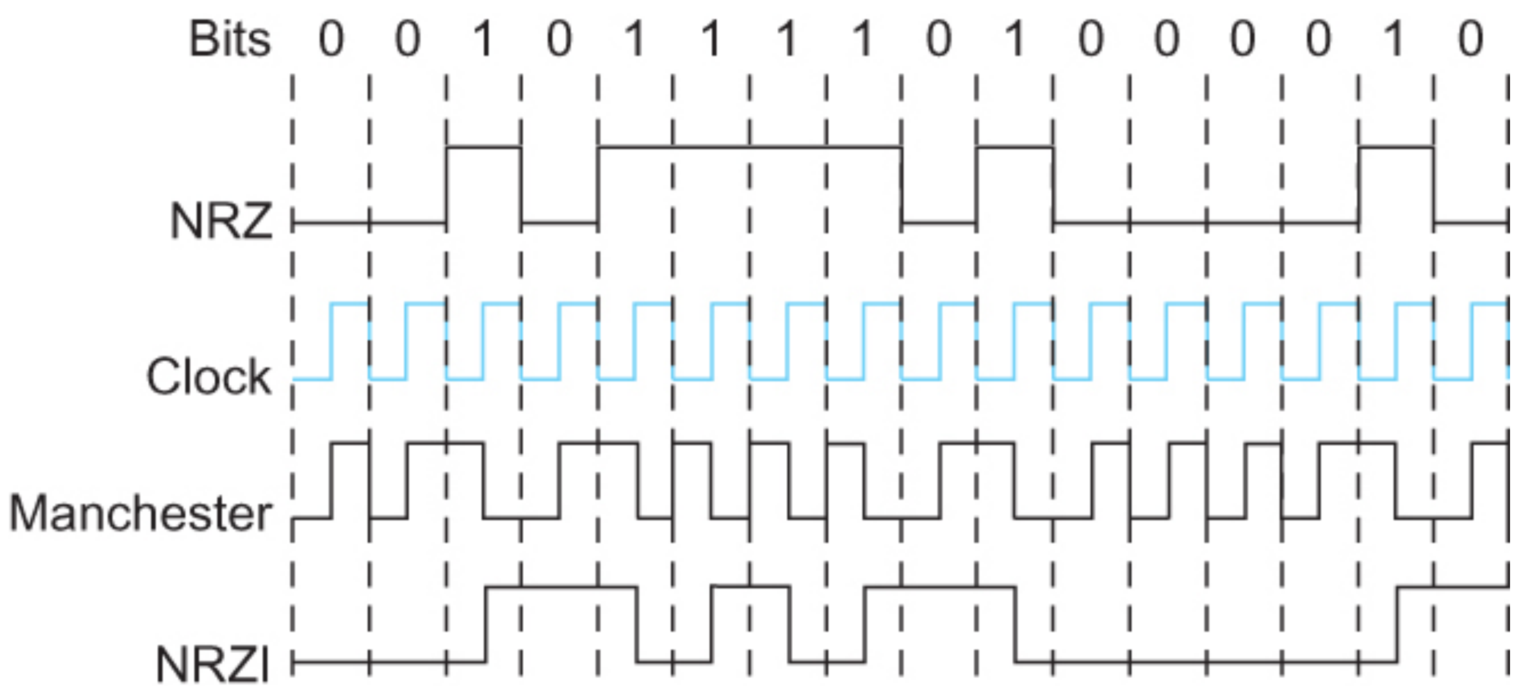
Nonreturn to zero inverted (NRZI)

- Sender makes a transition from the current signal to encode 1 and stay at the current signal to encode 0
- Solves for consecutive 1’s, not 0’s



Manchester encoding

- A low/high pair is considered as one clock cycle – encoding one bit
- In Manchester encoding
  - 0: low→ high transition
  - 1: high→ low transition



Problem with Manchester encoding

- Doubles the rate at which the signal transitions are made on the link
- The rate at which the signal changes is called the link's *baud rate*
- In Manchester the bit rate is half the baud rate

4B/5B encoding

- Insert extra bits into bit stream so as to break up the long sequence of 0’s and 1’s
- Every 4-bits of actual data are encoded in a 5- bit code that is transmitted to the receiver
- 5-bit codes are selected in such a way that each one has no more than one leading 0(zero) and no more than two trailing 0’s.
- No pair of 5-bit codes results in more than three consecutive 0’s
- 5-bit codes are transmitted using NRZI
  - Solves the problem of consecutive 1’s

4-bit data symbol	5-bit code
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011

4-bit data symbol	5-bit code
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

4B/5B encoding

16 5B left

11111 – when the line is idle

00000 – when the line is dead

00100 – to mean halt

13 left : 7 invalid, 6 for various control signals

Overview

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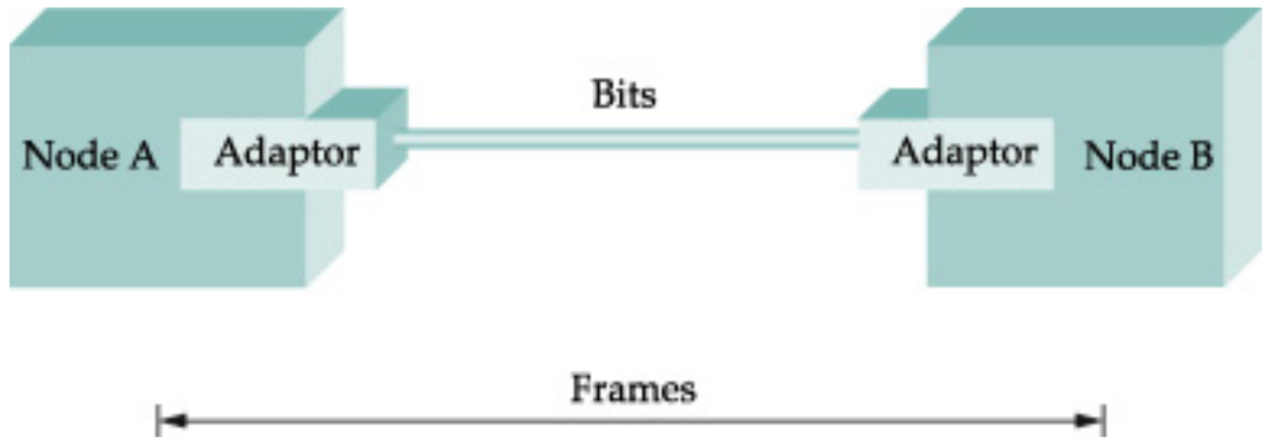
  - **Framing**
  - Error detection
  - Reliable transmission

Framing

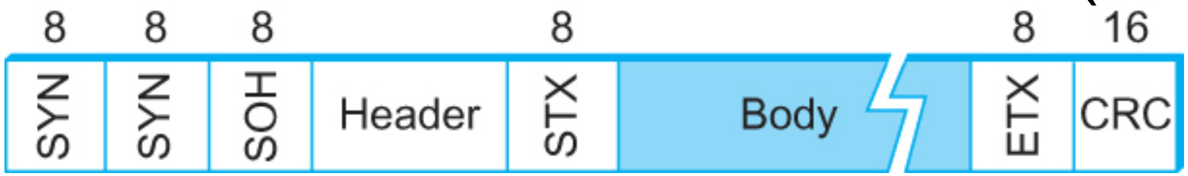


- Now we’ve seen how to encode bitstreams
- But nodes send blocks of data (frames)
  - A’s memory → adaptor → adaptor → B’s memory
- An adaptor must determine the boundary of frames

Framing Protocols

- Byte-oriented protocols
  - Sentinel-based approach
    - BISYNC
    - PPP
  - Byte-counting approach
    - DDCMP
- Bit-oriented protocols
  - HDLC
- Clock-based framing
  - SONET

Binary Synchronous Communication (BISYNC)



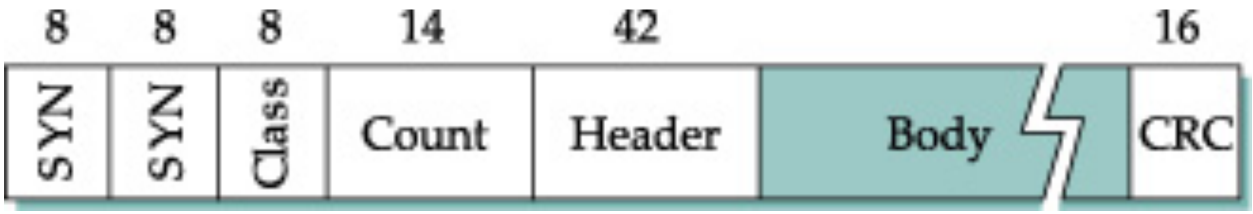
BISYNC Frame Format

- by IBM in late 60s
- Frames transmitted beginning with leftmost field
- Beginning of a frame is denoted by sending a special SYN (synchronize) character
- Data portion of the frame is contained between special sentinel character STX (start of text) and ETX (end of text)
- SOH : Start of Header
- CRC: Cyclic Redundancy Check for error detection
- What if special characters appear in a data stream?
  - Character stuffing
    - Escape character: Data Link Escape (DLE)

Point-to-Point Protocol (PPP)

- Flag: 01111110;
- Address & Control: default
- Protocol: de-multiplexing
  - IP, Link Control Protocol, …,
- Checksum: two or four bytes
- Link Control Protocol
  - Set up and terminate the link
  - Negotiate other parameters
    - Checksum size

Byte-oriented protocols: byte-counting approach



- Digital Data Communication Message Protocol (DDCMP)

  - A byte count field

Bit-oriented protocols

- High-level Data Link Control (HDLC) protocol

- Frame: a collection of bits
- Beginning/ending sequence: 01111110
- Bit-stuffing for body of data

The bit-stuffing algorithm

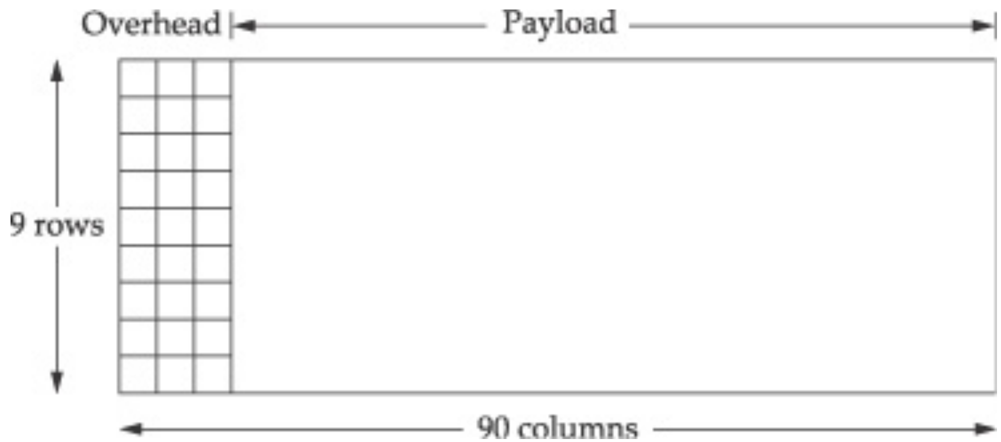
- Bit-stuffing for data
  - Sender: inserts a 0 after every five consecutive 1's
  - Receiver: after five consecutive 1's,
    - If the next bit is 0, removes it
    - If the next bit is 1
      - If the next bit is 0 (i.e. the last 8 bits are 01111110), then frame ends
      - Else error; discard frame, wait for next 01111110 to receive

An exercise

- Suppose a receiver receives the following bit sequence
  - 011010111110101001111111011001111110

- What’s the resulting frame after removing stuffed bits? Indicate any error.

Clock-based Framing



- Synchronous Optical Network (SONET)
- Each frame is 125 us long

Summary

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