Transport layer

- Review principles:
  - Reliable data transfer
  - Flow control
  - Congestion control
- Instantiation in the Internet
  - UDP
  - TCP

UDP: User Datagram Protocol [RFC 768]

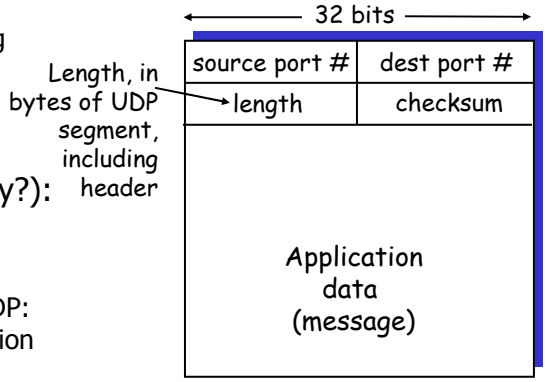
- "No frills," "bare bones" Internet transport protocol
- "Best effort" service, UDP segments may be:
  - Lost
  - Delivered out of order to application
- *Connectionless:*
  - No handshaking between UDP sender, receiver
  - Each UDP segment handled independently of others

Why is there a UDP?

- No connection establishment (which can add delay)
- Simple: no connection state at sender, receiver
- Small segment header
- No congestion control: UDP can blast away as fast as desired

UDP: More

- Often used for streaming multimedia apps
  - Loss tolerant
  - Rate sensitive
- Other UDP uses (why?):
  - DNS
  - SNMP
- Reliable transfer over UDP: add reliability at application layer
  - Application-specific error recover!



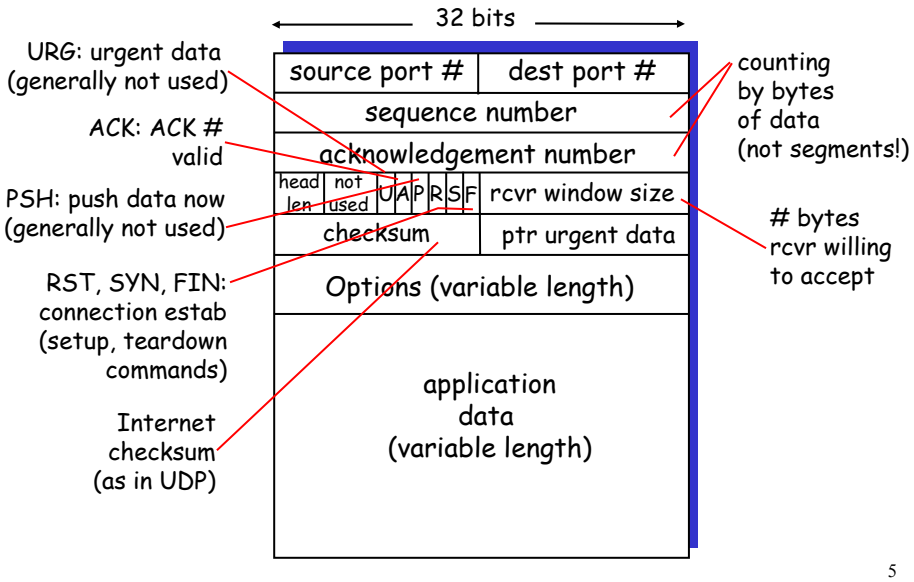
UDP segment format

TCP: Overview

RFCs: 793, 1122, 1323, 2018, 2581

- Point-to-point:
  - One sender, one receiver
- Reliable, in-order *byte stream:*
  - No "message boundaries"
- Pipelined:
  - TCP congestion and flow control set window size
- Full duplex data:
  - Bi-directional data flow in same connection
  - MSS: maximum segment size
- Connection-oriented:
  - Handshaking (exchange of control msgs) init's sender, receiver state before data exchange
- Flow controlled:
  - Sender will not overwhelm receiver

TCP segment structure



TCP seq. #'s and ACKs

Seq. #'s:

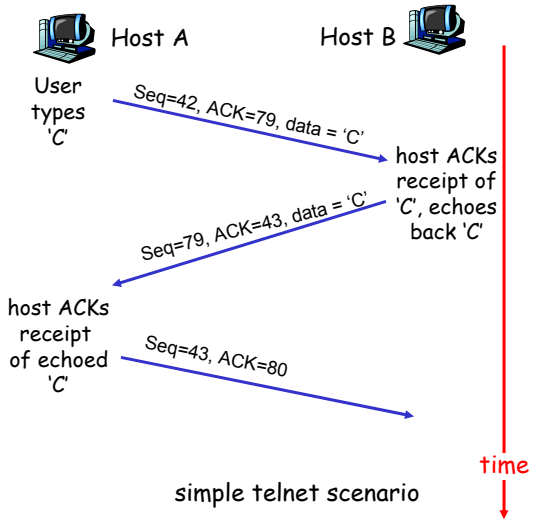
- Byte stream "number" of first byte in segment's data

ACKs:

- Seq # of next byte expected from other side
- Cumulative ACK

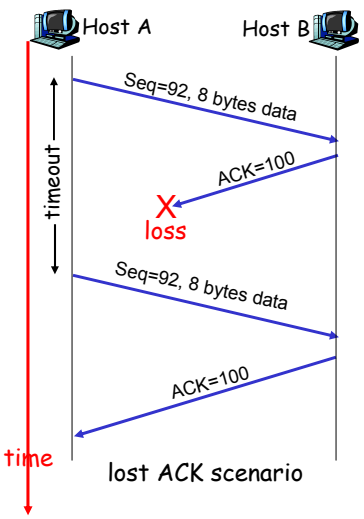
Q: How receiver handles out-of-order segments

- A: TCP spec doesn't say – up to implementor

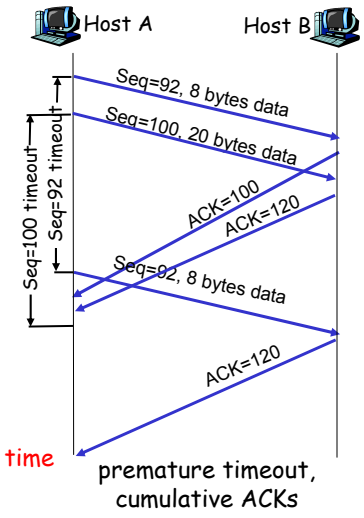


simple telnet scenario

TCP: Retransmission scenarios



lost ACK scenario

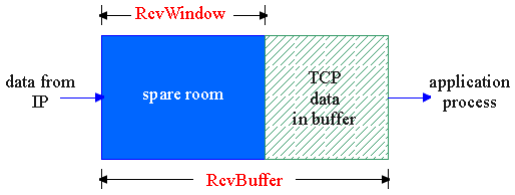


premature timeout, cumulative ACKs

TCP Flow Control

flow control

sender won't overrun receiver's buffers by transmitting too much, too fast



receiver buffering

Receiver: explicitly informs sender of (dynamically changing) amount of free buffer space

- `rcvr window size` field in TCP segment

Sender: amount of transmitted, unACKed data less than most recently-receiver `rcvr window size`

TCP Round-trip Time (RTT) and Timeout estimation

- Wait at least one RTT before retransmitting
- Importance of accurate RTT estimators:
  - Low RTT → unneeded retransmissions
  - High RTT → poor throughput
- RTT estimator must adapt to change in RTT
  - But not too fast, or too slow!
- Spurious timeouts
  - "Conservation of packets" principle – more than a window worth of packets in flight

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TCP connection management

Recall: TCP sender, receiver establish "connection" before exchanging data segments

- Initialize TCP variables:
  - Seq. #s
  - Buffers, flow control info (e.g. `RcvWindow`)
- *Client:* connection initiator
- *Server:* contacted by client

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TCP connection management (2)

Three way handshake:

Step 1: Client end system sends TCP SYN control segment to server
- Specifies initial seq #
- Specifies initial window #

Step 2: Server end system receives SYN, replies with SYNACK control segment
- ACKs received SYN
- Allocates buffers
- Specifies server → receiver initial seq. #
- Specifies initial window #

Step 3: Client system receives SYNACK

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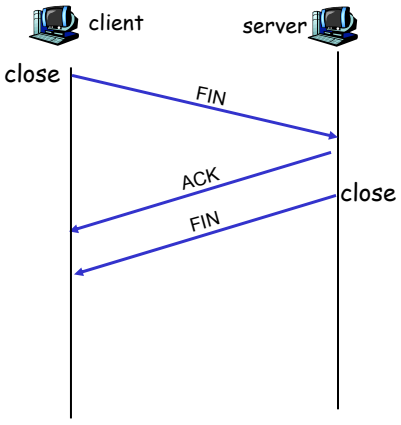
TCP connection management (3)

Closing a connection:

Client closes socket:
`clientSocket.close();`

Step 1: Client end system sends TCP FIN control segment to server

Step 2: Server receives FIN, replies with ACK. Closes connection, sends FIN.



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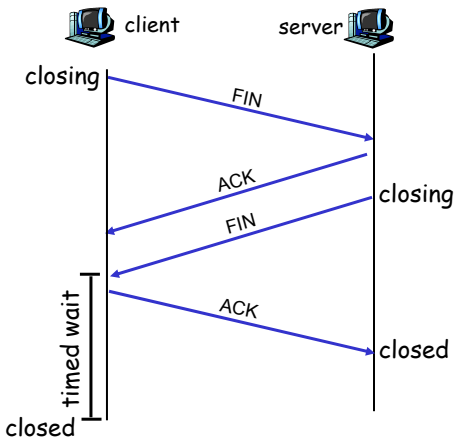
TCP connection management (4)

Step 3: Client receives FIN, replies with ACK.

- Enters "timed wait" – will respond with ACK to received FINs

Step 4: Server, receives ACK. Connection closed.

Note: With small modification, this can handle simultaneous FINs.



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Principles of congestion control

Congestion:

- Informally: "too many sources sending too much data too fast for *network* to handle"
- Different from flow control!
- Manifestations:
  - Lost packets (buffer overflow at routers)
  - Long delays (queueing in router buffers)

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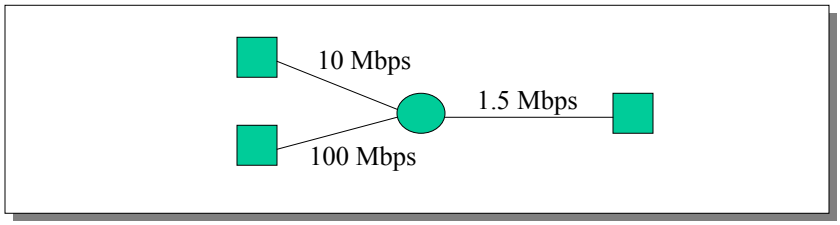
Congestion



- Different sources compete for resources inside network
- Why is it a problem?
  - Sources are unaware of current state of resource
  - Sources are unaware of each other
  - In many situations will result in < 1.5 Mbps of throughput (congestion collapse)

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Congestion collapse

- Definition: *Increase in network load results in decrease of useful work done*
- Many possible causes
  - Spurious retransmissions of packets still in flight
    - Classical congestion collapse
    - How can this happen with packet conservation
    - Solution: better timers and TCP congestion control
  - Undelivered packets
    - Packets consume resources and are dropped elsewhere in network
    - Solution: congestion control for ALL traffic

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TCP congestion control

- "probing" for usable bandwidth:
  - Ideally: transmit as fast as possible (**`Congwin`** as large as possible) without loss
  - *Increase* **`Congwin`** until loss (congestion)
  - Loss: *decrease* **`Congwin`**, then begin probing (increasing) again
- Two "phases"
  - Slow start
  - Congestion avoidance
- Important variables:
  - **`Congwin`**
  - **`threshold:`** defines threshold between two slow start phase, congestion control phase

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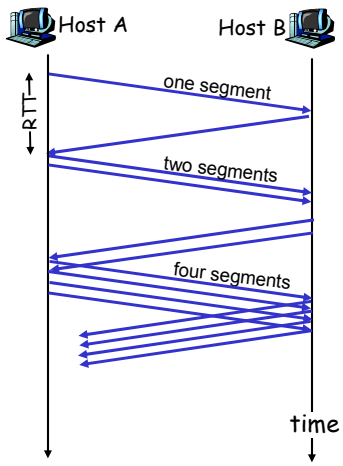
TCP slowstart

- Exponential increase (per RTT) in window size (not so slow!)
- Loss event: timeout (Tahoe TCP) and/or or three duplicate ACKs (Reno TCP)

Slowstart algorithm

```
initialize: Congwin = 1
for (each segment ACKed)
      Congwin++
until (loss event OR
       CongWin > threshold)
```



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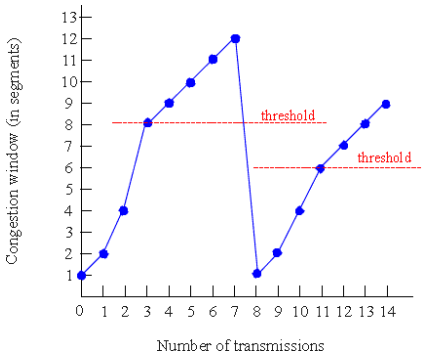
TCP congestion avoidance

Congestion avoidance

```
/* slowstart is over        */
/* Congwin > threshold */
Until (loss event) {
  every w segments ACKed:
      Congwin++
  }
threshold = Congwin/2
Congwin = 1
perform slowstart[1]
```



1: TCP Reno skips slowstart (fast recovery) after three duplicate ACKs

Return to slow start

- If packet is lost we lose self clocking
  - Need to implement slow-start and congestion avoidance together
- When timeout occurs set *ssthresh* to 0.5*w*
  - If *cwnd* < *ssthresh*, use slow start
  - Else use congestion avoidance

Summary

- Reviewed principles of transport layer:
  - Reliable data transfer
  - Flow control
  - Congestion control
  - (Multiplexing)
- Instantiation in the Internet
  - UDP
  - TCP

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