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

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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?

- Solution 1: create 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.

Deal with Packet Loss: Timeouts

- Early timeout (possible for transport protocol, but unlikely for data link protocol)
  ⇒ duplicated packet ⇒ sequence number.

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

Efficiency = \( \frac{L}{R \cdot (RTT + \frac{L}{R})} \)

Example:

- Packet size \( L = 1 \text{KB} \) (8kbits),
- Transmission speed \( R = 1 \text{ Gbps} \),
- Roundtrip prop. delay \( RTT = 30 \text{ms} \).

\( 0.000024 \) vs. \( 0.030008 \) \( = 0.08\% \) efficiency!

Pipelined Protocols

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

Channel util efficiency = \( \frac{3 \cdot L}{R \cdot (RTT + \frac{L}{R})} = \frac{0.000024}{0.030008} = 0.08\% \)

Increase utilization by a factor of 3!
A pipelined protocol: Sliding Window

- Allow multiple outstanding (un-ACKed) packets
- Upper bound on un-ACKed packets, called \textit{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
  - 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 in Action

Selective Repeat: Sender, Receiver

Windows

(a) sender view of sequence numbers

(b) receiver view of sequence numbers

Selective Repeat: Sender Implementation

Sender

- 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!)

Sender Implementation 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 be in 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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