Lecture 5:
Flow Control

HW 1 due FRIDAY
Moving up the Stack

Application Layer

Transport Layer

Network Layer

Link Layer

host

host

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Simple Idea: ARQ

- Receiver sends **acknowledgments** (ACKs)
  - Sender “times out” and retransmits if it doesn’t receive them
- Basic approach is generically referred to as **Automatic Repeat Request** (ARQ)
Not So Fast…

- Loss can occur on ACK channel as well
  - Sender cannot distinguish data loss from ACK loss
  - Sender will retransmit the data frame
- ACK loss—or early timeout—results in duplication
  - The receiver thinks the retransmission is new data

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Sequence Numbers

- Sequence numbers solve this problem
  - Receiver can simply ignore duplicate data
  - But must still send an ACK! (Why?)

- Simplest ARQ: Stop-and-wait
  - Only one outstanding frame at a time

How many bits does stop-and-wait need for sequence numbers?

A. 1
B. 2
C. Depends on timeout
D. I don’t know

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Stop-and-Wait Performance

- Lousy performance if time to transmit 1 packet (serialization delay) << time to get to the receiver (propagation delay)
  - How bad? Depends on round trip time (RTT)

- Want to utilize all available bandwidth
  - Need to keep more data “in flight”
  - How much? Called the bandwidth-delay product

- Also limited by quality of timeout (how long?)

How many bits do we want to keep in flight?

A. Bandwidth * one-way delay
B. Bandwidth * round-trip delay
C. Depends on timeout
D. I don’t know
Pipelined Transmission

- Keep multiple packets “in flight”
  - Allows sender to make efficient use of the link
  - Sequence numbers ensure receiver can distinguish frames

- Sender buffers outstanding un-acked packets
  - Receiver ACKs the highest consecutive frame received
  » ACKs are cumulative (covers current frame and all previous)
Go-Back-\(N\)

- Retransmit all packets from point of loss
  - Packets sent after loss event are ignored (i.e., sent again)

- Simple to implement (receiver doesn’t need to buffer)
- Sender controls how much data is “in flight”
Send Window

- **Bound on number of outstanding packets**
  - Window “opens” upon receipt of new ACK
  - Window resets entirely upon a timeout

- **Limits amount of waste**
  - Still lots of duplicates in Go-Back-N
  - We can do better with **selective retransmission**

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Sliding Window

- Single mechanism that supports:
  - Multiple outstanding packets
  - Reliable delivery
  - In-order delivery
  - Flow control

- Sender and receiver each maintain “window” abstractions to track outstanding packets
  - At the core of all modern ARQ protocols

- Go-Back-N is a special case
  - Receive window size of one
Window bounds outstanding unACKed data
  - Implies need for buffering at sender

“Last” ACK applies to in-order data

What to do on a timeout?
  - Go-Back-N: resend all unacknowledged data on timeout
  - Selective Retransmit: timer per packet, resend as needed
Receiver buffers too:
- data may arrive out-of-order
- or faster than can be consumed
  - **Flow control**: tell sender how much buffer left at receiver

Receiver sends an ACK for every segment:
- **Cumulative**, Selective (exempt missing frames), or Negative (only missing frames)
Deciding When to Retransmit

- How do you know when a packet has been lost?
  - Ultimately sender uses timers to decide when to retransmit

- But how long should the timer be?
  - Too long: inefficient (large delays, poor use of bandwidth)
  - Too short: may retransmit unnecessarily (causing extra traffic)

- Right timer is based on the round-trip time (RTT)
  - Which can vary greatly for reasons we will see later
Can we shortcut the timeout?

- Timeout is long in practice
  - Lots of variation in RTT and timeout must be conservative

- If packets are usually *in order* then duplicate cumulative ACKs imply that a packet was lost
  - Fast retransmit
    » When sender receives multiple duplicate acknowledgements resends missing packet

**Duplicate ACKs for packet N indicate which packet was lost?**

- A. Packet N-1
- B. Packet N
- C. Packet N+1
- D. Packet N+2
- E. You can’t tell
Fast retransmit

- Don’t bother waiting
  - Receipt of duplicate acknowledgement (dupACK) indicates loss
  - Retransmit immediately

- Used in TCP
  - Need to be careful if frames can be reordered
  - TCP Reno identifies a loss if there are three duplicate ACKs in a row
For Next Time

- Read 5-5.2 in P&D
- HW 1 due at the beginning of class Friday
- (Keep) going on the project…