Direct link networks

- **Encoding – How do you transmit one bit?**
- **Framing – How to delineate frames?**
- **Error detection**
- **Reliability – mostly for point-to-point**
- **Media Access Control (MAC) – for shared media**

Physical media

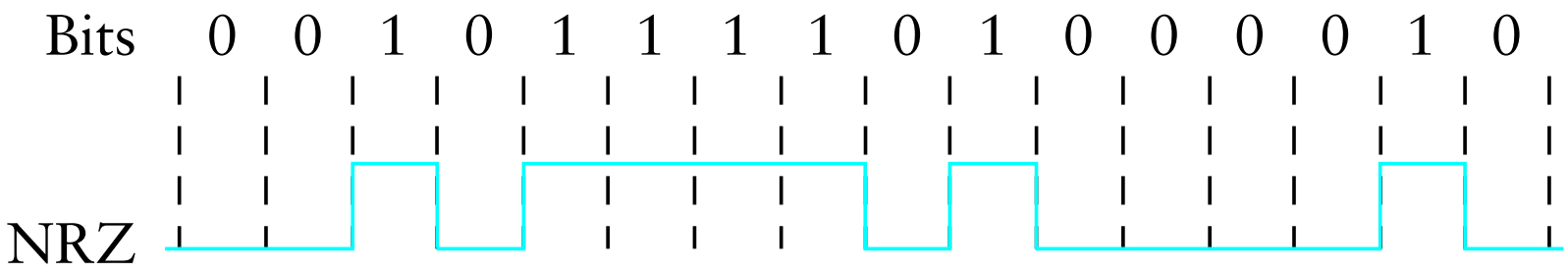
- **Signals propagate over a physical medium**
  - E.g.: Copper wires, fiber, space
- **Can modulate the signal in some way**
  - Signal can be viewed as wave
  - Change amplitude (e.g., turn light switch on and off)
  - Change frequency, phase
- **Speed is usually speed of light**
  - In vacuum 3×10^8 m/s, in copper $\sim 2 \times 10^8$

How fast can you transmit information

- **Depends on frequency, and signal/noise ratio**
- **Shannon:** $C = B \log_2(1 + S/N)$
  - C is channel capacity in bps
  - B is bandwidth of line
  - S and N are avg. signal & noise power
- **Example: Telephone line**
  - 3 KHz b/w, 30 db S/N $= 10^{30/10} = 1000$
  - $C \approx 30$ Kbps (so 56 Kbps modems need better S/N ratio)
- **Intuition for Shannon**
  - V voltage levels encode $\log_2 V$ bits
  - To sample sine wave, need at least two samples per period

NRZ

- **Now assume we can somehow modulate signal**
- **How to encode binary data onto signals?**
- **One approach: Non-return to zero (NRZ)**
  - Transmit 0 as low, 1 as high



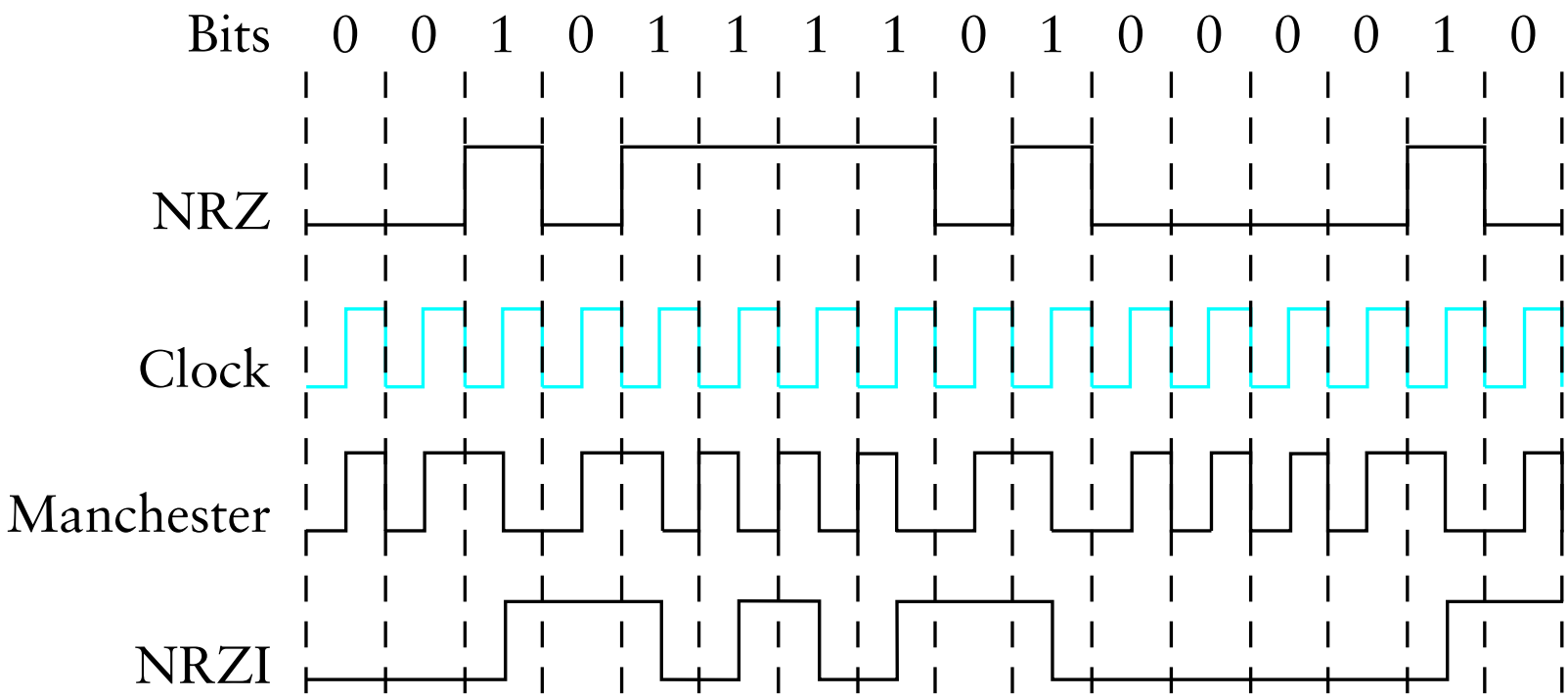
NRZ drawbacks

- **Consecutive 1s or 0s are problematic**
- **Non signal could be interpreted as 0s (or vice versa)**
- **"Baseline wander" problem**
  - Where is threshold between low and high?
  - Could compare signal to average value, but avg. will drift
- **Clock recovery problem**
  - For long stretch of consecutive bits, might miscount

Alternate Encodings

- **Non-return to Zero Inverted (NRZI)**
  - Encode 1 with transition from current signal
  - Encode 0 by staying at same level
  - At least solves problem of consecutive 1s
- **Manchester**
  - XOR of NRZ symbol with clock
  - But now lose 50% efficiency

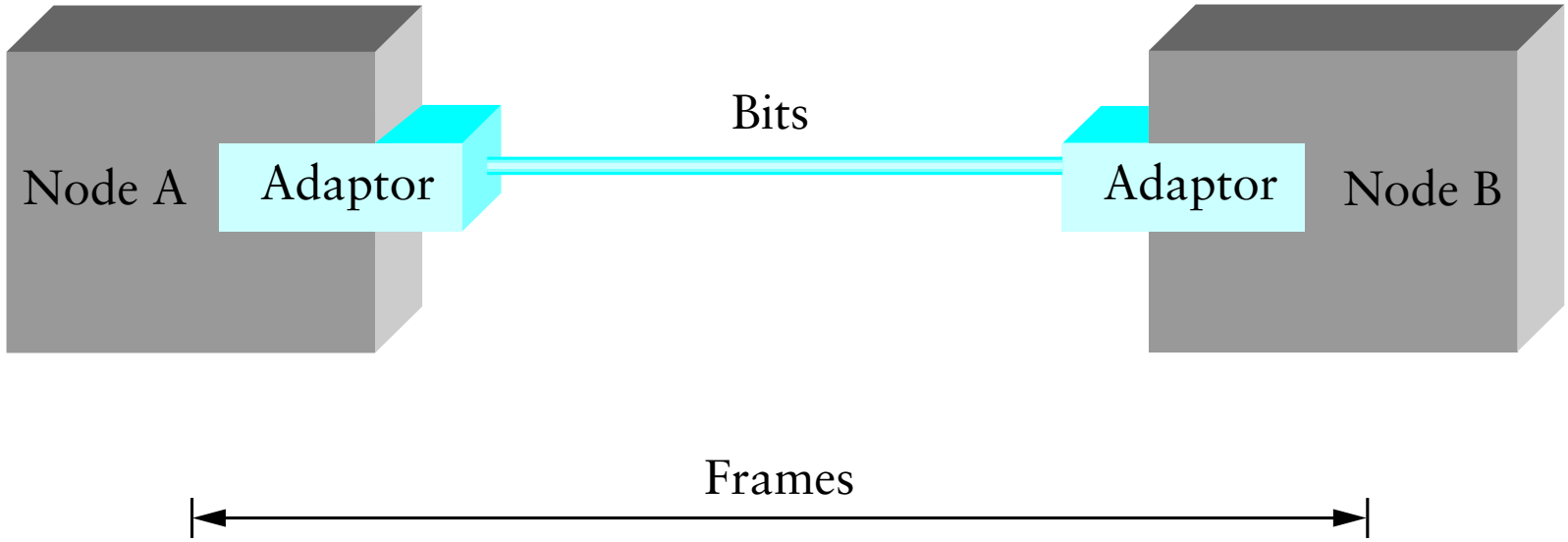
Illustration



4B/5B

- **Every 4 bits of data encoded in a 5-bit code (see Table 2.4 in text)**
- **Remaining 13 codes used for other purposes**
  - 11111 – line idle, 00000 – line dead, 00100 halt
- **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 5bit codes are transmitted using NRZI**
- **achieves 80% efficiency**

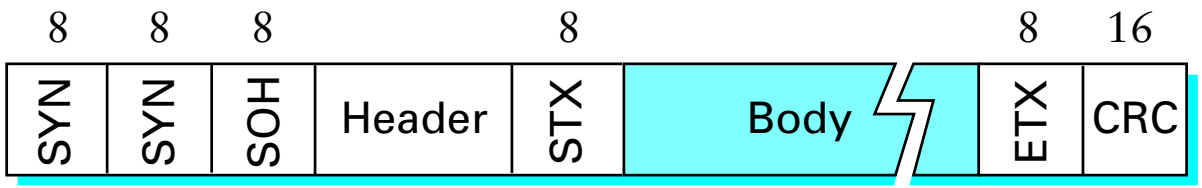
Framing



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

Sentinel-based framing

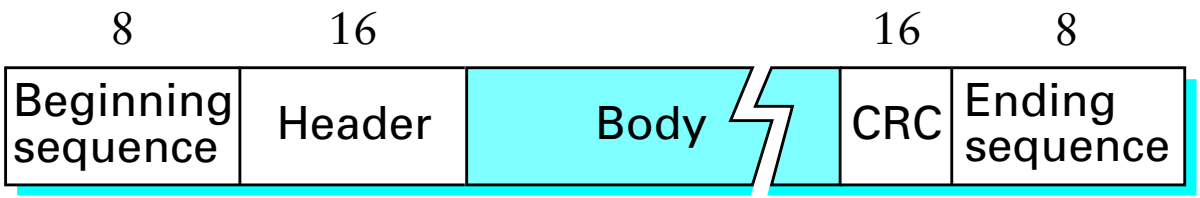
- **Byte-oriented protocols (e.g., BISYNC, PPP)**
  - Place special bytes (SOH, ETX) at beginning, end of message



- **What if ETX appears in the body?**
  - Escape ETX byte by prefixing DEL byte
  - Escape DEL byte by prefixing DEL byte
  - Technique known as *character stuffing*

Bit-oriented protocols

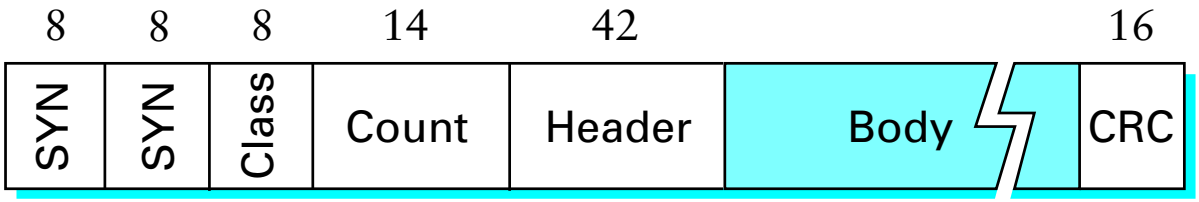
- **View message as stream of bits, not bytes**
- **Can similarly use sentine (e.g., HDLC)**



  - HDLC begin/end sequence 01111110
- **Use *bit-stuffing* technique to escape 01111110**
  - When transmitting message, always append 0 to five consecutive 1s
  - Receiver uses bit to distinguish from begin/end sequence, strips bit out of payload

Counter approach

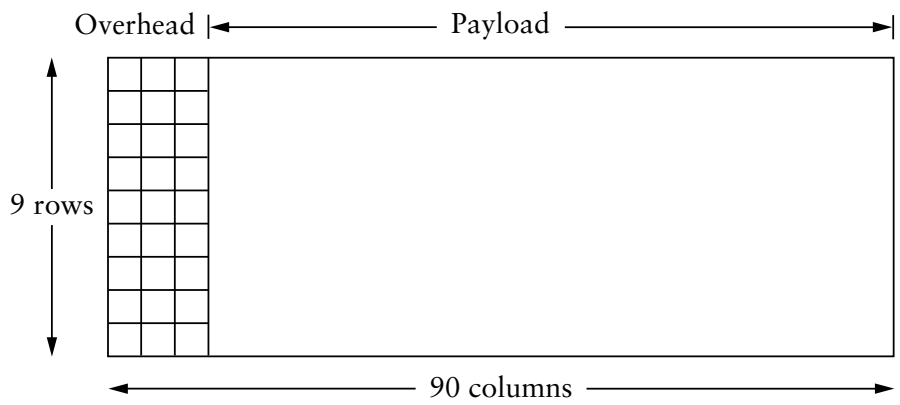
- **Drawback of "stuffing techniques"**
  - Length of frame depends on contents of payload
- **Alternative: Put length in header (e.g., DDCMP)**

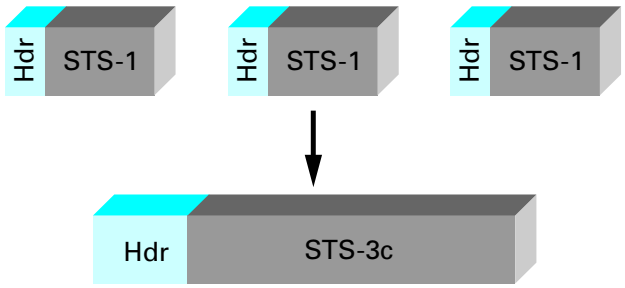


- **Danger: Framing errors**
  - What if high bit of count gets corrupted
  - Adds 8K to length of frame, may lose many frames
  - CRC checksum helps detect error

Clock-based framing

- **E.g., SONET: Synchronous Optical Network**
  - Each frame is 125μs long
  - Look for header every 125μs
  - Encode w. NRZ, but scramble payload to help ensure lots of transitions



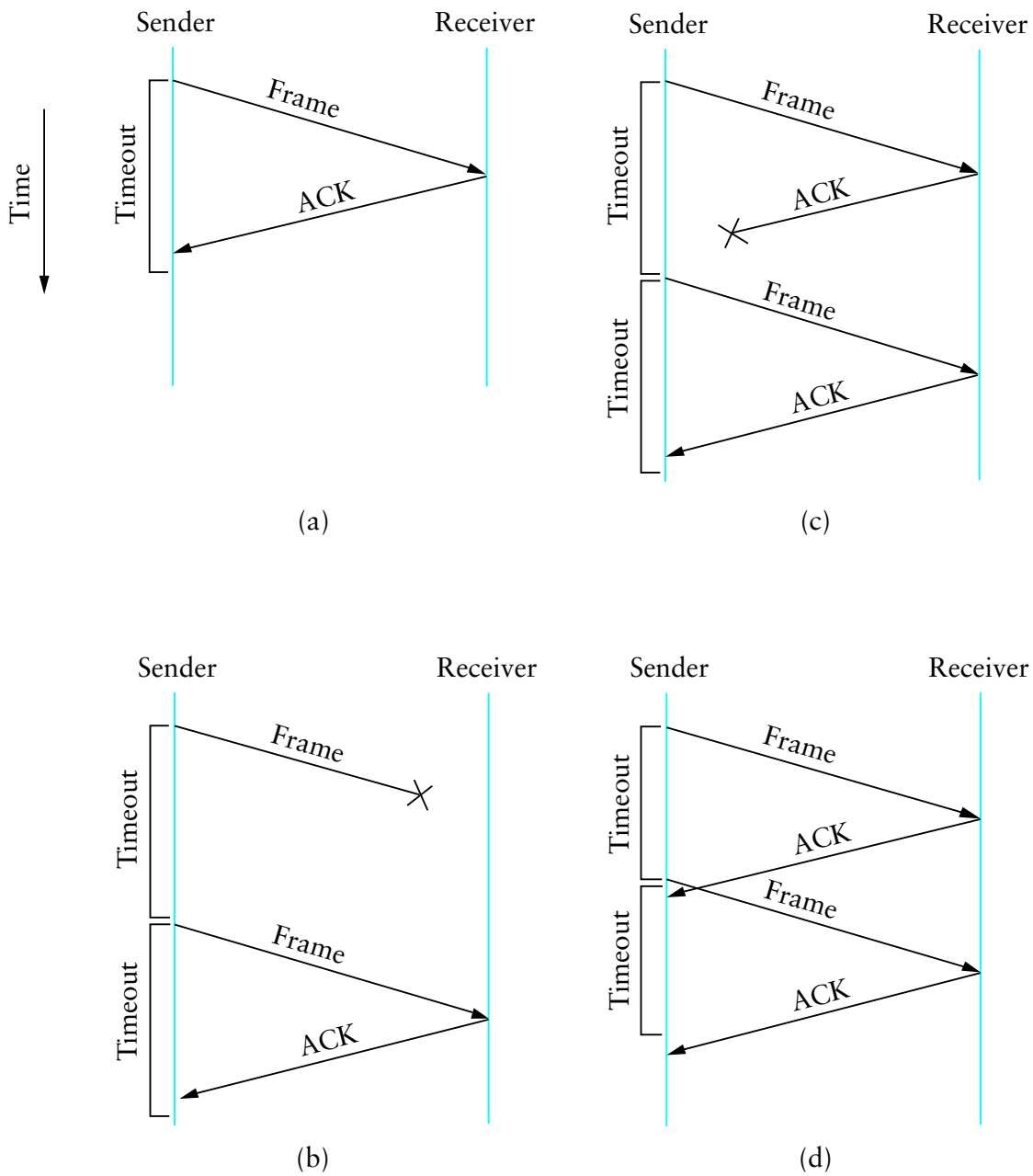


Error detection

- **Basic idea: Use a checksum**
  - Compute small checksum value, like a hash of the packet
  - If packet chances, checksum is likely to be wrong
- **Good checksum algorithms**
  - Want several properties, e.g., detect any single bit error
  - Details in a later lecture
- **Next problem: If discarding bad packets, how to ensure reliable delivery?**

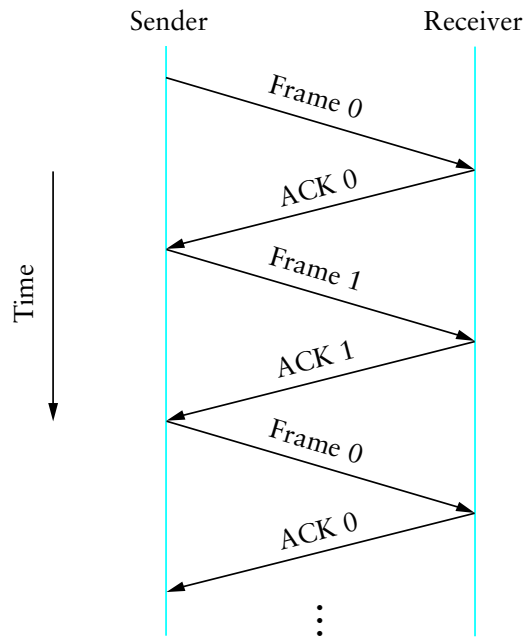
Acknowledgements and Timeouts

- **Stop and wait approach**
  - Send packet, wait
  - Receive packet, send ACK
  - Receive ACK, send next packet
  - Don't receive ACK, timeout and retransmit
- **Problems**
  - Might duplicate packet
  - Can't keep pipe full (remember bandwidth-delay product)


Sender
Receiver
Time
Timeout
Frame
ACK
(a)
Sender
Receiver
Timeout
Frame
ACK
Timeout
Frame
ACK
(c)
Sender
Receiver
Timeout
Frame
Timeout
Frame
ACK
(b)
Sender
Receiver
Timeout
Frame
ACK
Timeout
Frame
ACK
(d)

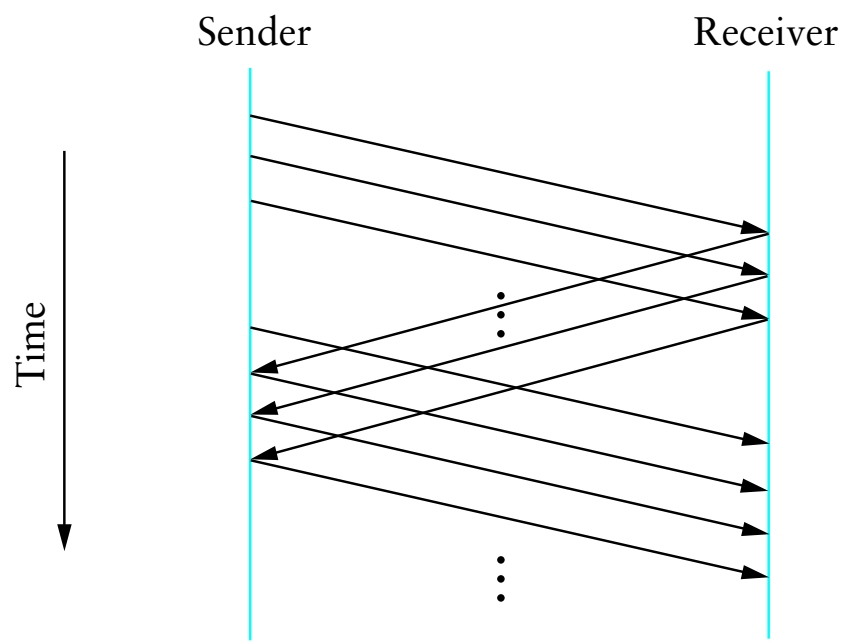
Duplicates

- **Can solve problem with 1-bit counter**
  - Place in both Frame and ACK
  - Receiver knows if duplicate of last frame
  - Sender won't interpret duplicate old ACK as for new packet



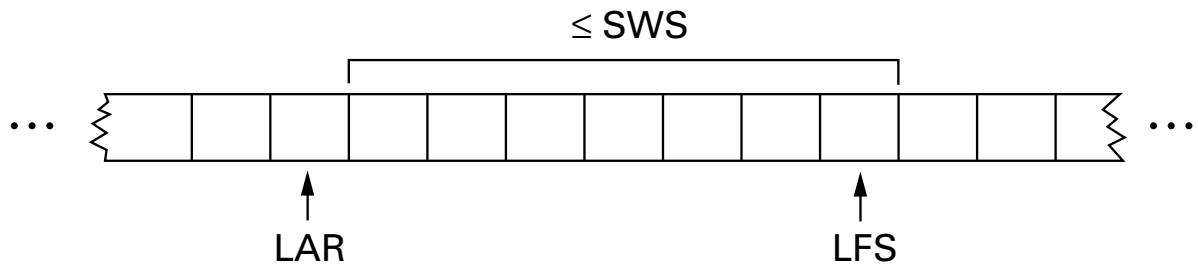
Sliding window protocol

- **Still have problem of keeping the pipe full**
  - Can generalize with > 1-bit counter
  - Allow multiple outstanding (unACKed) frames
  - Upper bound on unACKed frames, called window



SW sender

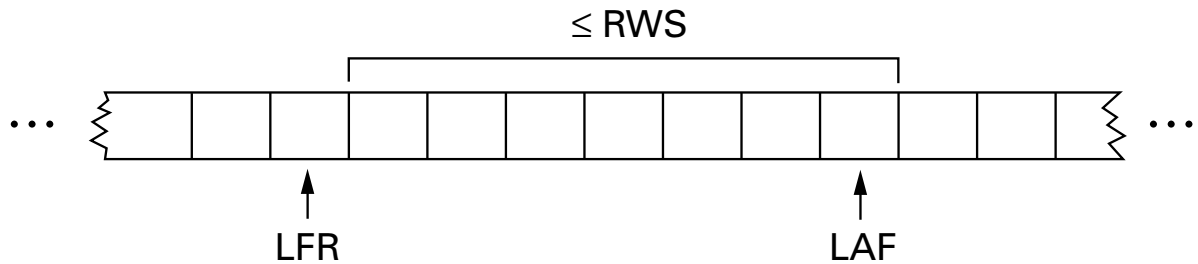
- **Assign sequence number to each frame (SeqNum)**
- **Maintain three state variables:**
  - send window size (SWS)
  - last acknowledgment received (LAR)
  - last frame sent (LFS)



- **Maintain invariant: LFS − LAR ≤ SWS**
- **Advance LAR when ACK arrives**
- **Buffer up to SWS frames**

SW receiver

- **Maintain three state variables**
  - receive window size (RWS)
  - largest acceptable frame (LAF)
  - last frame received (LFF)



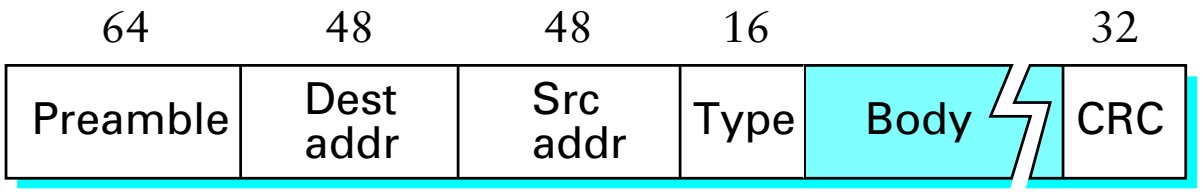
- **Maintain invariant: LFA − LFR ≤ RWS**
- **Frame SeqNum arrives:**
  - if LFR < SeqNum ≤ LFA accept
  - if SeqNum ≤ LFR or SeqNum > LFA discarded
- **Send cumulative ACKs**

Sequence number space

- **How big should RWS be?**
  - At least 1, no bigger than SWS
- **How many distinct sequence numbers needed**
  - If RWS=1, need at least SWS+1
  - If RWS=SWS, need at least 2SWS+1

Ethernet

- **One of the most popular LAN network types**
- **CSMA/CD**
  - carrier sense
  - multiple access
  - collision detection
- **Frame format (Manchester encoding)**



Ethernet 2

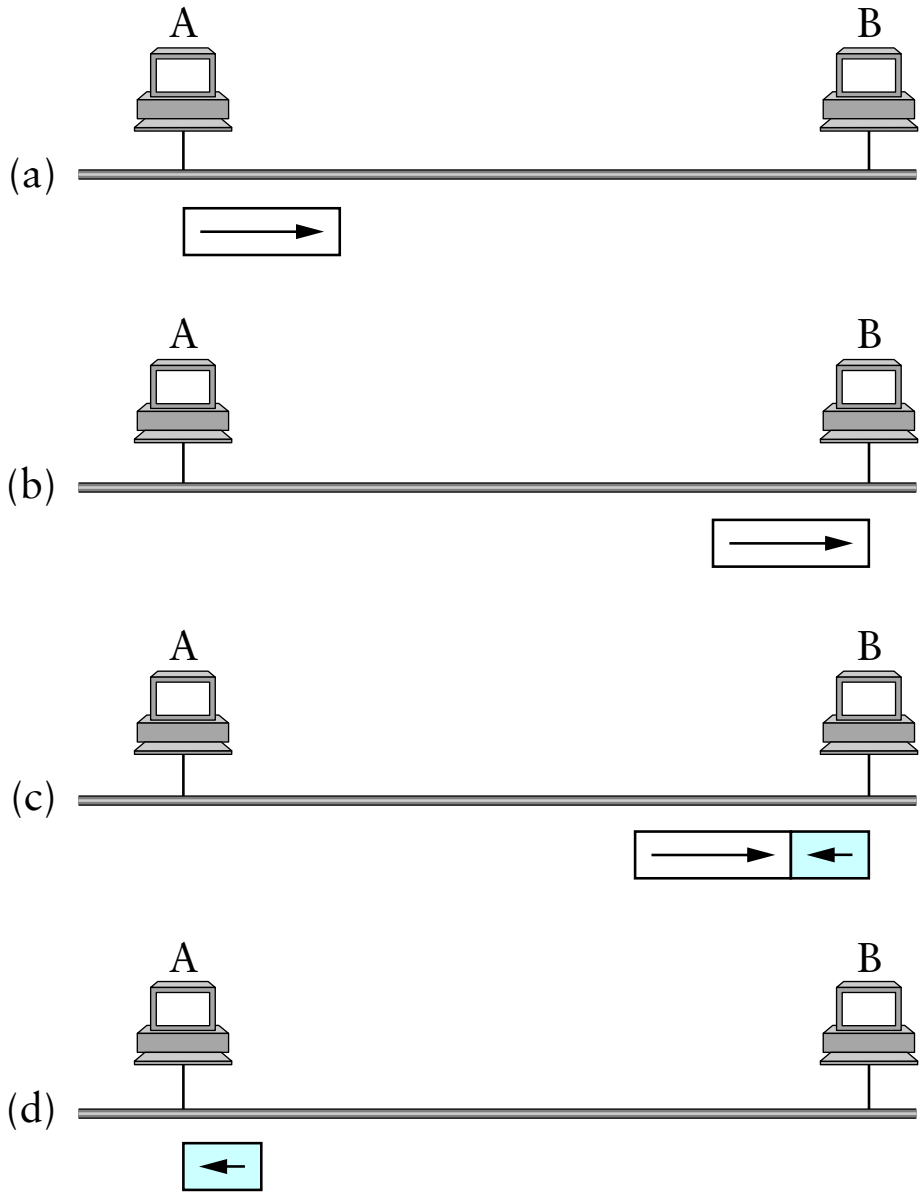
- **Addresses**
  - unique, 48-bit unicast address assigned to each adapter
  - example: 00:07:e9:52:c3:93
  - broadcast: all 1s
  - multicast: first bit is 1
- **Bandwidth: 10Mbps, 100Mbps, 1Gbps**
- **Length: 2500m (500m segments with 4 repeaters)**
- **Problem: Distributed algorithm to provide fair access**

Transmit algorithm

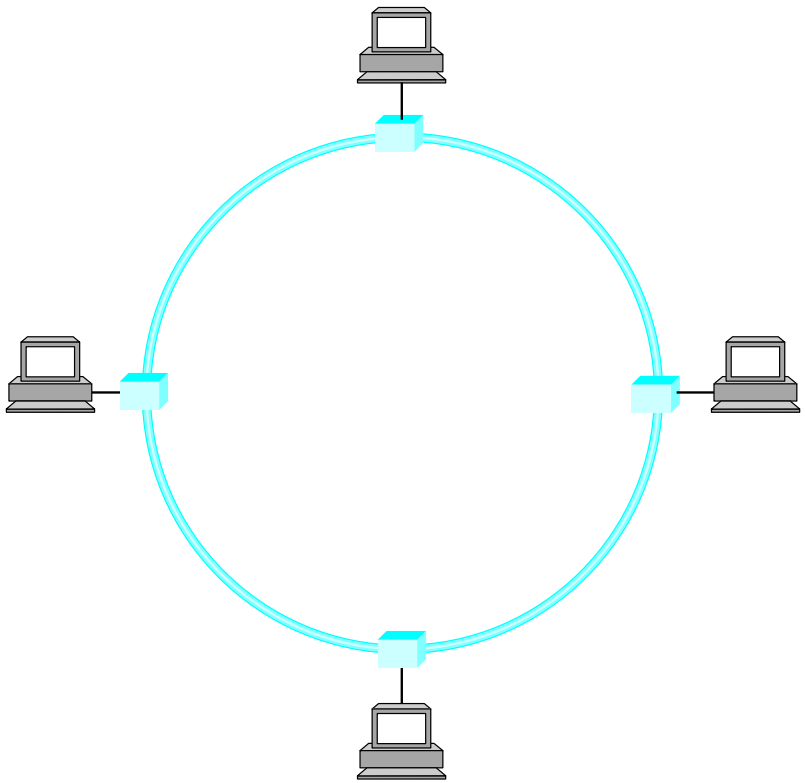
- **If line is idle**
  - send immediately
  - upper bound message size of 1500 bytes
  - must wait 9.6μs between back-to-back frames
- **If line is busy**
  - wait until idle and transmit immediately
  - called 1-persistent (special case of p-persistent)

Handling collisions

- **If collision**
  - jam for 32 bits, then stop transmitting frame
  - minimum frame is 64 bytes (header + 46 bytes of data)
  - delay and try again
- **nth time: $k \times$ 51.2μs, for** $k \leftarrow_R \{0 \ldots 2^{\min(n,10)-1}\}$
  - 1st time: 0 or 51.2μs
  - 2nd time: 0, 51.2, or 102.4μs
  - 3rd time51.2, 102.4, or 153.6μs
- **give up after several tries (usually 16)**
- **Min packet size determines max net length…**

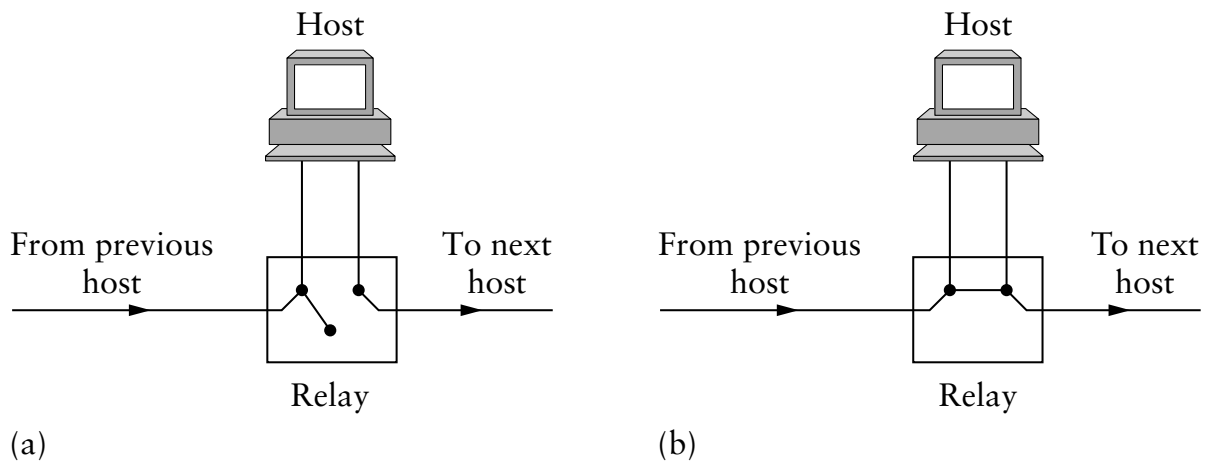

A
B
(a)
A
B
(b)
A
B
(c)
A
B
(d)

Token ring



- Idea: Frames flow around ring
- Capture special “token” bit pattern to transmit

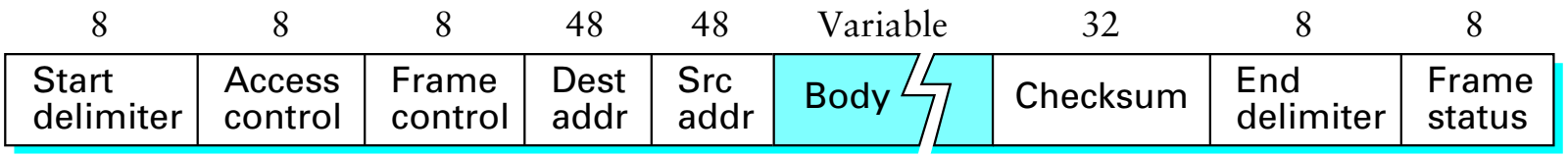
Interface cards



- **Danger if host dies, can wedge net**
- **Hardware typically has relays**
  - In interface cards, or multi-station access units (MASUs)

Token ring frames

- **Frame format (Manchester encoding)**



- **First two bits of token differ from preamble by one bit**
  - Can just flip bit as you grab the token, so don't need to buffer more than one byte at host
- **Token maintenance**
  - Various complications required to recover from lost token, etc.