CompSci 356: Computer Network Architectures

Lecture 6: Link layer: Error Detection and Reliable transmission Ref. Chap 2.4, 2.5

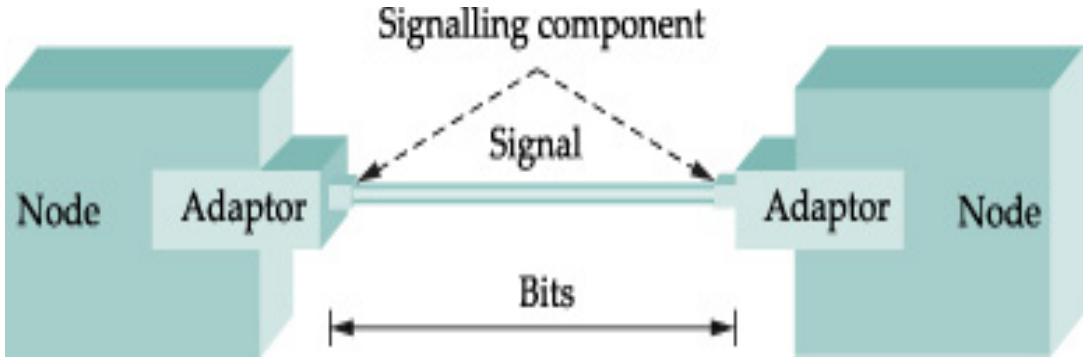
Xiaowei Yang

xwy@cs.duke.edu

Overview

- Link layer functions
  - Encoding
    - NRZ, NRZI, Manchester, 4B/5B
  - Framing
    - Byte-oriented, bit-oriented, time-based
    - Bit stuffing
  - Error detection
    - Parity, checkshum, CRC
  - Reliability
    - FEC, sliding window

Link-layer functions



- Most functions are completed by adapters
  - Encoding
  - Framing
  - Error detection
  - Reliable transmission

Error detection

- Error detection code adds redundancy
  - Analogy: sending two copies
  - Parity
  - Checksum
  - CRC

- Error correcting code

Cyclic Redundancy Check

- Cyclic error-correcting codes
- High-level idea:
  - Represent an n+1-bit message with an n degree polynomial M(x)
  - Divide the polynomial by a degree-k divisor polynomial C(x)
  - k-bit CRC: remainder
  - Send Message + CRC that is dividable by C(x)

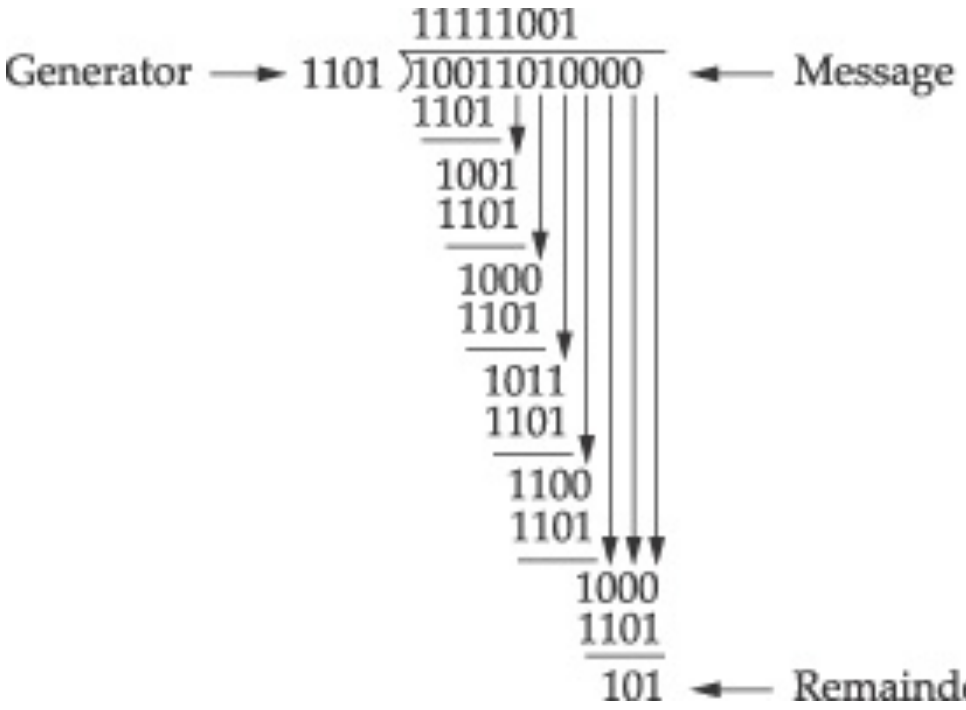
Polynomial arithmetic modulo 2

- B(x) can be divided by C(x) if B(x) has higher degree
- B(x) can be divided once by C(x) if of same degree
  - x^3 + 1 can be divided by x^3 + x^2 + 1
  - The remainder would be 0*x^3 + 1*x^2 + 0*x^1 + 0*x^0 (obtained by XORing the coefficients of each term)
- Remainder of B(x)/C(x) = B(x) – C(x)
- Substraction is done by XOR each pair of matching coefficients

CRC algorithm

1. Multiply M(x) by x^k. Add k zeros to Message. Call it T(x)
2. Divide T(x) by C(x) and find the remainder
3. Send P(x) = T(x) – remainder
   - Append remainder to T(x)
- P(x) dividable by C(x)

An example



8-bit msg

- 10011010

Divisor (3bit CRC)

- 1101

Msg sent: 10011010101

How to choose a divisor

- Arithmetic of a finite field
- Intuition: unlikely to be divided evenly by an error
- Corrupted msg is P(x) + E(x)
- If E(x) is single bit, then $E(x) = x^i$
- If C(x) has the first and last term nonzero, then detects all single bit errors
- Find C(x) by looking it up in a book

Overview

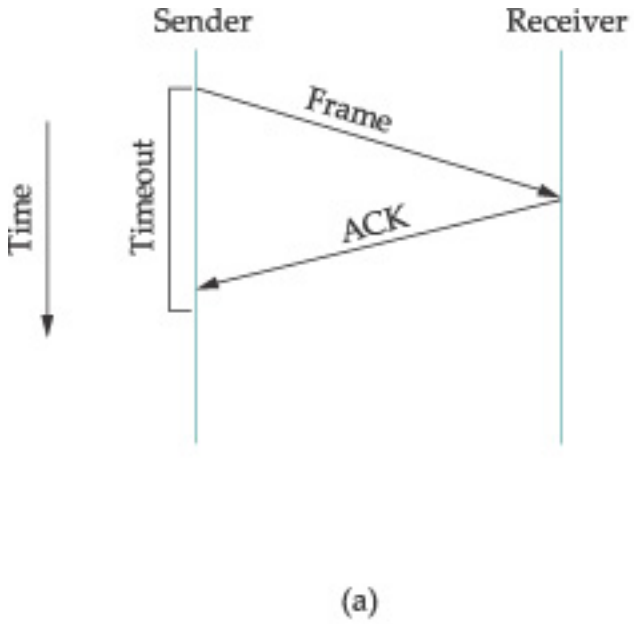
- Link layer functions
  - Encoding
    - NRZ, NRZI, Manchester, 4B/5B
  - Framing
    - Byte-oriented, bit-oriented, time-based
    - Bit stuffing
  - Error detection
    - Parity, checkshum, CRC
  - Reliability
    - FEC, sliding window

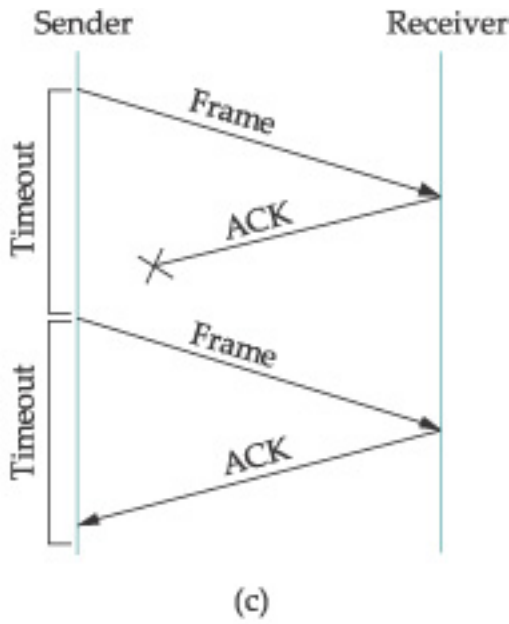
Reliable transmission

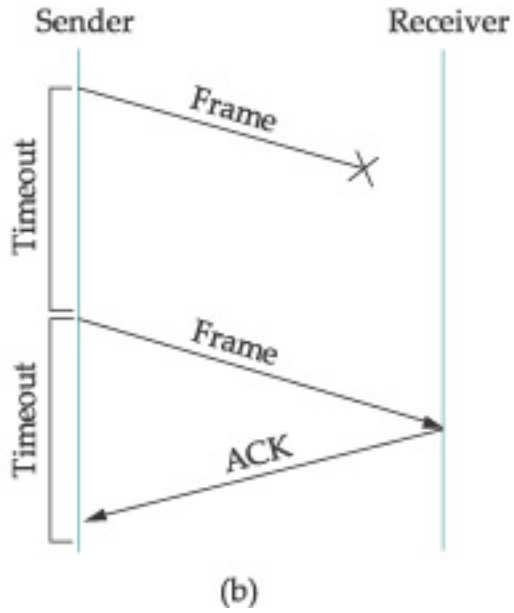
- What to do if a receiver detects bit errors?
- Two high-level approaches
  - Forward error correction (FEC)
  - Retransmission
    - Acknowledgements
      - Can be "piggybacked" on data packets
    - Timeouts
    - Also called Automatic repeat request (ARQ)

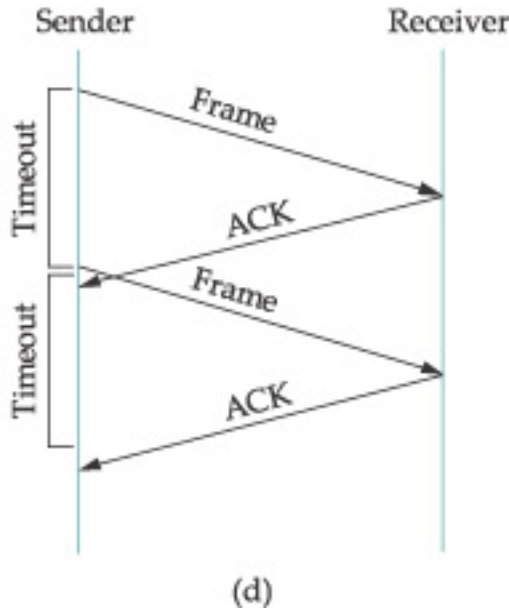
Stop-and-wait

- Send one frame, wait for an ack, and send the next
- Retransmit if times out
- Note in the last figure (d), there might be confusion: a new frame, or a duplicate?



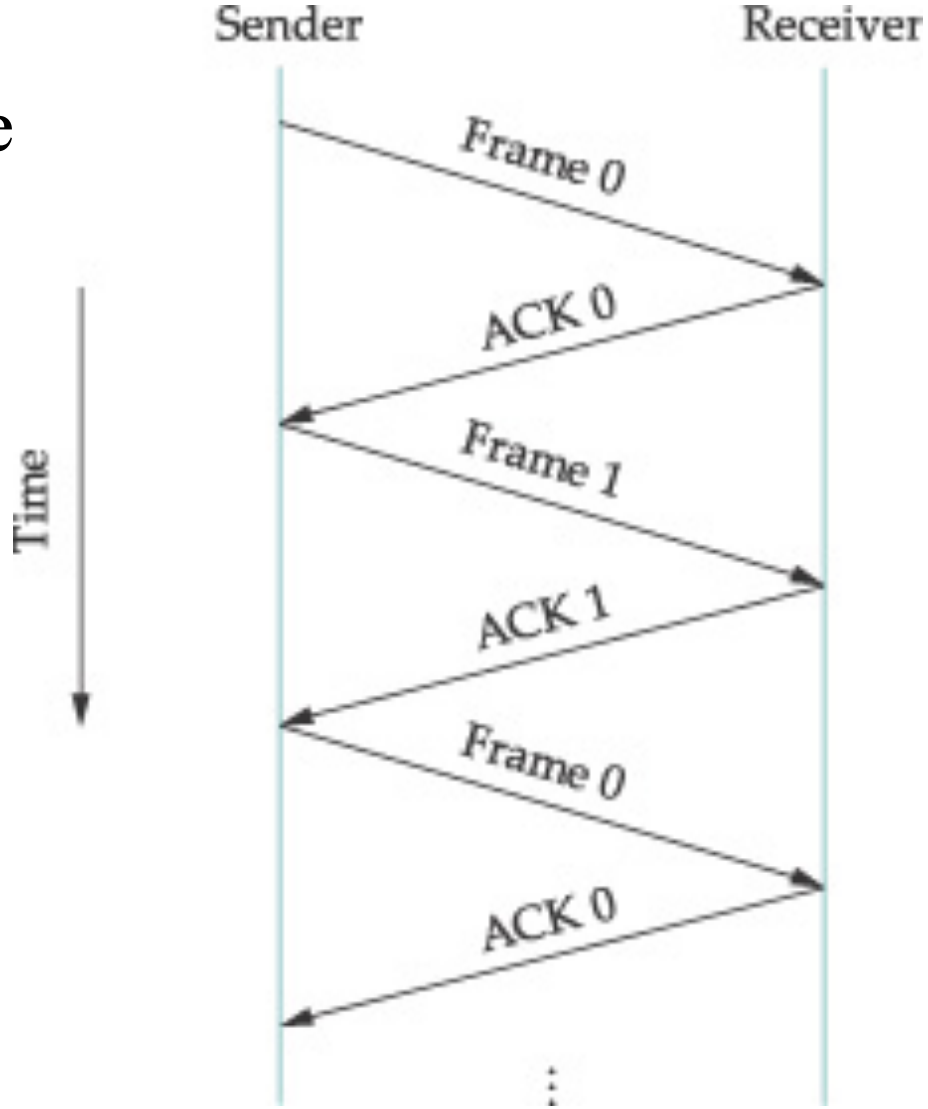






Sequence number

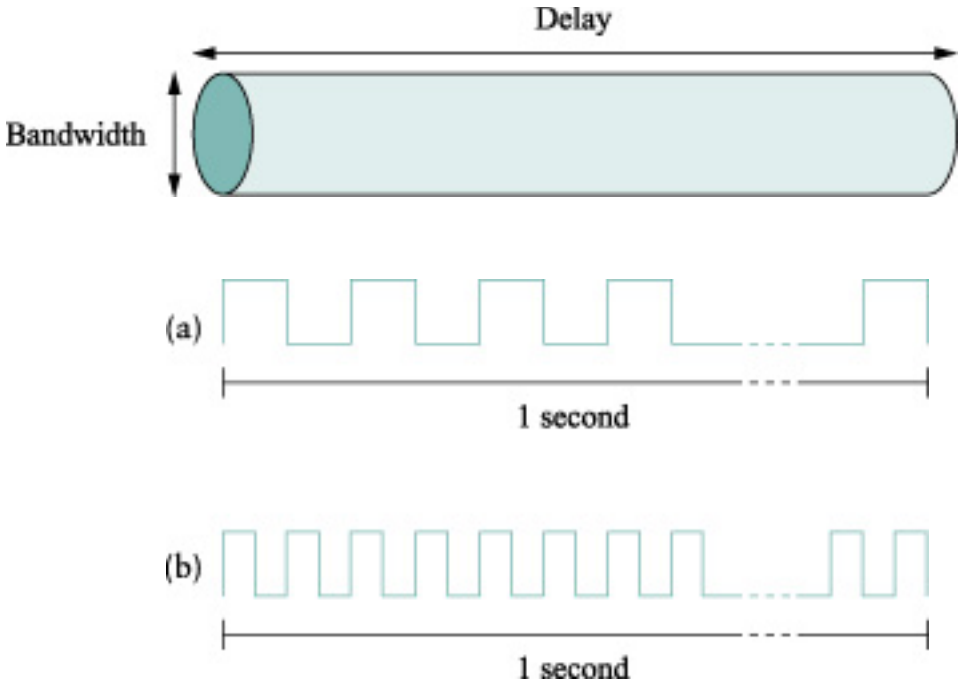
- Add a sequence numbe to each frame to avoid the ambiguity



Stop-and-wait drawback

- Revisiting bandwidth-delay product
  - Total delay/latency = transmission delay + propagation delay + queuing
    - Queuing is the time packet sent waiting at a router's buffer
    - Will revisit later (no sweat if you don't get it now)

Delay * bandwidth product



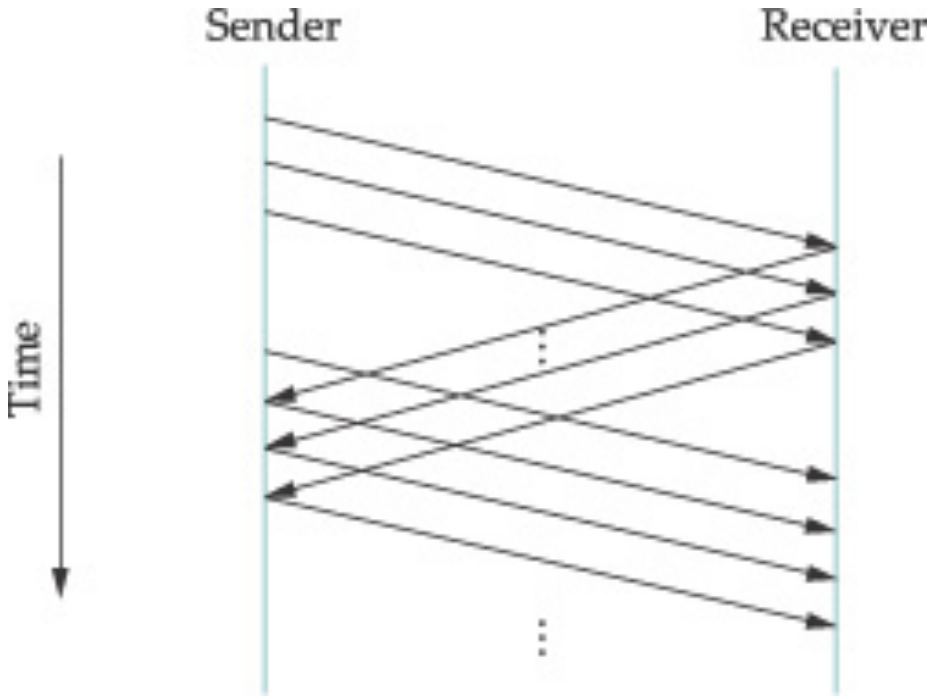
- For a 1Mbps pipe, it takes 8 seconds to transmit 1MB. If the link latency is less than 8 seconds, the pipe is full before all data are pumped into the pipe
- For a 1Gbps pipe, it takes 8 ms to transmit 1MB.

Stop-and-wait drawback

- A 1Mbps link with a 100ms two-way delay (round trip time, RTT)
- 1KB frame size
- Throughput = 1KB/ (1KB/1Mbps + 100ms) = 74Kbps << 1Mbps
- Delay * bandwidth = 100Kb
- So we could send ~12 frames before the pipe is full!
- Throughput = 100Kb/(1KB/1Mbps + 100ms) = 926Kbps

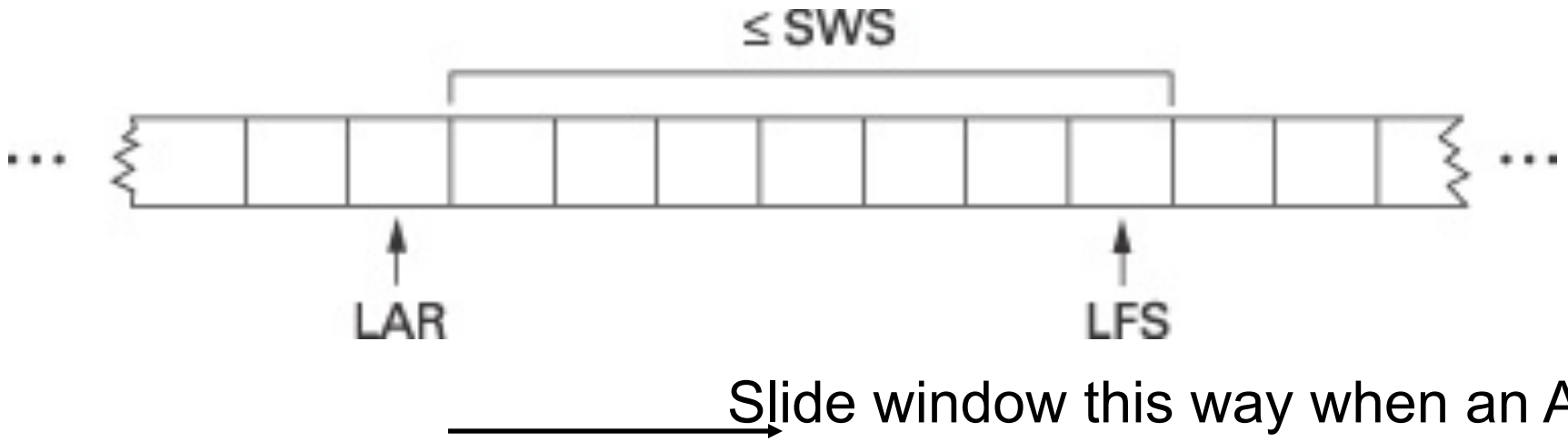
Sliding window

- Key idea: allowing multiple outstanding (unacked) frames to keep the pipe full



Sliding window on sender

- Assign a sequence number (SeqNum) to each frame
- Maintains three variables
  - Send Window Size (SWS)
  - Last Ack Received (LAR)
  - Last Frame Sent (LFS)
- Invariant: LFS – LAR ≤ SWS



- Sender actions
  - When an ACK arrives, moves LAR to the right, opening the window to allow the sender to send more frames
  - If a frame times out before an ACK arrives, retransmit

Sliding window on receiver

- Maintains three window variables
  - Receive Window Size (RWS)
  - Largest Acceptable Frame (LAF)
  - Last frame received (LFR)
- Invariant
  - $LAF - LFR \leq RWS$

- When a frame with SeqNum arrives
  - Discards it if out of window
    - Seq ≤ LFR or Seq > LAF
  - If in window, decides what to ACK
    - Cumulative ack
    - Acks SeqNumToAck even if higher-numbered packets have been received
    - Sets LFR = SeqNumToAck-1, LAF = LFR + RWS
    - Updates SeqNumToAck

- Ex: LFR = 5; RWS = 4, frames 7, 8, 6 arrives

Finite sequence numbers

- Things may go wrong when SWS=RWS, SWS too large
- Example
  - 3-bit sequence number, SWS=RWS=7
  - Sender sends 0, …, 6; receiver acks, expects (7,0, …, 5), but all acks lost
  - Sender retransmits 0,…,6; receiver thinks they are new
- SWS < (MaxSeqNum+1)/2
  - Alternates between first half and second half of sequence number space as stop-and-wait alternates between 0 and 1

Multiple functions of the sliding window algorithm

- Remark: perhaps one of the best-known algorithms in computer networking
- Multiple functions
  - Reliable deliver frames over a link
  - In-order delivery to upper layer protocol
  - Flow control
    - Not to over un a slow slower
  - Congestion control (later)
    - Not to congest the network

Other ACK mechanisms

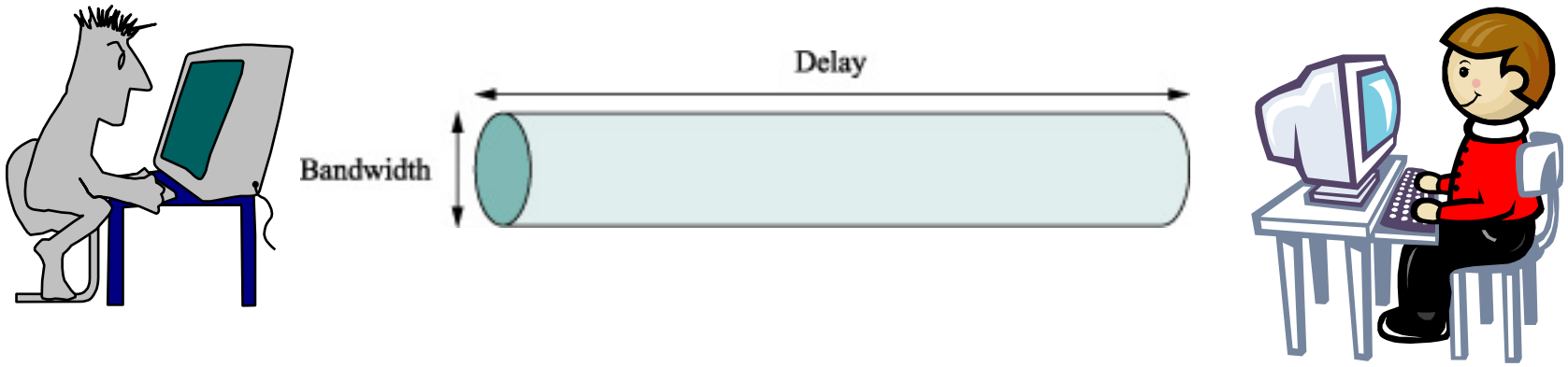
- NACK: negative acks for packets not received
  - unnecessary, as sender timeouts would catch this information

- SACK: selective ACK the received frames
  - + No need to send duplicate packets
  - - more complicated to implement
  - Newer version of TCP has SACK

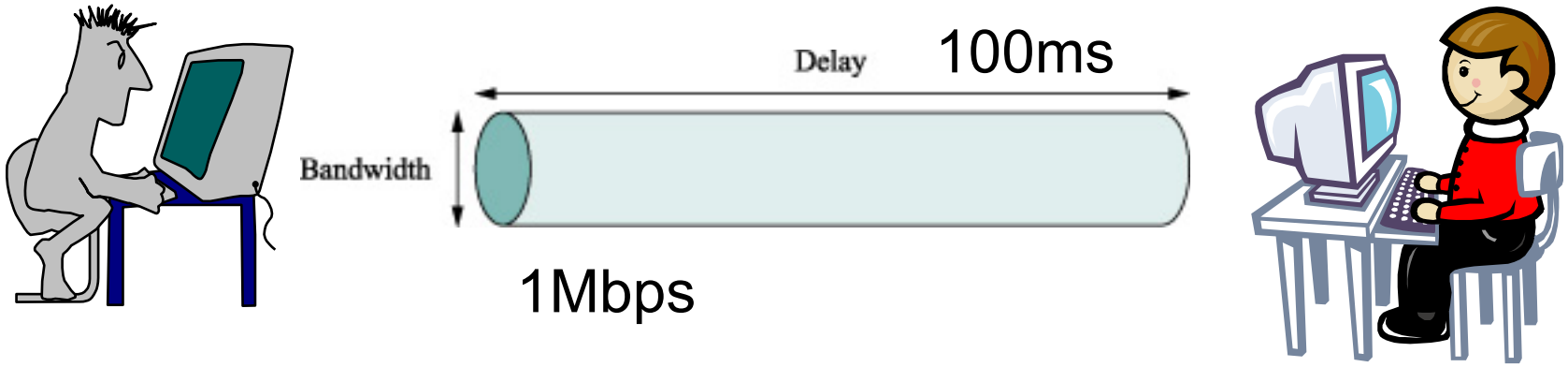
Concurrent logical channels

- A link has multiple logical channels
- Each channel runs an independent stop-and-wait protocol
- + keeps the pipe full
- - no relationship among the frames sent in different channels: out-of-order

Exercise



- Delay: 100ms; Bandwidth: 1Mbps; Packet Size: 1000 Bytes; Ack: 40 Bytes
- Q: the smallest window size to keep the pipe full?



- Window size = largest amount of unacked data
- How long does it take to ack a packet?
  - RTT = 100 ms * 2 + transmission delay of a packet (1000B) + transmission delay of an ack (40B) ~=208ms
- How many packets can the sender send in an RTT?
  - 1Mbps * 208ms / 8000 bits = 26
- Roughly 13 packets in the pipe from sender to receiver, and 13 acks from receiver to sender

Summary

- CRC
- Reliability
  - FEC, sliding window
- Next
  - Multi-access link