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Chapter 3 outline

- 3.1 Transport-layer services
- 3.2 Multiplexing and demultiplexing
- 3.3 Connectionless transport: UDP
- 3.4 Principles of reliable data transfer
- 3.5 Connection-oriented transport: TCP
  - segment structure
  - reliable data transfer
  - flow control
  - connection management
- 3.6 Principles of congestion control
- 3.7 TCP congestion control
TCP reliable data transfer

- TCP creates rdt service on top of IP’s unreliable service
- Pipelined segments
- Cumulative acks
- TCP uses single retransmission timer

- Retransmissions are triggered by:
  - timeout events
  - duplicate acks

- Initially consider simplified TCP sender:
  - ignore duplicate acks
  - ignore flow control, congestion control
TCP sender events:

**data rcvd from app:**
- Create segment with seq #
- seq # is byte-stream number of first data byte in segment
- start timer if not already running (think of timer as for oldest unacked segment)
- expiration interval: TimeOutInterval

**timeout:**
- retransmit segment that caused timeout
- restart timer

**Ack rcvd:**
- If acknowledges previously unacked segments
  - update what is known to be acked
  - start timer if there are outstanding segments
NextSeqNum = InitialSeqNum
SendBase = InitialSeqNum

loop (forever) {
    switch(event)

    event: data received from application above
        create TCP segment with sequence number NextSeqNum
        if (timer currently not running)
            start timer
        pass segment to IP
        NextSeqNum = NextSeqNum + length(data)

    event: timer timeout
        retransmit not-yet-acknowledged segment with
        smallest sequence number
        start timer

    event: ACK received, with ACK field value of y
        if (y > SendBase) {
            SendBase = y
            if (there are currently not-yet-acknowledged segments)
                start timer
        }

} /* end of loop forever */
Fast Retransmit

- Time-out period often relatively long:
  - long delay before resending lost packet
- Detect lost segments via duplicate ACKs.
  - Sender often sends many segments back-to-back
  - If segment is lost, there will likely be many duplicate ACKs.
- If sender receives 3 ACKs for the same data, it supposes that segment after ACKed data was lost:
  - **fast retransmit**: resend segment before timer expires
Fast retransmit algorithm:

**event**: ACK received, with ACK field value of \( y \)

```java
if (y > SendBase) {
    SendBase = y
    if (there are currently not-yet-acknowledged segments)
        start timer
} else {
    increment count of dup ACKs received for \( y \)
    if (count of dup ACKs received for \( y = 3 \)) {
        resend segment with sequence number \( y \)
    }
}
```

- a duplicate ACK for already ACKed segment
- fast retransmit
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TCP Flow Control

- Receive side of TCP connection has a receive buffer:

  - App process may be slow at reading from buffer

- Flow control:
  - Sender won't overflow receiver's buffer by transmitting too much, too fast
  - Speed-matching service: matching the send rate to the receiving app's drain rate
TCP Flow control: how it works

- Rcvr advertises spare room by including value of RcvWindow in segments
- Sender limits unACKed data to RcvWindow
  - guarantees receive buffer doesn’t overflow

(Suppose TCP receiver discards out-of-order segments)

- spare room in buffer
  - \( \text{RcvWindow} \)
  - \( \text{RcvBuffer} - [\text{LastByteRcvd} - \text{LastByteRead}] \)
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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
  ```java
  Socket clientSocket = new Socket("hostname","port number");
  ```

- **server:** contacted by client
  ```java
  Socket connectionSocket = welcomeSocket.accept();
  ```

**Three way handshake:**

**Step 1:** client host sends TCP SYN segment to server
  - specifies initial seq #
  - no data

**Step 2:** server 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 Management (cont.)

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.
TCP Connection Management (cont.)

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, can handle simultaneous FINs.
TCP Connection Management (cont)

TCP client lifecycle

TCP server lifecycle