Reliable Data Transfer

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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

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

```
Sender  |  Receiver
---|---
packet1  |  ACK
packet2  |  correct
packet3  |  resend
```

**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.

```
Sender  |  Receiver
---|---
packet1  |  NAK
packet2  |  packet1
packet2  |  correct
```

**Deal with Packet Loss: Timeouts**

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

```
Sender  |  Receiver
---|---
resend  |  packet #0
timeout  |  sender
```

**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 = \( \frac{L}{R(T+L/R)} \)

Example:

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

\( \Rightarrow 0.027\% \) efficiency!

Pipelined Protocols

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

\( \text{Channel util efficiency} = \frac{3L/R}{RTT + L/R} \) = 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 window

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 in Action

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Selective Repeat: Sender, Receiver

- **Windows**
  - send_base: number of packets already sent
  - nextseqnum: number of next packet to send
  - usable, not yet sent
  - sent, not yet acknowledged
  - already acknowledged

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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)
Selective Repeat: Sequence Numbers at Receiver

- $r_{cvbase}$ is the first expected packet.
- Is it possible to see an arriving packet with sequence number of $r_{cvbase}+N$ or greater?
  - No since $r_{cvbase}$ is still in send window which can’t go beyond $r_{cvbase}+N-1$.
- Is it possible to see an arriving packet with sequence number smaller than $r_{cvbase}$?
  - 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?
  - $r_{cvbase}-N$.

Selective Repeat: Receiver Implementation

- Receiver
  - pkt n in [$r_{cvbase}$, $r_{cvbase}+N-1$]
    - 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 [$r_{cvbase}-N$, $r_{cvbase}-1$]
    - $ACK(n)$
  - 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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