# Connection-oriented Transport: TCP

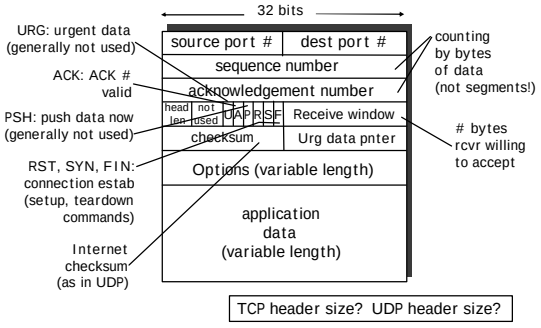
Outline:
- segment structure
- reliable data transfer
- flow control
- connection management

## TCP: Overview

- point-to-point:
  - one sender, one receiver
- reliable data transfer:
  - guaranteed arrival, no error, in order
- pipelined:
  - multiple in-flight segments
- full duplex data:
  - bi-directional data flow in same connection
- connection-oriented:
  - handshaking (exchange of control msgs) to initialize sender, receiver state before data exchange
- flow controlled:
  - sender does not overwhelm receiver
- congestion controlled:
  - sender does not overwhelm the network
- no delay or bandwidth guarantee.



## TCP Segment Structure




TCP header size? UDP header size?



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## TCP Reliable Data Transfer

- TCP provides reliable data transfer service on top of IP's unreliable service
- Pipelined transmissions & cumulative ACKs
- Looks like Go-back-N, however the receiver could buffer out-of-order segments
- TCP uses single retransmission timer
- Retransmissions are triggered by:
  - timeout events
  - duplicate ACKs



## TCP Timeout

Q: how to set TCP timeout value?
- longer than RTT (round trip time)
  - but RTT varies
- too short: premature timeout and unnecessary retransmissions
- too long: slow reaction to segment loss

## Estimating TCP Round Trip Time

Q: how to estimate RTT?

- **SampleRTT**: measured time from segment transmission until ACK receipt
- **SampleRTT** fluctuates, we want estimated RTT "smoother" to avoid short-term spikes
  - average several recent measurements, not just current **SampleRTT**
- we also want to give more recent measurements higher weight in case things do change



## EWMA – Exponentially Weighted Moving Average

$$\begin{aligned}\text{EstimatedRTT} &= \alpha*\text{SampleRTT}_1 \\ &+ \alpha*(1-\alpha)*\text{SampleRTT}_2 \\ &+ \alpha*(1-\alpha)^2*\text{SampleRTT}_3 \\ &+ \alpha*(1-\alpha)^3*\text{SampleRTT}_4 \\ &+ \ldots\ldots\end{aligned}$$

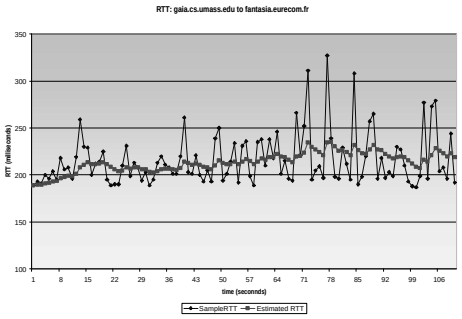
$\text{SampleRTT}_1$ is the most recent sample TTL,
$\text{SampleRTT}_2$ is the next recent sample TTL, etc.

Þ $\text{EstimatedRTT} = (1-\alpha)*\text{EstimatedRTT}_{last} + \alpha*\text{SampleRTT}_1$

- influence of past sample decreases exponentially fast
- typical value: $\alpha = 0.125$



## Example RTT Estimation






## TCP Timeout

Setting the timeout:

- **EstimtedRTT** plus "safety margin"
  - large variation in **EstimatedRTT ->** larger safety margin
- we need to estimate of how much SampleRTT deviates from EstimatedRTT (EWMA):

$$\text{DevRTT} = (1-\beta)*\text{DevRTT}_{last} + \beta*|\text{SampleRTT}-\text{EstimatedRTT}|$$

(typically, $\beta = 0.25$)

Then set timeout interval:

$$\text{TimeoutInterval} = \text{EstimatedRTT} + 4*\text{DevRTT}$$



## TCP Sender Events and Processing

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 un-ACKed segment)
- timeout vale: we just decided it!!

timeout:

- retransmit segment that caused timeout
- restart timer

ACK rcvd:

- If acknowledges previously unacked segments
  - slide sender window
  - start timer if there are outstanding segments



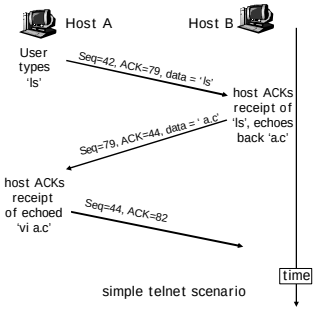
## TCP byte-oriented seq. #'s and ACKs

Seq. #'s:

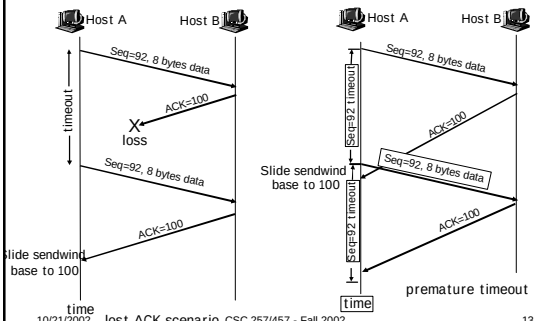
- byte stream "number" of first byte in segment's data

ACKs:

- seq # of next byte expected from other side
- cumulative ACK

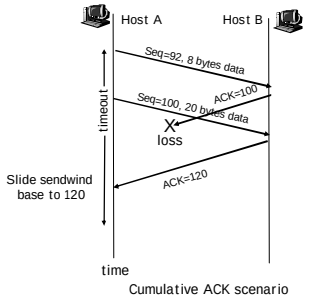


## TCP in Action: Retransmissions






## TCP in Action: Cumulative ACK



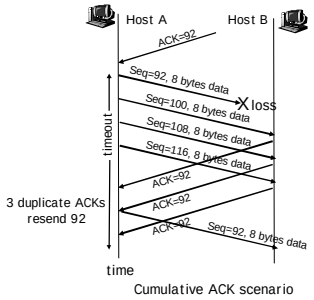



## Fast Retransmission

- 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.
- When receiver receives out-of-order segments, it re-ACK 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



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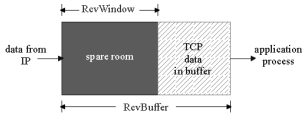
## TCP Flow Control

- receive side of TCP connection has a receive buffer:

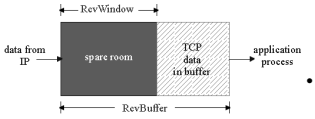



- app process may be slow at reading from buffer

flow control: sender does not 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

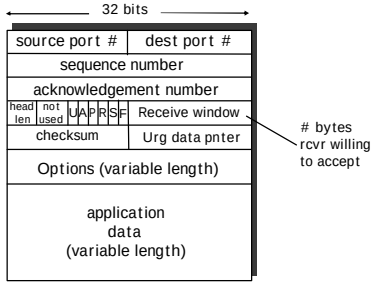
**= RcvWindow**

**= 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



## Where is **RcvWindow** in each segment?



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## 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**)
- MSS is the maximum TCP segment size each side is willing to accept
  - typically the largest segment size fit into a link-layer frame
  - What is MSS for a IPv4 host connected with Ethernet?
- Teardown:
  - freeing up resources after mutually close



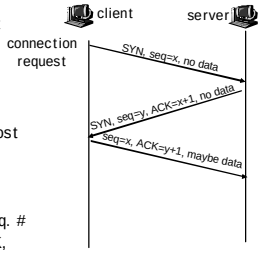
## TCP Connection Establishment

Three way handshake:

Step 1: client (active open) host 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:

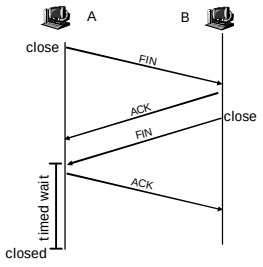
close socket: **close(sockfd);**

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

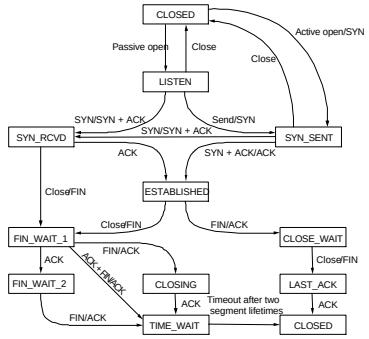
Step 2: B (passive closing host) receives FIN, replies with ACK. Closes connection, sends FIN.

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



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