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

<table>
<thead>
<tr>
<th>Field</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>source port #</td>
<td>16-bit source port number</td>
</tr>
<tr>
<td>dest port #</td>
<td>16-bit destination port number</td>
</tr>
<tr>
<td>sequence number</td>
<td>32-bit sequence number</td>
</tr>
<tr>
<td>acknowledgement number</td>
<td>32-bit acknowledgement number</td>
</tr>
<tr>
<td>urgent data</td>
<td>1-bit URG flag</td>
</tr>
<tr>
<td>data</td>
<td>variable length of application data</td>
</tr>
<tr>
<td>checksum</td>
<td>32-bit checksum</td>
</tr>
<tr>
<td>receive window</td>
<td>16-bit number of bytes receiver can accept</td>
</tr>
<tr>
<td>urg data ptr</td>
<td>16-bit pointer of urgent data</td>
</tr>
<tr>
<td>options</td>
<td>variable length of options</td>
</tr>
</tbody>
</table>

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 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)
  - one challenge is that 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 (premature 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

\[
\text{ExpectedRTT} = \frac{\text{SampleRTT}_1 + \alpha \cdot \text{SampleRTT}_2 + \alpha^2 \cdot \text{SampleRTT}_3 + \ldots}{1 + \alpha + \alpha^2 + \ldots}
\]

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

\[
\Rightarrow \text{ExpectedRTT} = \alpha \cdot \text{ExpectedRTT}_{\text{last}} + (1 - \alpha) \cdot \text{SampleRTT}_1
\]

- typical value in TCP: \( \alpha = 0.875 \)
Example RTT Estimation

RTT: gaia.cs.umass.edu to fantasia.eurecom.fr

Sample RTT
Estimated RTT

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

simple telnet scenario
TCP in Action: Cumulative ACK

- Time-out period often relatively long:
  - long delay before sending 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

- Fast Retransmission

Outline

- segment structure
- reliable data transfer
- flow control
- connection management
TCP Flow Control

- Receive side of TCP connection has a receive buffer.
- Application 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

- **CLOSED**
- **LISTEN**
  - Passive open
  - Close
  - Active open/SYN
- **SYN_RCVD**
  - SYN/SYN + ACK
  - SYN/SYN + ACK
  - SYN + ACK/ACK
  - SYN/SYN + ACK
  - ACK
- **SYN_SENT**
  - Send/SYN
  - SYN/SYN + ACK
  - SYN + ACK/ACK
  - SYN/SYN + ACK
- **ESTABLISHED**
  - Send/SYN
  - SYN/SYN + ACK
  - SYN + ACK/ACK
  - SYN/SYN + ACK
  - ACK
- **CLOSE_WAIT**
  - Close/FIN
  - FIN/ACK
  - Timeout after two segment lifetimes
  - ACK
- **LAST_ACK**
  - Close/FIN
  - FIN/ACK
  - Timeout after two segment lifetimes
  - ACK
- **FIN_WAIT_2**
  - Close/FIN
  - FIN/ACK
  - Timeout after two segment lifetimes
  - ACK
- **FIN_WAIT_1**
  - Close/FIN
  - FIN/ACK
  - Timeout after two segment lifetimes
  - ACK
- **TIME_WAIT**
  - Close/FIN
  - FIN/ACK
  - Timeout after two segment lifetimes
  - ACK
- **CLOSED**

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