# Transport Layer



- this layer supports two protocols: UDP and TCP.

- UDP (User Datagram Protocol): supports connectionless communication within applications

- TCP (Transmission Control Protocol): supports connection communication within applications

# Appl. Servers on Top of UDP 38

- appl. server aps is deployed in well-known host sh on top of well-known low-numbered UDP port i

- aps is always running in sh

- initially aps allocates UDP port i and any UDP socket ss and binds ss to i and adds entry (port = i, socket = ss) to UDP socket table in sh

- when sh rcvs a UDP segment whose src is (ch, j) and whose dst is (sh, i), sh checks its socket table and adds rcvd segment to in-bff of ss

- later, aps rcvs the rcvd segment, prepares a reply whose src is (sh, i) and whose dst is (ch, j), and sends the reply as a UDP segment to (ch, j)

# Appl. Clients on Top of UDP 

- appl. client apc is deployed in any client host ch on top of any high-numbered UDP port j

- apc runs, only when needed, in any ch

- when apc runs, it allocates any UDP port j and any UDP socket cs, binds cs to j, and adds entry (port=j, socket=cs) to UDP socket table in ch

- now apc can send a UDP segment to the appl. server aps by making the src of this segment (ch, j) and its dst (sh, i)

- later, apc rcvs a reply to its sent segment from the in-bff of socket cs and removes the entry (port=j, socket=ss) from the socket table of ch.

# UDP Segments

- each UDP segment has five fields:
  - UDP header:
    - src UDP port number
    - dst UDP port number
    - length of segment
    - checksum of segment
  - appl. msg

  (all five fields together: UDP segment)

- length of UDP segment is number of Bytes in segment (UDP header + appl. msg)

- checksum of UDP segment is used to detect (most) end-to-end corruptions in the segment

# Objectives of UDP



- addressing of applications running on top of UDP

- end-to-end detection of (most) corruptions in UDP segments

- "best effort" data transfer

# Objectives of TCP



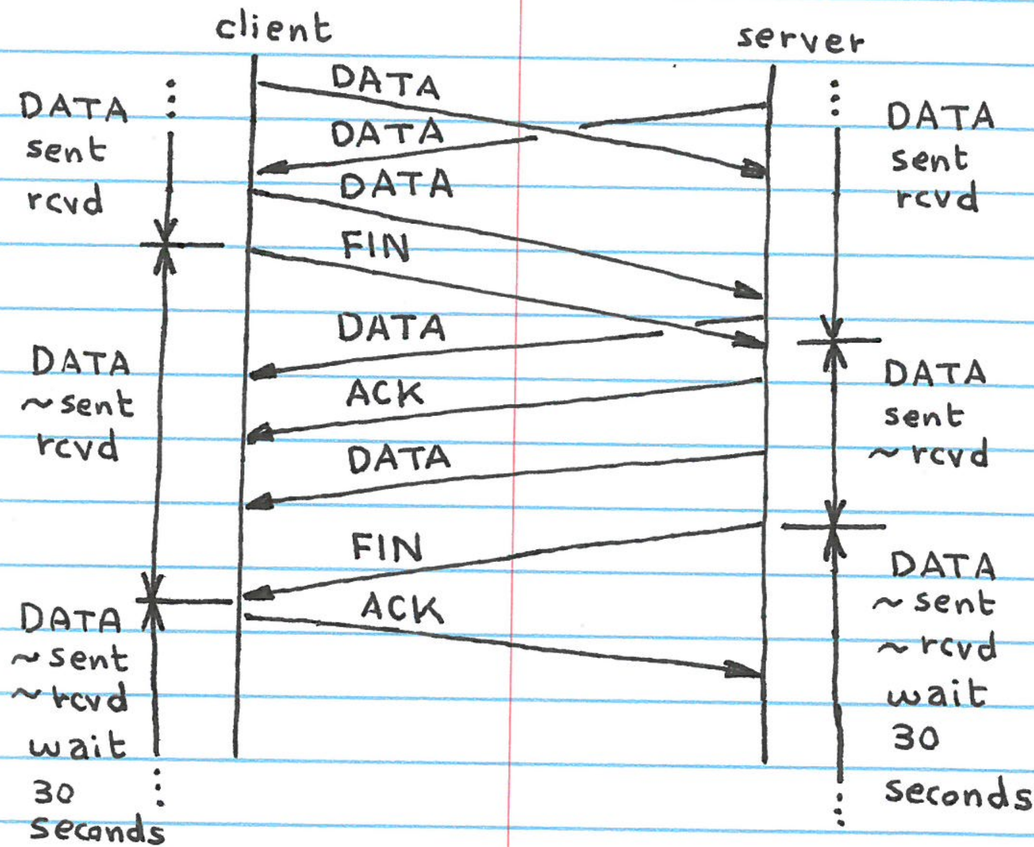
- addressing of applications running on top of TCP
- end-to-end detection of (most) corruptions in TCP segments
- connection management (i.e. establishment, removal and reset)
- control of seq#'s and ack's in TCP segments
- reliable data transfer
- flow control
- congestion control

# TCP Connection Establishment

- **server sh:**
  add entry (src = any , dst (sh, i), ss) to TCP socket table of sh. (ss is the welcome socket.)
- **client ch1:**
  add entry (src = (sh, i), dst = (ch1, j1), cs1) to TCP socket table of ch1. Send SYN seg
  (src = (ch1, j1), dst (sh, i))
- **server sh:**
  rcv SYN seg and add it to in_bff of socket ss in sh. Add entry
  (src = (ch1, j1), dst = (sh, i), ss1)
  to TCP socket table of sh. Send SYN_ACK seg
  (src = (sh, i), dst (ch1, j1))
- **client ch1:**
  rcv SYN_ACK seg and add it to in_bff of socket cs1 in ch1. Send ACK seg
  (src = (ch1, j1), dst = (sh, i))
- **server sh:**
  rcv ACK seg and add it to in_bff of socket ss1 in sh. Send DATA seg
  (src = (sh, i), dst = (ch1, j1))

# Connection Removal






- client and server wait 30 seconds of no activity before they release port j1 and sockets cs1 and ss1 and update their TCP socket tables

# Connection Reset



- if server sh rcvs a TCP seg
  (src = (ch1, j1), dst = (sh, i)) and does not
  find an entry
  (src = (ch1, j1), dst = (sh, i), ss1)
  in the TCP socket table of sh

- then sh sends back a RST seg
  (src = (sh, i), dst = (ch1, j1))

## Seq #'s



- for simplicity, consider TCP connection between two sides: called src and dst. Side src sends Data seg's to dst and side dst sends Ack seg's to src

- each Data seg has, say 100, data bytes, and the data bytes in the Data seg's constitute a byte stream. Consecutive bytes in this stream have consecutive seq#'s. The first seq# in the stream, say 5, is selected at random by src

- each Data seg has seq#, which is the seq# of the first data byte in the seg. Thus, the first two Data seg's sent from src to dst are:

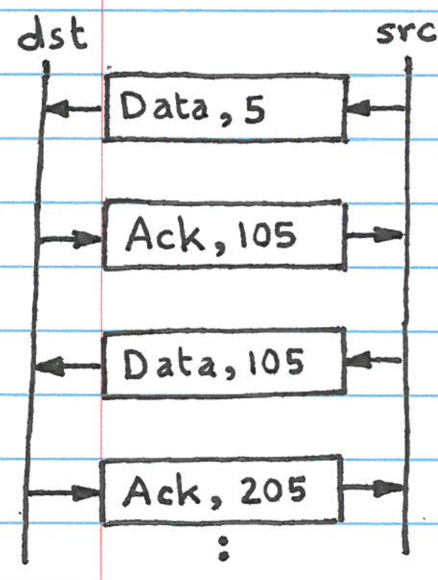
  dst ← (Data,5), (Data,105), ... ← src

# Ack#'s



- each Ack seg sent from dst to src has an ack # which is the seq# of the next data byte that dst expects to rcv from src

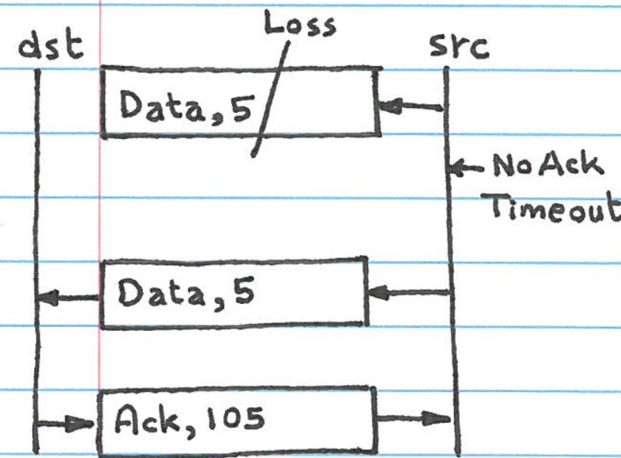
- example:



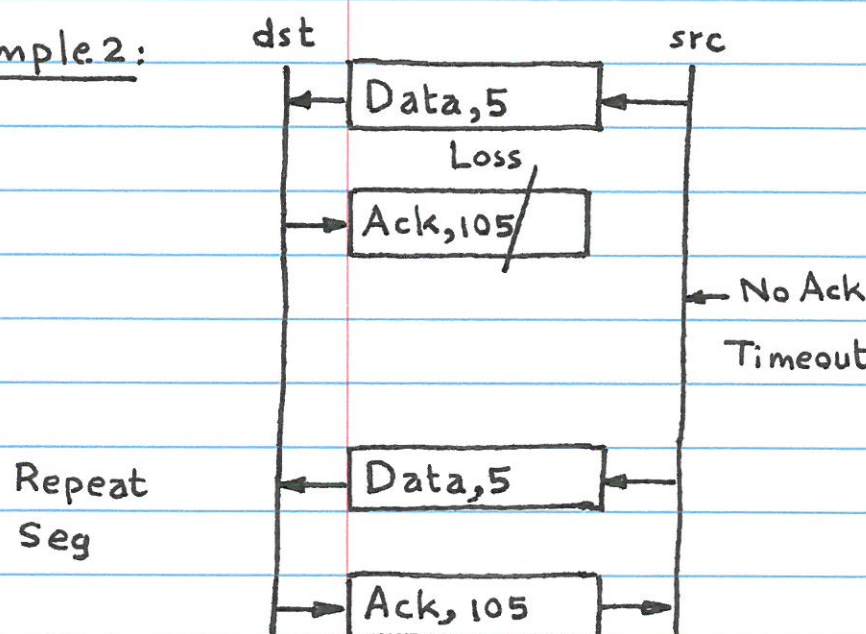

seq # of the first Data seg is 5
Ack # of the first Ack seg is 105

# Examples of Reliable Data Transfer 48

- Example 1:




- Example 2:



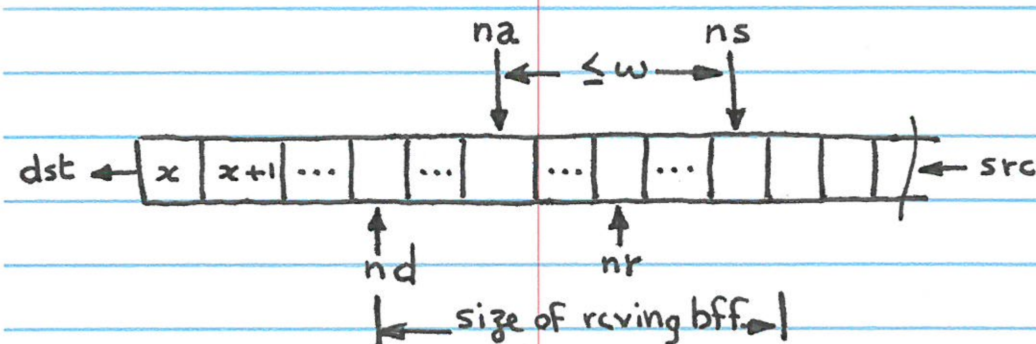
# Sliding Window Protocol



- $x, x+1, \ldots$ seq#'s of data bytes in stream

- na : seq# of next data byte to be acked by dst
  ns : " " " " " " " sent by src
  w : max number of data bytes that have been sent by src and not yet ackd by dst

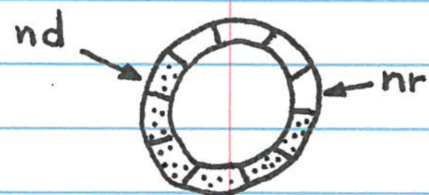
- nd : seq# of next data byte to be read by applic.
  nr : " " " " " " " rcvd by dst




- Next, we discuss how src keeps track of w

# Flow Control

- Side dst has circular bff to store rcvd data bytes from src until these bytes are rcvd by the application:




- Side dst keeps track of the rcv window wr as follows:

  wr := (bff size) – (nr – nd) Bytes

  Side dst includes the latest wr in every Ack seg that dst sends to src

- when side src rcvs an Ack seg with wr from side dst, then src computes w as follows:

  w := max(wr, 1) Bytes

- when wr = 0 in dst, then w = 1 in src and side src can continue to send segments with 1 Byte of data each.

# Congestion Control 

- side src keeps track of window size w as follows:

  $$w := \min(\max(wr, 1), wc) \text{ Bytes}$$

  where wc is <u>congestion window</u> computed by src through alternating phases of <u>slow start</u> and <u>congestion avoidance</u>

- <u>Slow start:</u>
  1. Initially, wc := 1 MSS where MSS is max seg size 1500 Bytes
  2. As long as no sent seg is lost, then wc := 2 * wc every RTT seconds
  3. When a sent seg is lost, then wc := 1 MSS, and Step 2 is repeated until value of wc is half of its value when seg loss is detected, and proceed to Step 1 in congestion avoidance phase

- <u>Congestion Avoidance:</u>
  1. As long as no sent seg is lost, then wc := wc + MSS Bytes every RTT sec.
  2. When a sent seg is lost, then proceed to Step 3 in slow start phase

# TCP Segments



each TCP segment seg has following fields:

- src TCP port (in host that sent seg)
  dst TCP port (in host that rcvd seg)
- seq # of seg
  ack # of seg
- flags: SYN, ACK, FIN, RST
- rcv window wr of host that sent seg
- TCP checksum
- data bytes -- optional