

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

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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

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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

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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.

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Deal with Packet Loss: Timeouts

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

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Deal with Duplicated ACKs

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

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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.

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Efficiency of Stop-and-Wait

Example:

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

\Rightarrow **0.027% efficiency!**

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

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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

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Pipelining: Increased Efficiency

Increase utilization by a factor of 3!

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

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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.

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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

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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

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GBN in Action

Drawback:

- Resend out-of-order packets

To fix it:

- Receiver buffering
- Selective acknowledgement

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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

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Selective Repeat: Sender, Receiver Windows

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Selective Repeat in Action

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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!**)

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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?
 - $rcvbase-N$.

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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

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Selective Repeat: Sequence Numbers

- Out-of-bound packets
 - Wrapped sequence numbers
 - Packets belonging to earlier sessions between the same communication hosts
 - Malicious attacker injects packets

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