Chapter 3
Transport Layer

A note on the use of these ppt slides:
We're making these slides freely available to all (faculty, students, readers). They're in powerpoint form so you can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:
- If you use these slides (e.g., in a class) in substantially unaltered form, that you mention their source (after all, we'd like people to use our book!)
- If you post any slides in substantially unaltered form on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach Featuring the Internet, 2nd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2002.

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: Overview

RFCs: 793, 1122, 1323, 2018, 2581

point-to-point:
one sender, one receiver

reliable, in-order *byte steam:*
no "message boundaries"

pipelined:
TCP congestion and flow control set window size

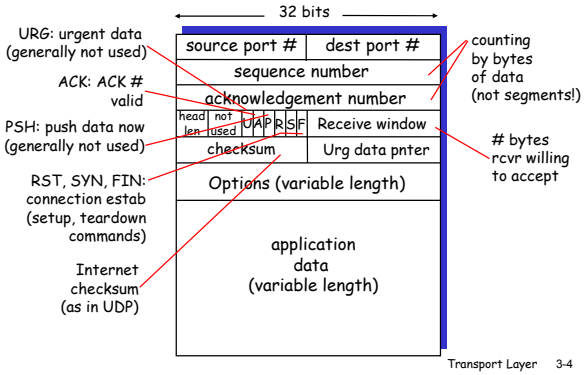
send & receive buffers

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

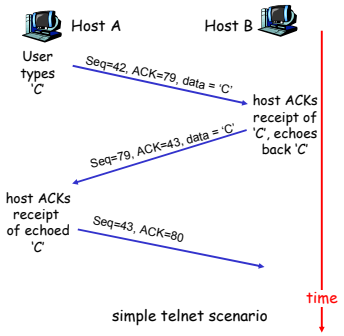


TCP seq. #'s and ACKs

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

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 */
```

TCP sender (simplified)

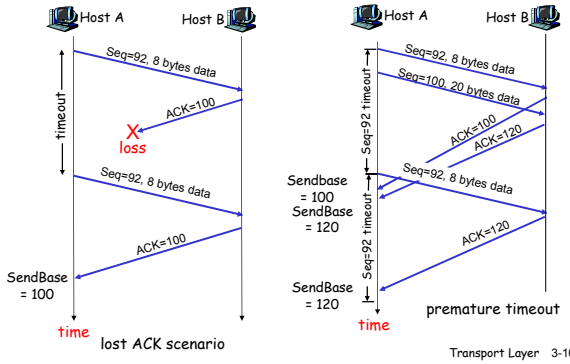
Comment:

- SendBase-1: last cumulatively ack'ed byte

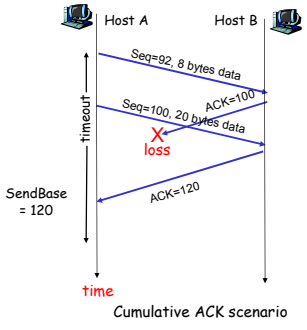
Example:

- SendBase-1 = 71; y= 73, so the rcvr wants 73+ ; y > SendBase, so that new data is acked

TCP: retransmission scenarios



TCP retransmission scenarios (more)



TCP ACK generation [RFC 1122, RFC 2581]

Event at Receiver	TCP Receiver action
Arrival of in-order segment with expected seq #. All data up to expected seq # already ACKed	Delayed ACK. Wait up to 500ms for next segment. If no next segment, send ACK
Arrival of in-order segment with expected seq #. One other segment has ACK pending	Immediately send single cumulative ACK, ACKing both in-order segments
Arrival of out-of-order segment higher-than-expect seq. # . Gap detected	Immediately send duplicate ACK, indicating seq. # of next expected byte
Arrival of segment that partially or completely fills gap	Immediate send ACK, provided that segment startsat lower end of gap

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
        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

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 Flow Control

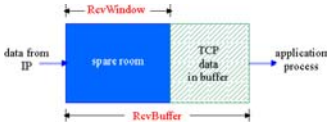
receive side of TCP connection has a receive buffer:

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



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

spare room in buffer

= `RcvWindow`

= `RcvBuffer-[LastByteRcvd - LastByteRead]`

Rcvr advertises spare room by including value of `RcvWindow` in segments

Sender limits unACKed data to `RcvWindow`
- guarantees receive buffer doesn't overflow

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 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

```
Socket clientSocket = new
Socket("hostname","port
number");
```

server: contacted by client

```
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.)

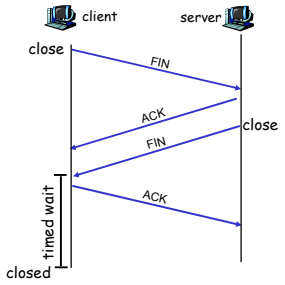
Closing a connection:

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.



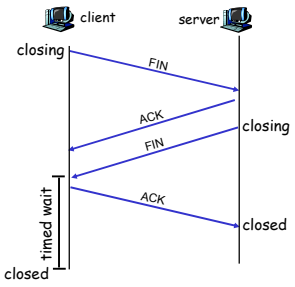
TCP Connection Management (cont.)

Step 3: client receives FIN, replies with ACK.

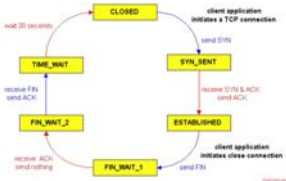
Enters "timed wait" - will respond with ACK to received FINs

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