TCP

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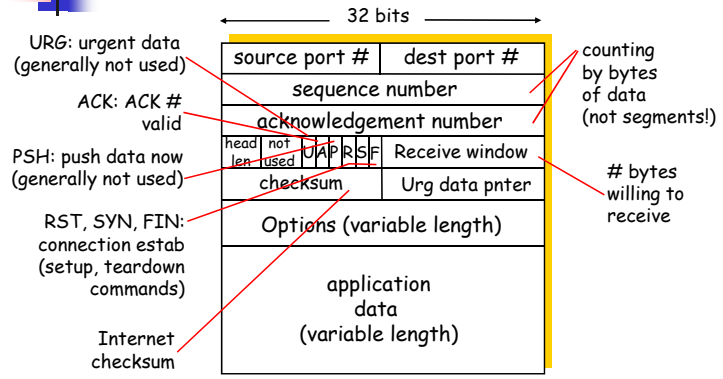
TCP: Overview

- Connection-oriented:
  - handshaking (exchange of control msgs) to initialize sender, receiver state before data exchange
- Reliable data transfer:
  - guaranteed arrival, no error, in order
- Flow controlled:
  - sender does not overwhelm receiver
- Congestion controlled:
  - sender does not overwhelm the network
- No delay or bandwidth guarantee.

TCP Segment Structure



Maximum Segment Size (MSS)

- MSS is the maximum TCP segment that'd fit into the link layer frame
- Local MSS
- Path MSS
  - Try and error probing

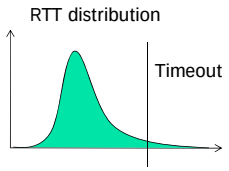
TCP Reliable Data Transfer

- TCP provides reliable data transfer service on top of IP's unreliable service
  - Pipelined transmissions
  - Cumulative ACKs
  - When the receiver receives out-of-order segments, it buffers them and re-ACKs the last in-order data
  - Retransmit a single segment at each timeout
  - The sender retransmits at timeout or when receiving duplicate ACKs
- Somewhere between Go-back-N and Selective Repeat, closer to which?

TCP Timeout

Q: principles for setting transmission timeout value?

- too short: premature timeout and unnecessary retransmissions
- too long: slow reaction to segment loss
- longer than normal RTT (round trip time)
  - but RTT varies



Expected Round Trip Time

Derive expected RTT from past RTT measurement.

- Basic measurement: measured time from segment transmission until ACK receipt
- Stability: RTT fluctuates, we want to avoid instability (pre-mature reaction to short-term spikes)
  - average several recent measurements, not just current RTT
- Agility: in case things do change, we want to adjust accordingly
  - give more recent measurements higher weight

EWMA – Exponentially Weighted Moving Average

- influence of past samples decreases exponentially fast

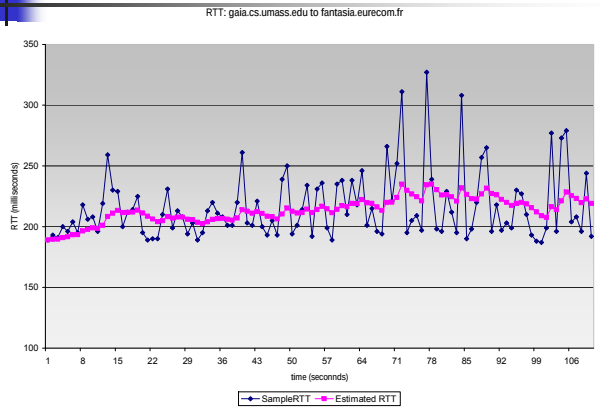
$$\text{ExpectedRTT} = \frac{\text{SampleRTT}_1 + \alpha*\text{SampleRTT}_2 + \alpha^2*\text{SampleRTT}_3 + \ldots\ldots}{1 + \alpha + \alpha^2 + \ldots\ldots}$$

SampleRTT_1 is RTT for the most recent data segment,
SampleRTT_2 is RTT for the next recent data segment, etc.

$\Rightarrow \text{ExpectedRTT} = \alpha*\text{ExpectedRTT}_{\text{last}} + (1-\alpha)*\text{SampleRTT}_1$

- typical value in TCP: $\alpha = 0.875$

Example RTT Estimation



TCP Timeout

Setting the timeout:

- **ExpectedRTT** plus "safety margin"
  - larger variation in **RTT** → larger safety margin
  - **`TimeoutInterval = ExpectedRTT + 4*DevRTT`**
- **DevRTT** also estimated using EWMA of past measurements

TCP Sender Events and Processing

Data ready to send:

- create segment with seq #
- seq # is byte-stream number of first data byte in segment
- start timer
- timeout value: we just decided it!!

Timeout:

- retransmit segment that caused timeout
- restart timer

ACK rcvd:

- slide sender window if acknowledges previously unacked segments
- retransmit if 3 duplicate ACKs

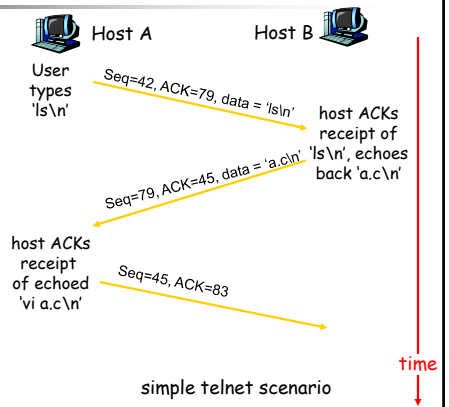
TCP byte-oriented seq. #'s and ACKs

Seq. #'s:

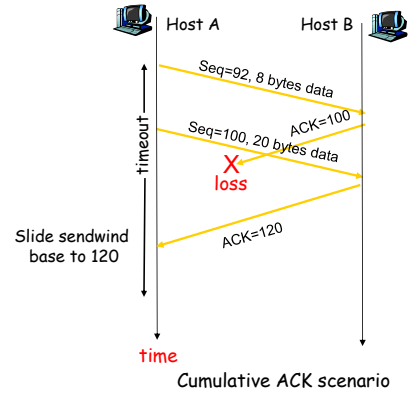
- byte stream "number" of first byte in segment's data

ACKs:

- seq # of next byte expected from other side
- cumulative ACK
- piggybacked in data segments in the reverse direction



TCP in Action: Cumulative ACK

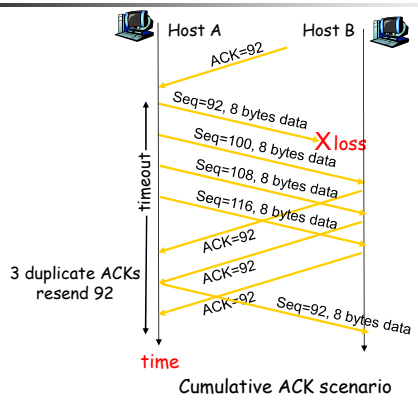


Cumulative ACK scenario

Fast Retransmission

- Time-out period often relatively long:
  - long delay before resending lost packet
- When receiver receives out-of-order segments, it re-ACKs the last in-order byte
- If sender receives 3 ACKs for the same data, it supposes that segment after ACKed data was lost:
  - fast retransmission: resend segment before timer expires, restart timer

TCP in Action: Duplicate ACKs and Fast Retransmission



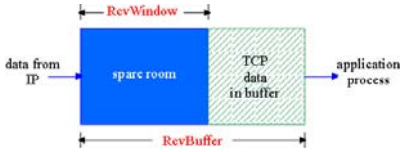
Cumulative ACK scenario

Outline

- Segment structure
- Reliable data transfer
- Flow control
- Connection management

TCP Flow Control

- Receive side of TCP connection has a receive buffer:
- App process may be slow at reading from buffer.



Flow Control:

- Receiver advertises spare room by including value of **`RcvWindow`** in segments
- Sender limits unACKed data to **`RcvWindow`**, therefore guarantees receive buffer doesn't overflow

TCP Connection Management

- Establishment:
  - TCP sender, receiver establish "connection" before exchanging data segments
  - Initialize TCP variables: starting seq. #s, MSS, buffers, flow control info (e.g. **`RcvWindow`**)
- Teardown:
  - Free up resources after mutually close

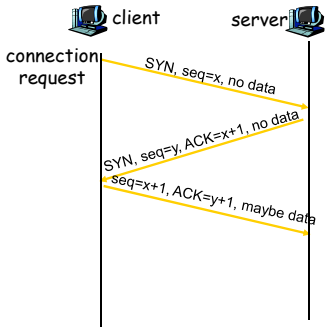
TCP Connection Establishment

Three-way handshake:

Step 1: client (active open) sends TCP SYN segment to server
- specifies initial seq #
- no data

Step 2: server (passive open) host receives SYN, replies with SYNACK segment
- server allocates buffers
- specifies server initial seq. #

Step 3: client receives SYNACK, replies with ACK segment, which may contain data



TCP Connection Teardown

Closing a connection:

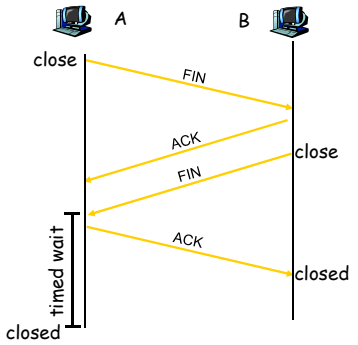
close socket: **close(sockfd);**

Step 1: A (active closing host) sends TCP FIN control segment.

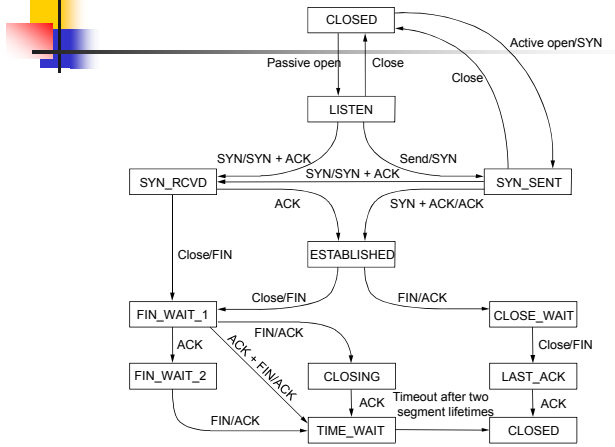
Step 2: B (passive closing host) receives FIN, replies with ACK. Closes connection, sends FIN.

Step 3: A receives FIN, replies with ACK. Enters "timed wait" – resend ACK in case it is lost.

Step 4: B receives ACK. Connection closed.



TCP State Transition Diagram



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