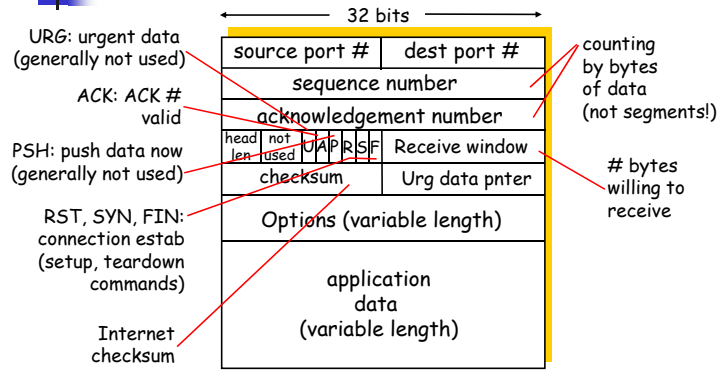
TCP

Kai Shen

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

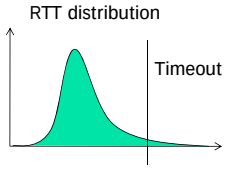
TCP Reliable Data Transfer

- 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 quickly
  - give more recent measurements higher weight

EWMA – Exponentially Weighted Moving Average

- influence of past samples decreases exponentially fast

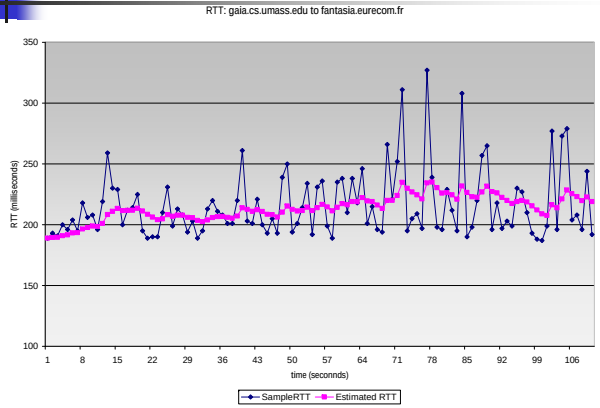
$$\text{ExpectedRTT} = \frac{\text{SampleRTT}_1 + \alpha*\text{SampleRTT}_2 + \alpha^2*\text{SampleRTT}_3 + \ldots \ldots}{1 + \alpha + \alpha^2 + \ldots \ldots}$$

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

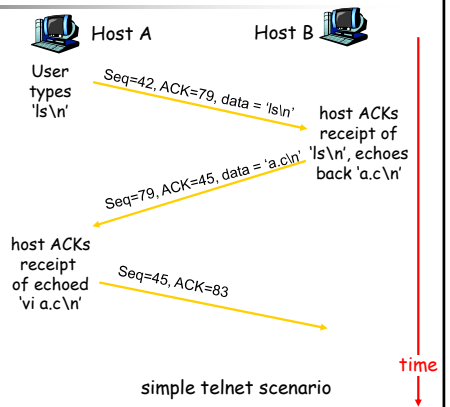
TCP byte-oriented seq. #'s and ACKs

Seq. #'s:

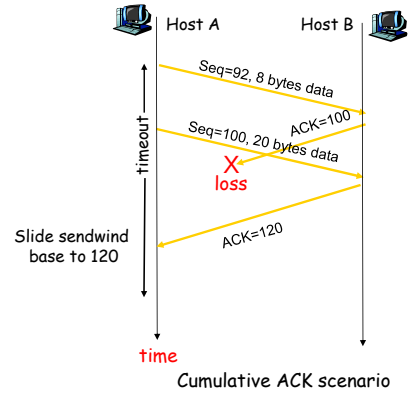
- byte stream "number" of first byte in segment's data

ACKs:

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



TCP in Action: Cumulative ACK

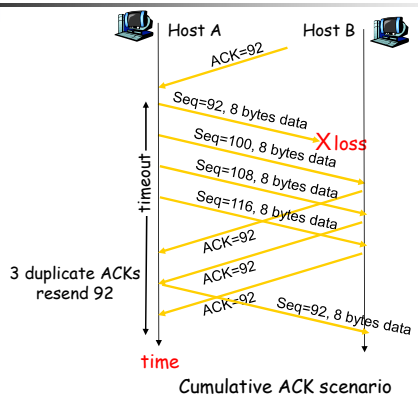


Cumulative ACK scenario

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



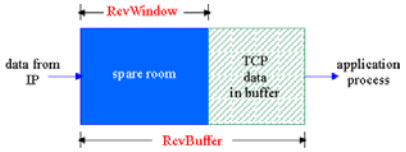
Cumulative ACK scenario

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

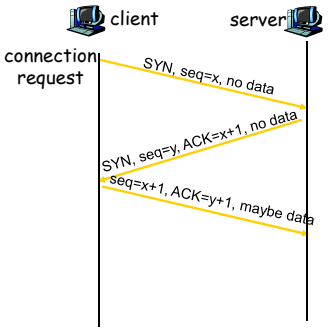
TCP Connection Establishment

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:

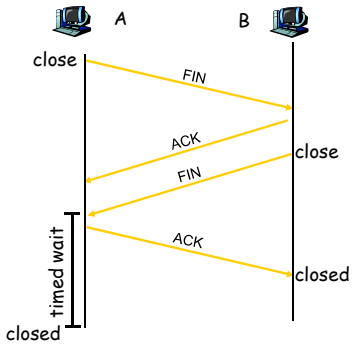
close socket: **close(sockfd);**

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

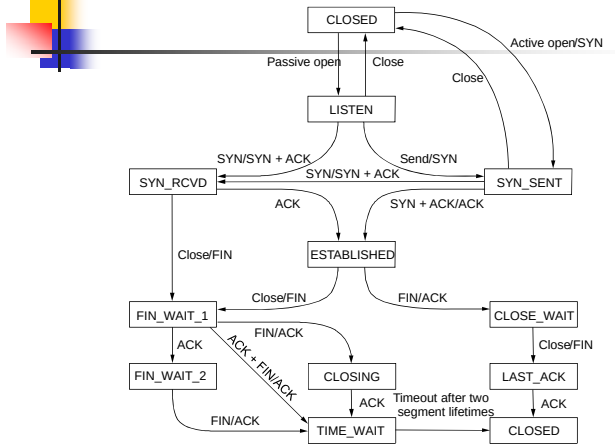
Step 2: B (passive closing host) receives FIN, replies with ACK. Closes connection, sends FIN.

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



Disclaimer

- Parts of the lecture slides contain original work of James Kurose, Larry Peterson, and Keith Ross. The slides are intended for the sole purpose of instruction of computer networks at the University of Rochester. All copyrighted materials belong to their original owner(s).