Reliable Data Transfer

Kai Shen

Dept. of Computer Science, University of Rochester

Reliable Data Transfer

- What is reliable data transfer?
  - guaranteed arrival
  - no error
  - in order delivery
- Why is it difficult?
  - end-system-only solution has no control of 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 IP
  - reliable data link service on top of unreliable physical layer

Principles of Reliable Data Transfer

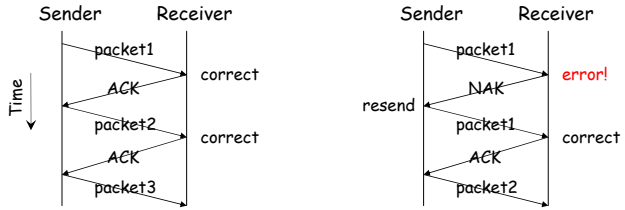
- Characteristics of unreliable channel will determine complexity of reliable data transfer protocol
  - e.g., delay in the channel is bounded in physical layer, not so for network layer
- Other services may interact with RDT protocol
  - e.g., flow control, congestion control
- Here we study the RDT principles, so
  - 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

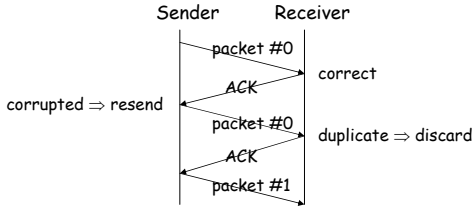
- First deal with errors, later deal with packet loss.
- ACK-based solution: receiver check errors
  - if correct, send back positive ACK
  - otherwise, send back negative NAK



What if ACK or NAK is corrupted?

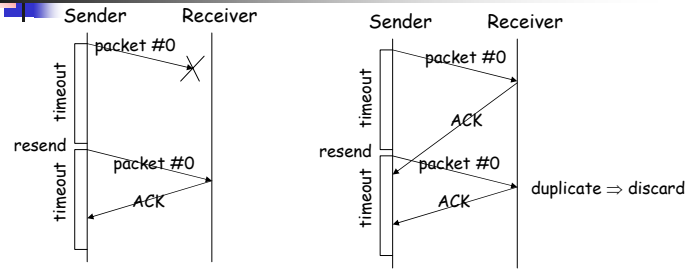
What if ACK or NAK is corrupted?

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



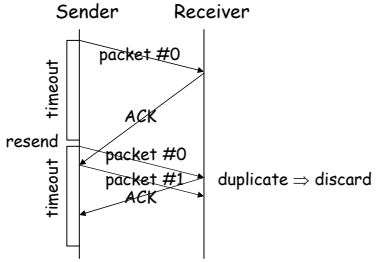
How many sequence numbers do we need here?

Deal with Packet Loss: Timeouts



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

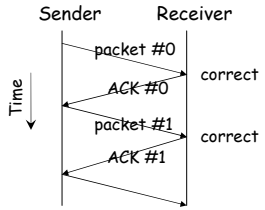
Deal with Duplicated ACKs



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

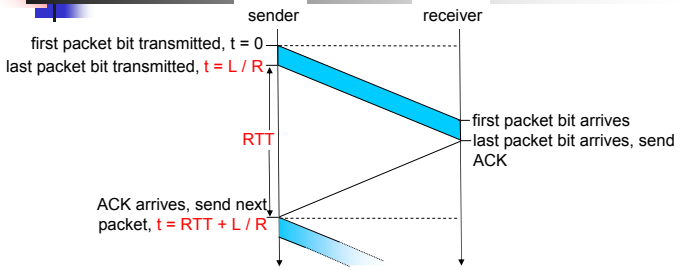
Stop-and-Wait

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



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

Efficiency of Stop-and-Wait (An Example)

- It works, but performance stinks!
- Example: 1 Gbps link, 30ms roundtrip prop. delay, 1KB (8kbits) packet.

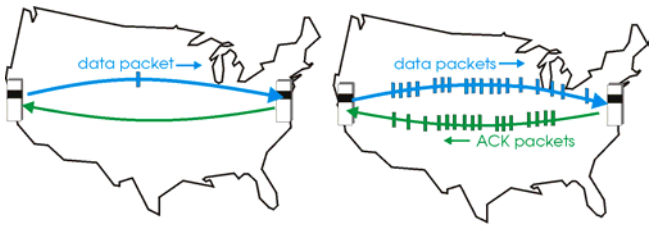
$$T_{transmit} = \frac{L \text{ (packet length)}}{R \text{ (transmission rate)}} = \frac{8 \text{ kb}}{1 \text{ gb/sec}} = 8 \text{ microsec}$$

$$\text{Throughput} = \frac{L}{T_{transmit} + RTT} = \frac{8kb}{0.03008sec} = 266Kbps$$

- 266Kps throughput over 1 Gbps link ⇒ 0.027% efficiency!
- network protocol limits use of physical resources!

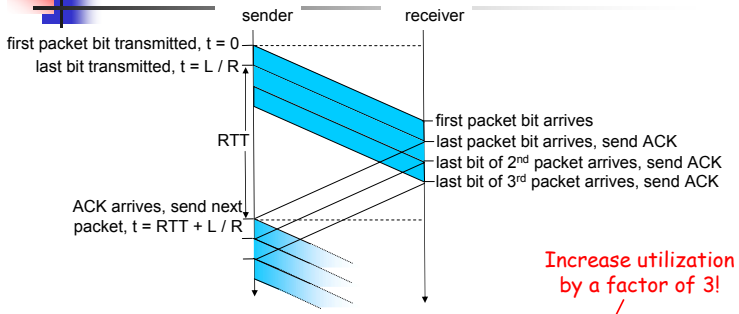
Pipelined Protocols

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

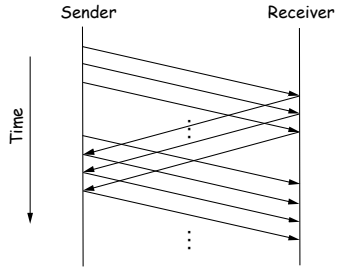


Increase utilization by a factor of 3!

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

A pipelined protocol: Sliding Window

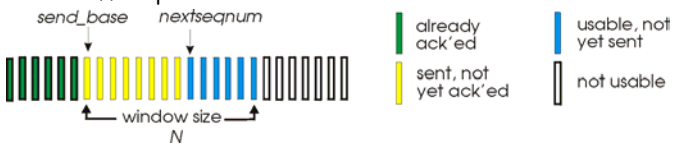
- Allow multiple outstanding (un-ACKed) packets
- Upper bound on un-ACKed packets, called window



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

Go-Back-N: Sender

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

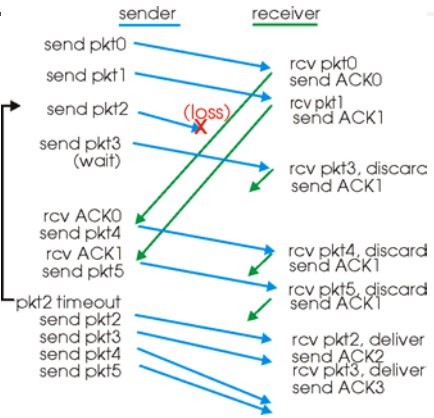


- cumulative ACK – ACK with seq #n stands for ACKs all packets up to, including seq #n
- recv ACKs in send window
  - sliding send window
- timer for each in-flight packet
- packet with seq #n timeouts:
  - retransmit #n and all higher seq # packets in window (buffering)

Go-Back-N: Receiver

- Send ACK for correctly-received packet with highest in-order seq #
  - Sliding receive window
- Out-of-order packet:
  - Discard (don't buffer) -> no receiver buffering!
  - 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

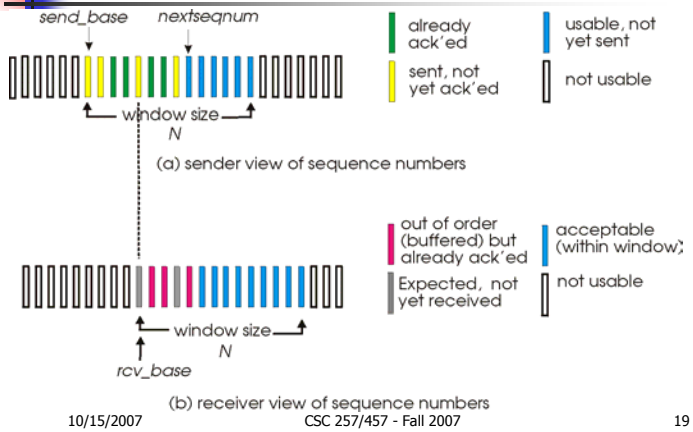
GBN in Action



Selective Repeat

- receiver individually acknowledges all correctly received packets.
  - buffer out-of-order packets for eventual in-order delivery to upper layer
- sender timer for each un-ACKed packet
  - sender only resends packets whose timers expire before ACKs are received

Selective Repeat: Sender, Receiver Windows



Selective Repeat

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!)

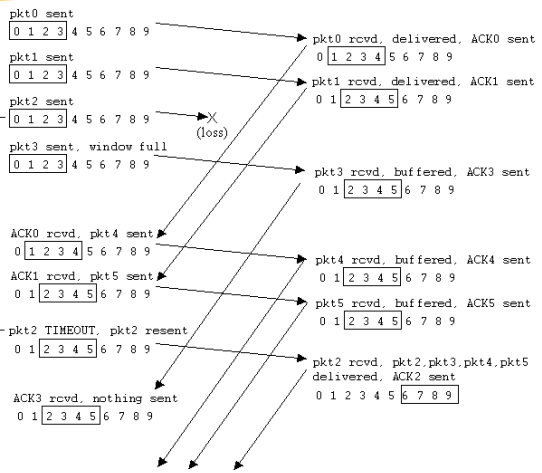
receiver

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

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

otherwise:
- ignore

Selective Repeat in Action



Sequence Number Space

- **SeqNum** field is finite; sequence numbers wrap around
  - 0, 1, …, S-1, 0, 1, …, S-1, 0, 1, …
- Sequence number space must be at least as big as the window size ⇒ S ≥ N
- Is this enough?
  - out-of-order channel: an old packet carrying the same sequence number confused with a packet of current concern

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