Reliable Data Transfer

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Reliable Data Transfer

- What is reliable data transfer?
  - guaranteed arrival
  - no error
  - in order delivery
- Why is it difficult?
  - unreliable underlying communication channel, which can be lossy, error-prone, and deliver packets out of order
- Where is it used in computer networks?
  - reliable transport service on top of unreliable network layer
  - reliable data link service on top of unreliable physical layer

Principles of Reliable Data Transfer

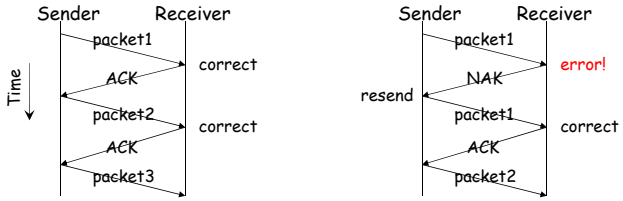
- Characteristics of unreliable channel will determine complexity of reliable data transfer protocol
  - e.g., delay in the channel is bounded in physical layer, not so for network layer
- Other services may interact with RDT protocol
  - e.g., flow control, congestion control
- Here we study widely applicable RDT principles
  - we don't make assumptions about the unreliable channel
  - we don't consider interaction with other services
- Later we see what RDT is like in practice
  - in a transport layer protocol – TCP

Outline

- Overview of reliable data transfer
- A correct protocol: stop-and-wait
  - one packet at a time
- An efficient protocol: sliding window
  - multiple packets simultaneously

Deal with Errors

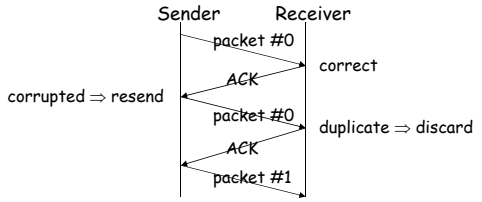
- First deal with errors, later deal with packet loss.
- ACK-based solution: receiver check errors
  - if correct, send back positive ACK
  - otherwise, send back negative NAK



What if ACK or NAK is corrupted?

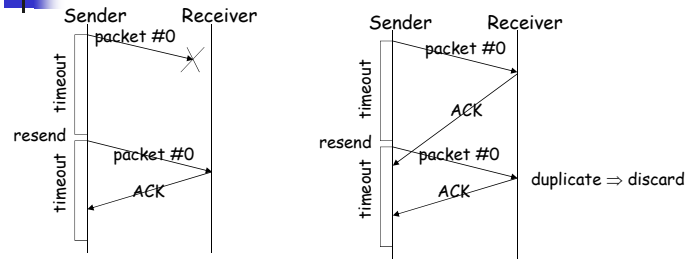
What if ACK or NAK is corrupted?

- Solution 1: creating special acknowledgments for ACKs/NAKs. What if they get corrupted too??
- Solution 2: treat corrupted acknowledgements as NAKs. Duplicated packets!!
- To solve duplicated packets: sequence number for each packet.



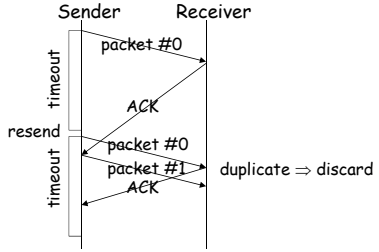
How many sequence numbers do we need here?

Deal with Packet Loss: Timeouts



- Early timeout ⇒ duplicated packet ⇒ sequence number. (not likely for data link protocol)

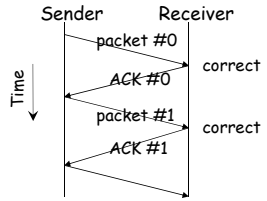
Deal with Duplicated ACKs



- Solution: each ACK carries sequence number.
- With timeout, NAK is not necessary any more.

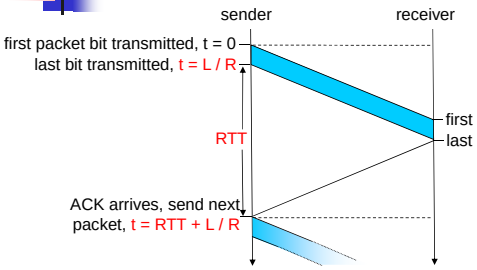
Stop-and-Wait

Now we have a *correct* protocol:



- Allow one outstanding (un-ACKed) packet – *stop-and-wait*
- By the way, we haven't talked about in-order delivery.

Efficiency of Stop-and-Wait



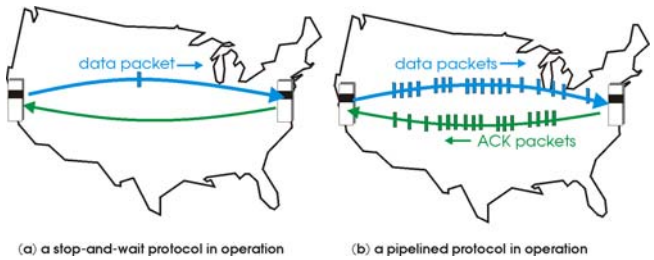
$$\text{efficiency} = \frac{L / R}{RTT + L / R}$$

Example:
- Packet size L = 1KB (8kbits),
- Transmission speed R = 1 Gbps,
- Roundtrip prop. delay RTT = 30ms.

⇨ 0.027% efficiency!

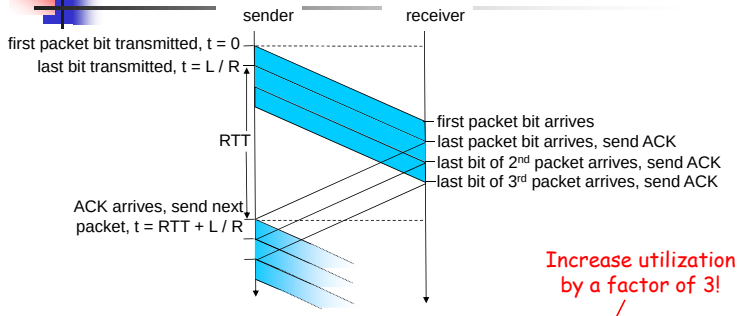
Pipelined Protocols

Pipelining: sender allows multiple, "in-flight", yet-to-be-acknowledged packets



(a) a stop-and-wait protocol in operation (b) a pipelined protocol in operation

Pipelining: Increased Efficiency

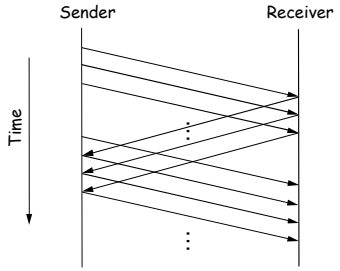


Increase utilization by a factor of 3!

$$\text{Channel util efficiency} = \frac{3*L / R}{RTT + L / R} = \frac{.000024}{.030008} = 0.08\%$$

A pipelined protocol: Sliding Window

- Allow multiple outstanding (un-ACKed) packets
- Upper bound on un-ACKed packets, called window



Two variations: go-back-N, and selective repeat.

Go-Back-N: normal operation

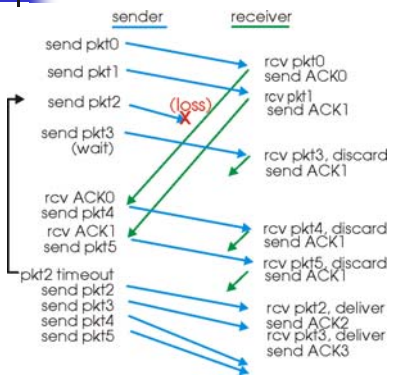
- Sender: "window" of up to N consecutive un-ACKed packets allowed; limit send buffer space

- Receiver: no buffering
- Cumulative ACK – ACK with seq #n stands for ACKs all packets up to, including seq #n
  - Receiver: acknowledge in-order packet arrival
  - Sender: if recv ACKs in send window, sliding send window

Go-Back-N: deal with problems

- Sender:
  - Timer for each in-flight packet (or first in-flight packet)
  - Packet with seq #n timeouts: retransmit #n and all higher seq # packets in window (buffering)
- Receiver: out-of-order packet:
  - Discard!
  - Optional: Re-ACK packet with highest in-order seq # (sort of a NACK)
    - alert sender something is wrong through duplicated ACKs
    - not critical for protocol correctness; but may improve performance

GBN in Action



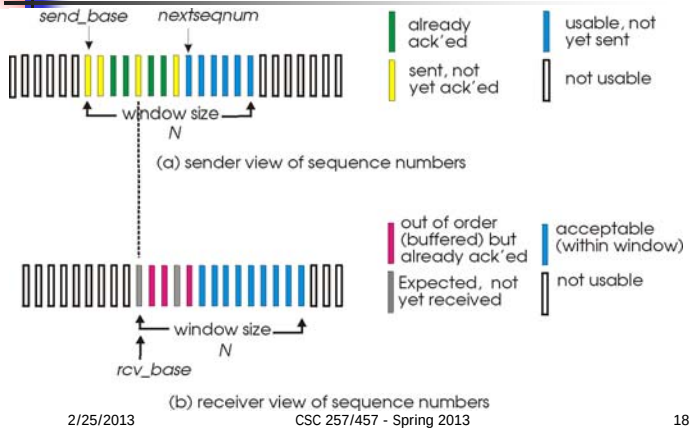
Drawback:
- Resend out-of-order packets

To fix it:
- Receiver buffering
- Selective acknowledgement

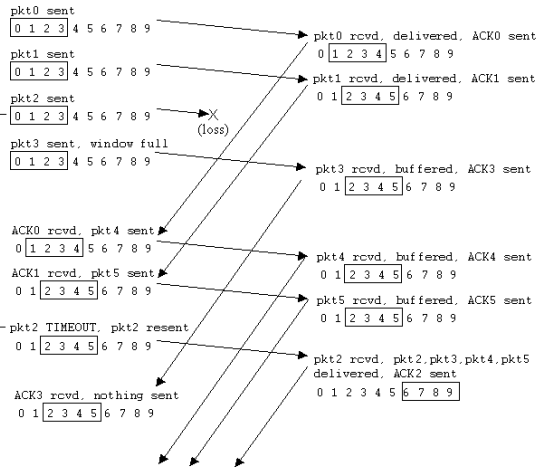
Selective Repeat

- Receiver
  - buffers out-of-order packets for eventual in-order delivery to upper layer
  - individually acknowledges all correctly received packets
- Sender
  - maintains timer for each un-ACKed packet
  - only resends packets whose timers expire before ACKs are received

Selective Repeat: Sender, Receiver Windows



Selective Repeat in Action



Selective Repeat: Sender Implementation

Sender

data from above:
- if there is available slot in window, send pkt

timeout(n):
- resend pkt n, restart timer

ACK(n):
- mark pkt n as received
- if n is smallest unACKed pkt, advance window base to next unACKed seq # (sliding!)

Selective Repeat: Sequence Numbers at Receiver

- rcvbase is the first expected packet.
- Is it possible to see an arriving packet with sequence number of rcvbase+N or greater?
  - No since rcvbase is still in send window which can't go beyond rcvbase+N-1.
- Is it possible to see an arriving packet with sequence number smaller than rcvbase?
  - Yes. For instance, due to lost acknowledgement.
- What is the smallest seq number receiver can possibly see?
  - All the way down to the first packet since a packet can hang inside the network for unbounded time.
- What is the smallest seq number that may still in the send window?
  - rcvbase-N.

Selective Repeat: Receiver Implementation

Receiver

pkt n in [rcvbase, rcvbase+N-1]
- send ACK(n)
- in-order: deliver (also deliver buffered, in-order pkts), advance window to next not-yet-received pkt (sliding!)
- out-of-order: buffer

pkt n in [rcvbase-N, rcvbase-1]
- ACK(n)

otherwise:
- ignore

Sequence Numbers

- Bounding of the currently relevant sequence number space?
  - We bound it at the first step of stop-and-wait when there is no packet loss and every packet is accounted for before the protocol moves on.
  - Cannot be bounded in practice when earlier sent packet (assumed lost by the protocol) may hang around in the network for a long time and then arrives suddenly.
- External (beyond the current communication session) reasons for out-of-bound sequence numbers:
  - Packets belonging to earlier sessions between the same communication hosts
  - Malicious attacker injects packets

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