Lesson 05-03: TCP

CS 326 E Elements of Networking

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Internet Reference Model

Example Protocols		Responsible for
FTP, HTTP, SMTP	Application	application specific needs
TCP, UDP	Transport	process to process data transfer
IP	Network	host to host data transfer across different network
Ethernet, WiFi	Link	data transfer between physically adjacent nodes
802.3 PHY	Physical	bit-by-bit or symbol-by-symbol delivery

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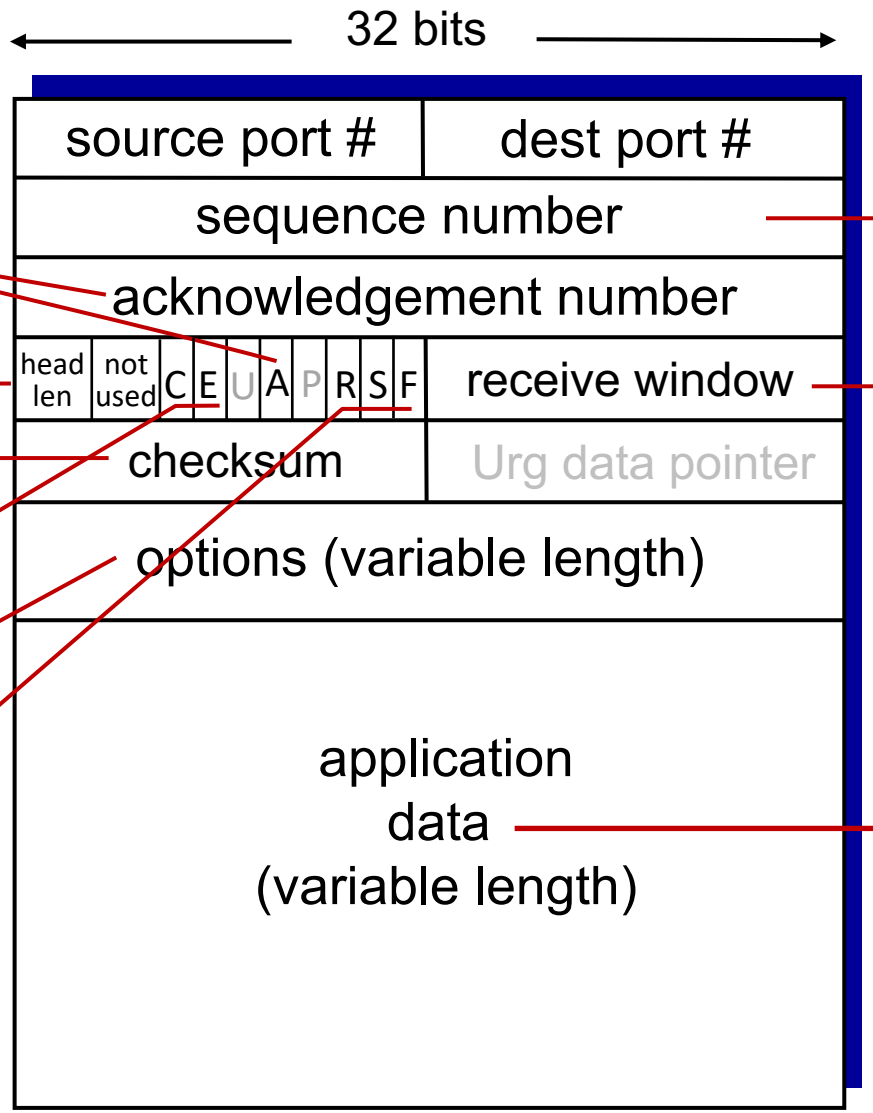
Outline

1. TCP overview

TCP: overview RFCs: 793,1122, 2018, 5681, 7323

- point-to-point:
  - one sender, one receiver
- reliable, in-order byte steam:
  - no “message boundaries"
- full duplex data:
  - bi-directional data flow in same connection
  - MSS: maximum segment size
- cumulative ACKs
  - ACK N acks all packets till N-1 cumulatively
  - ACK N means send me Seq N next
- timeouts
- pipelining:
  - TCP congestion and flow control set window size
- connection-oriented (handshake)
- flow controlled:
  - sender will not overwhelm receiver

TCP segment structure



ACK: seq # of next expected byte; A bit: this is an ACK

length (of TCP header)

Internet checksum

C, E: congestion notification

TCP options

RST, SYN, FIN: connection management

segment seq #: counting bytes of data into bytestream (not segments!)

flow control: # bytes receiver willing to accept

data sent by application into TCP socket

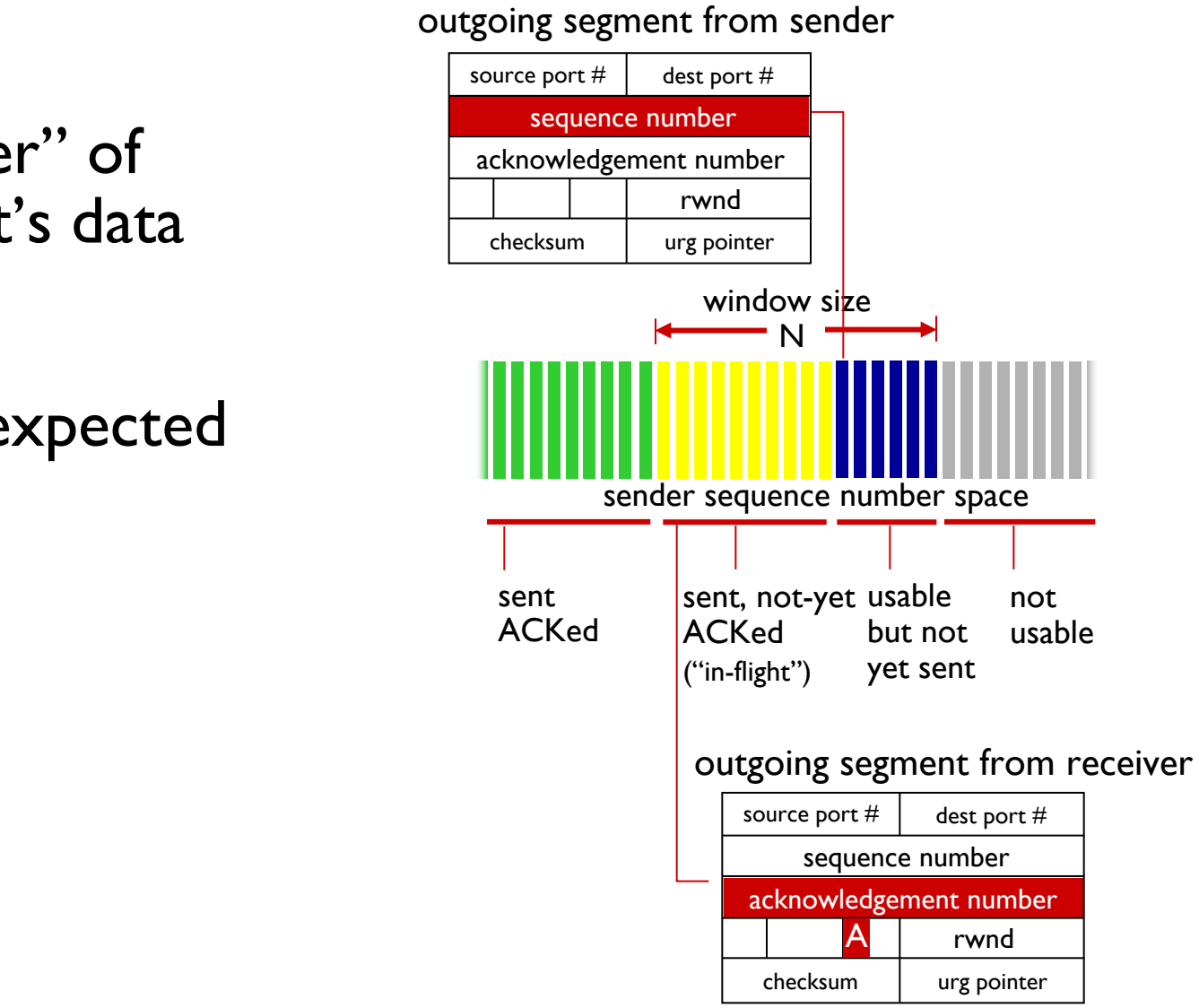
TCP sequence numbers, ACKs

Sequence numbers:

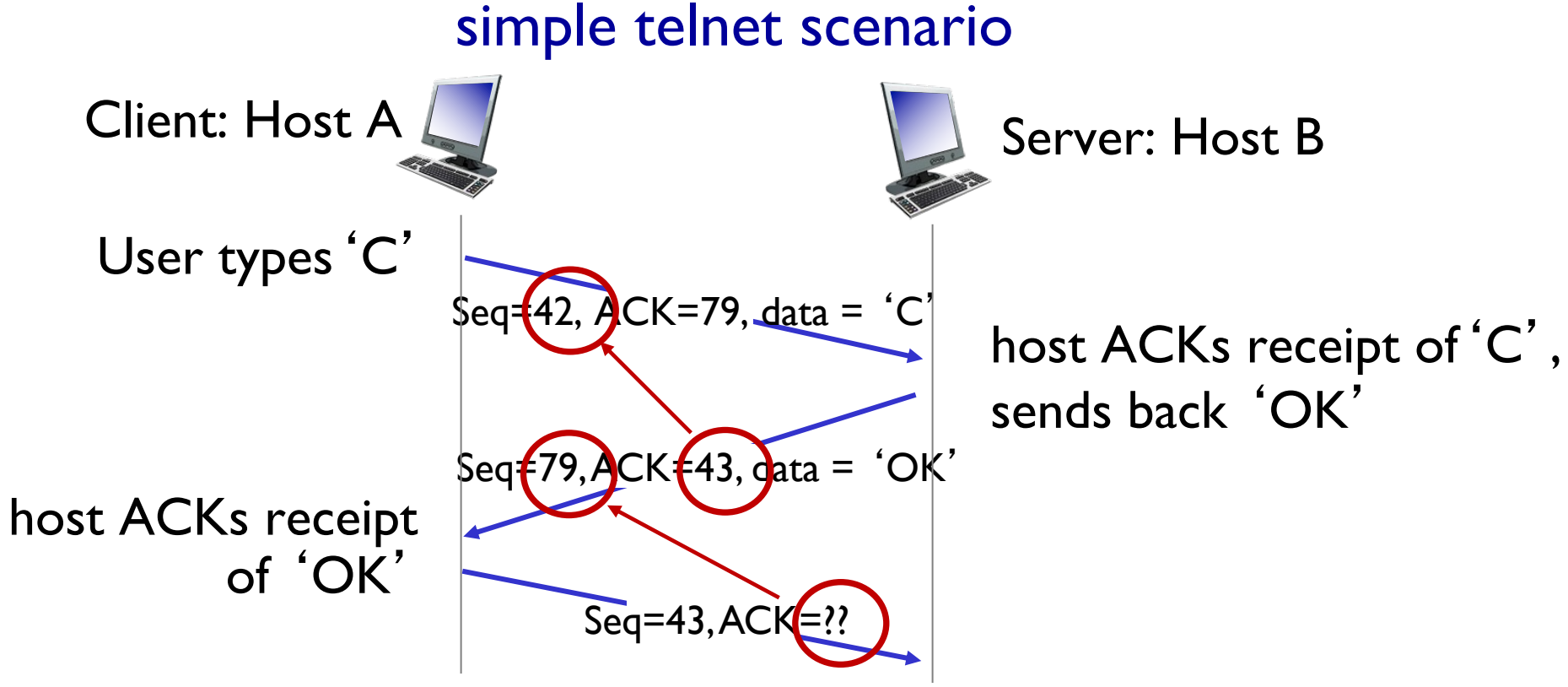
- byte stream "number" of first byte in segment's data

Acknowledgements:

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



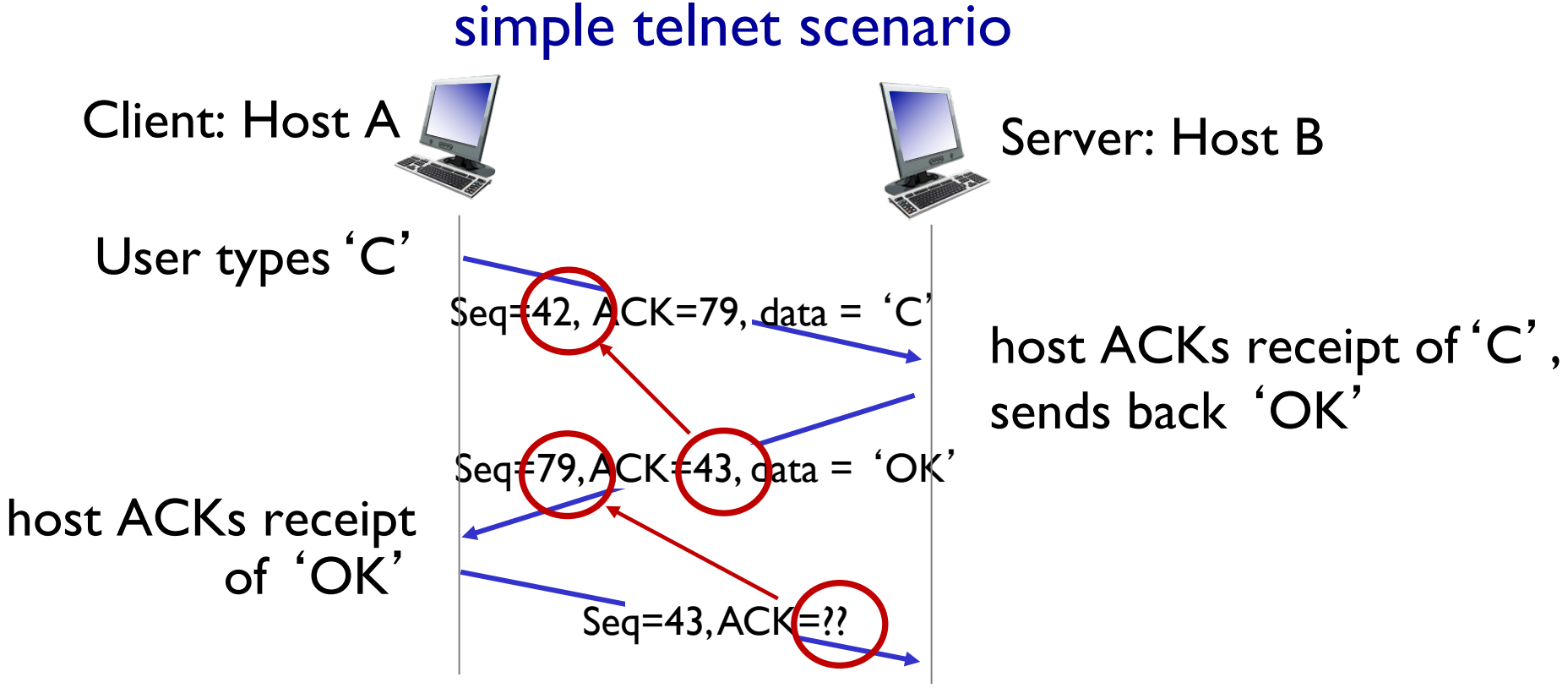
TCP ACK *n* means "please send me Seq *n*"



Seq number is calculated based on bytes sent

Num bytes sent is determined by network condition

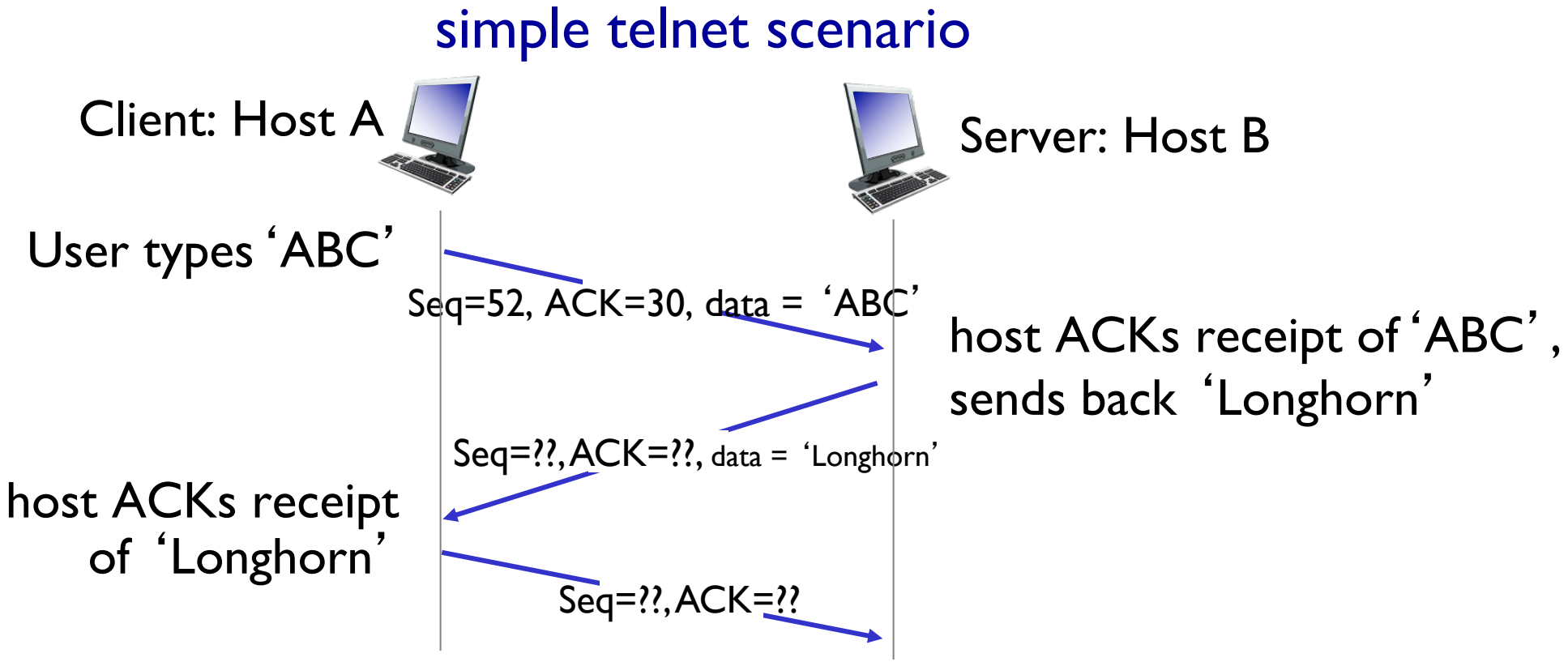
TCP ACKs can piggyback to DATA



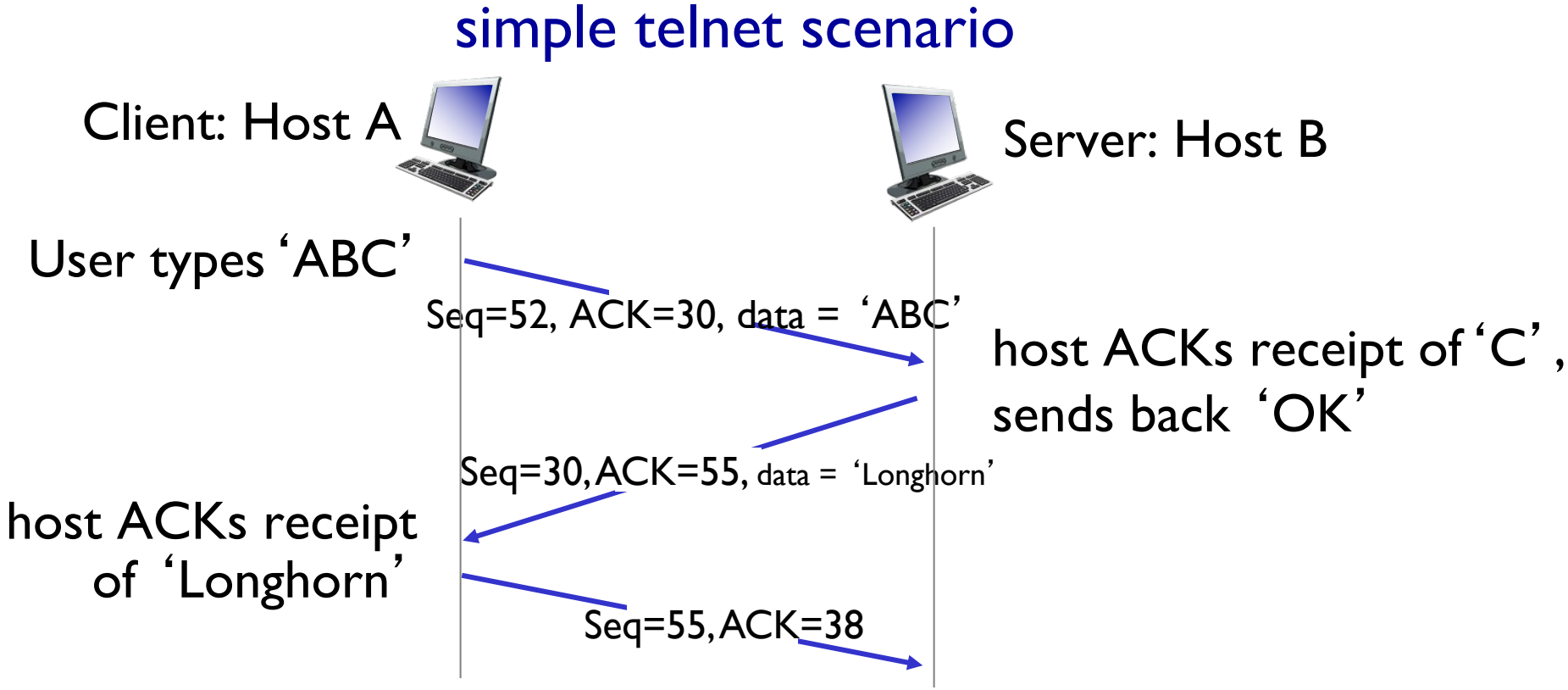
Which segments have the ACKs piggybacked to DATA?

Does the last segment have DATA? Why then seq no?

Practice one more time!



Practice one more time!



Outline

1. TCP overview
2. TCP timeout

How to set TCP timeout value?

- What happens if timeout value is too short?
- What happens if timeout value is too long?
- We know it should be at least longer than… what?

How to set TCP timeout value?

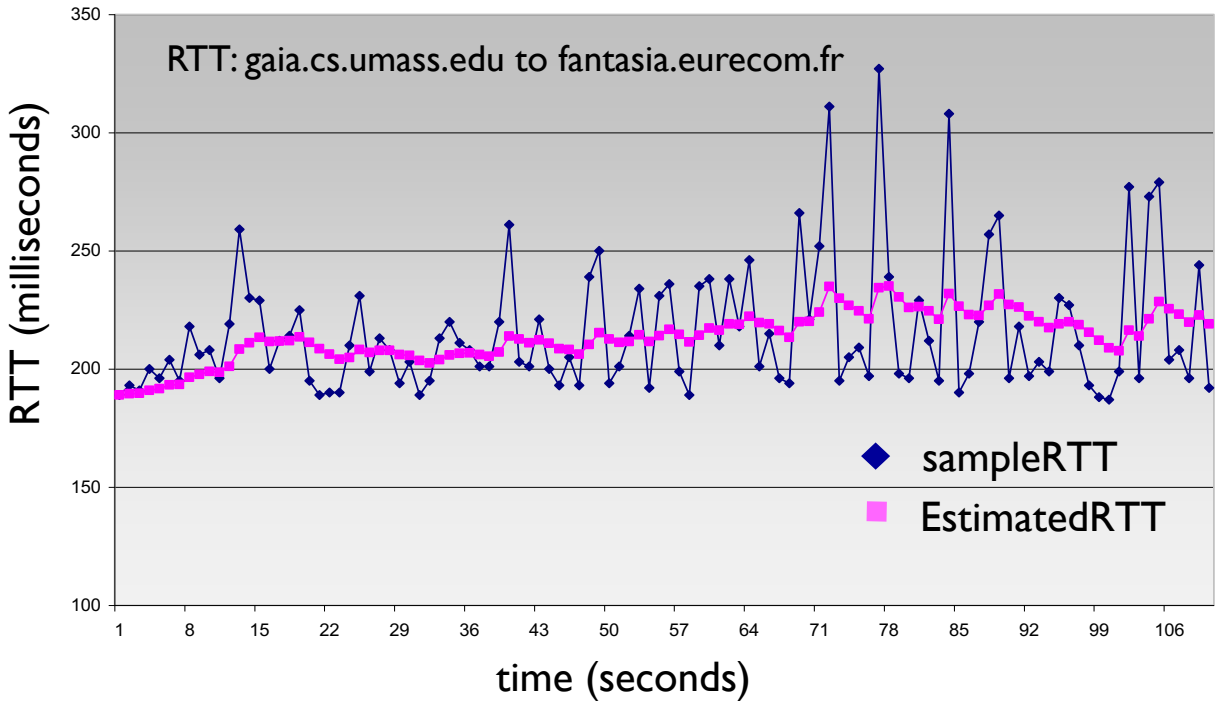
- too short: premature timeout, unnecessary retransmissions
- too long: slow reaction to segment loss
- It should be at least longer than RTT but RTT varies!
- TCP maintains timer for its oldest unACKed segment

TCP uses EWMA of Sample RTT plus safety margin

Estimate RTT uses EWMA to smooth out

$$EstimatedRTT_n = (1-\alpha)*EstimatedRTT_{n-1} + \alpha*SampleRTT_n$$

- exponential weighted moving average (EWMA)
- SampleRTT: measured time from segment transmission until ACK receipt
- influence of past sample decreases exponentially fast
- typical value: $\alpha = 0.125$



In addition, safety margin is added

- timeout interval: EstimatedRTT plus "safety margin"
  - large variation in EstimatedRTT: want a larger safety margin

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

estimated RTT

"safety margin"

- DevRTT: EWMA of SampleRTT deviation from EstimatedRTT:

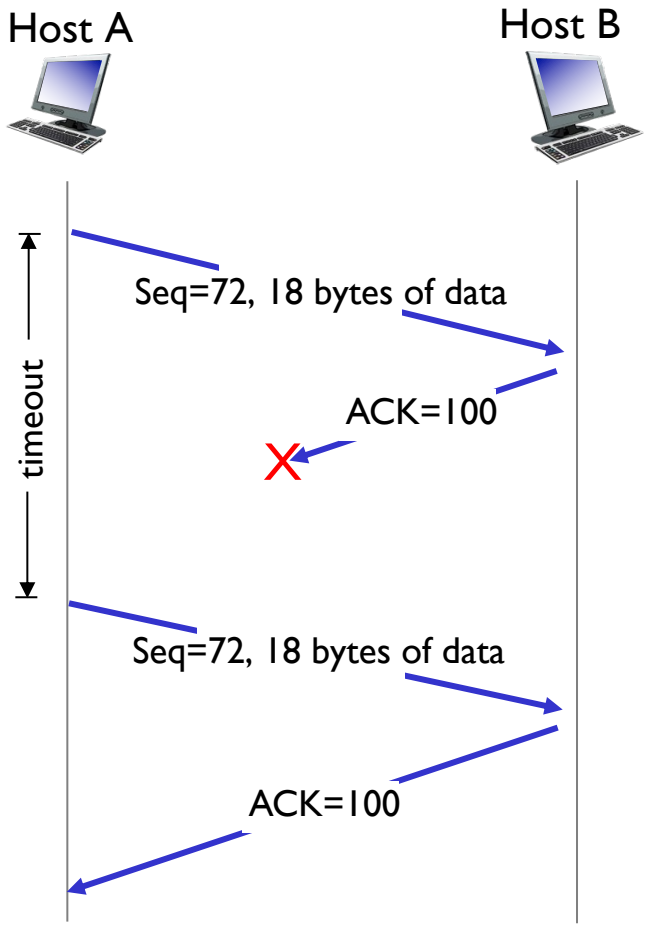
$$\text{DevRTT}_n = (1-\beta)*\text{DevRTT}_{n-1} + \beta*|\text{SampleRTT}_n - \text{EstimatedRTT}_n|$$

(typically, $\beta = 0.25$)

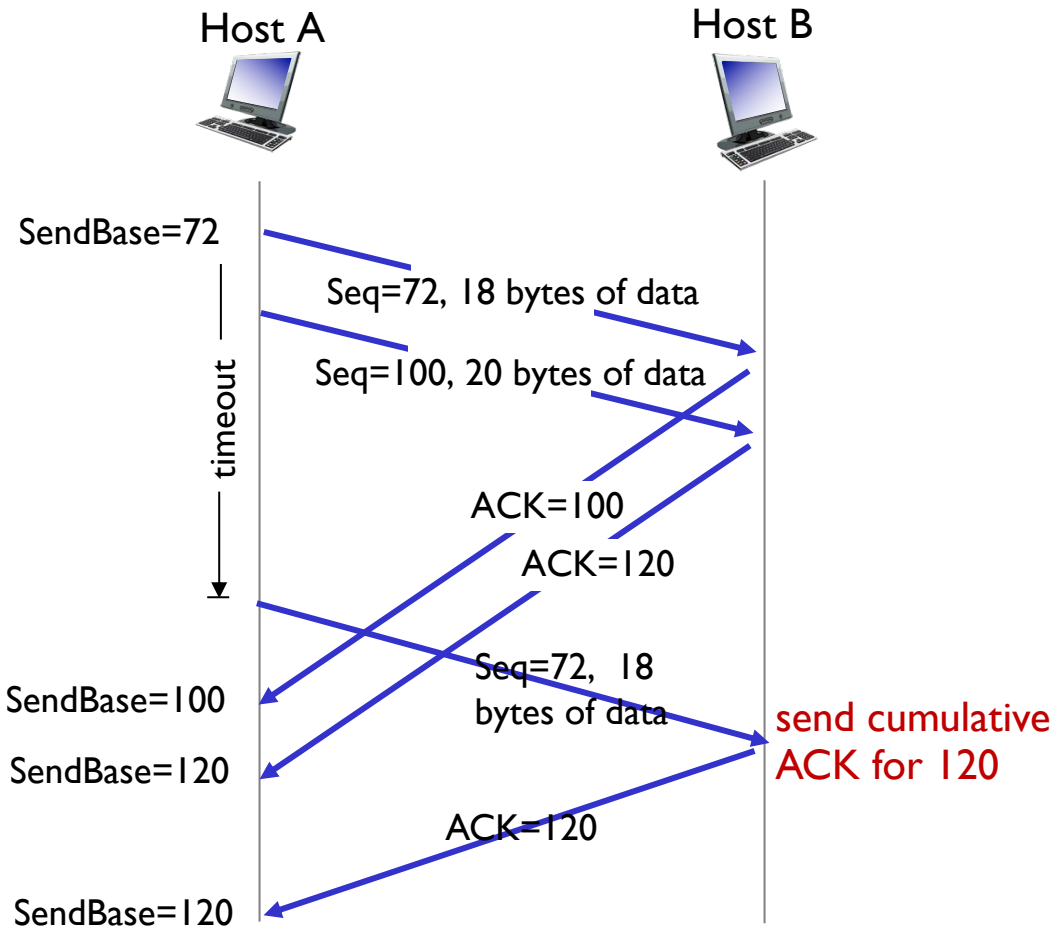
Outline

1. TCP overview
2. TCP timeout
3. TCP retransmissions

TCP: retransmission scenarios

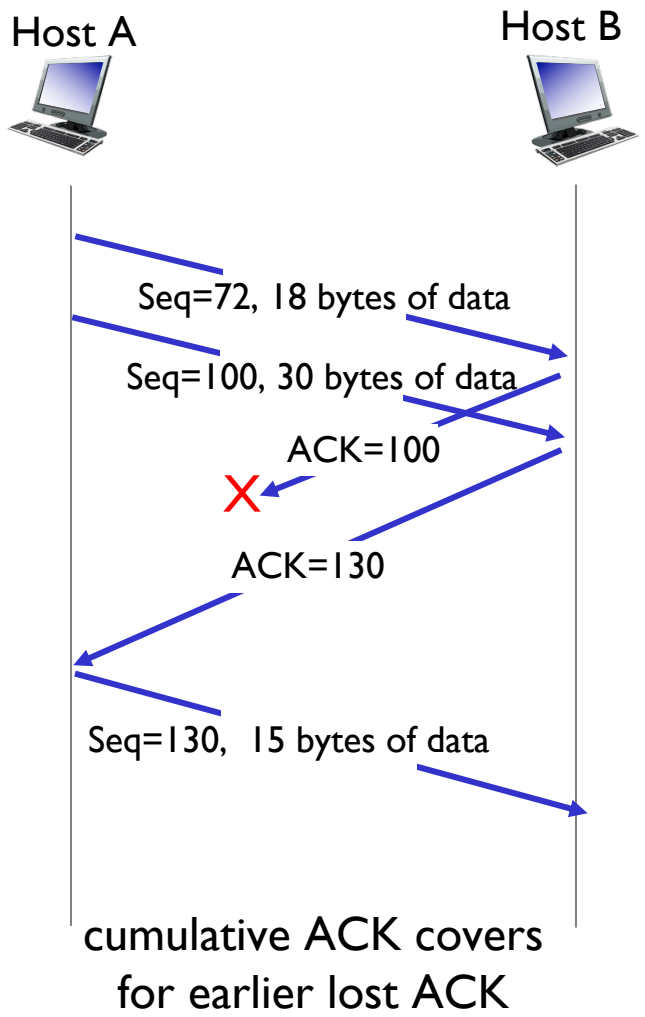


lost ACK scenario



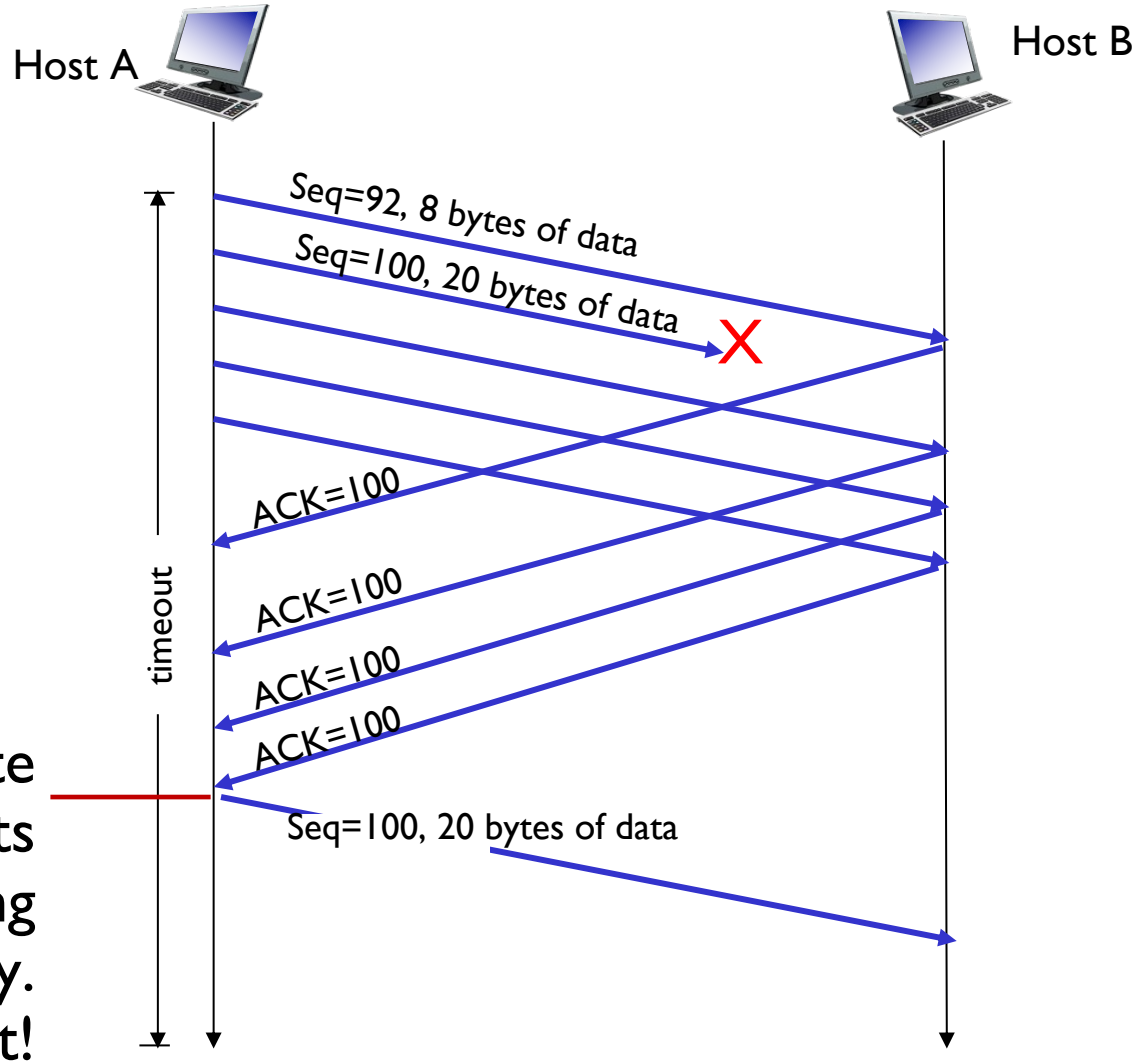
premature timeout

TCP: retransmission scenarios



TCP fast retransmit: upon receiving triple dup ACKs immediately retransmit without timeout

Receipt of three duplicate ACKs indicates 3 segments received after a missing segment – lost segment is likely. So retransmit!



Is it a good idea to retransmit as soon as possible?

- TCP assumes packet is lost upon timeout
- TCP assumes the packet is lost due to congestion

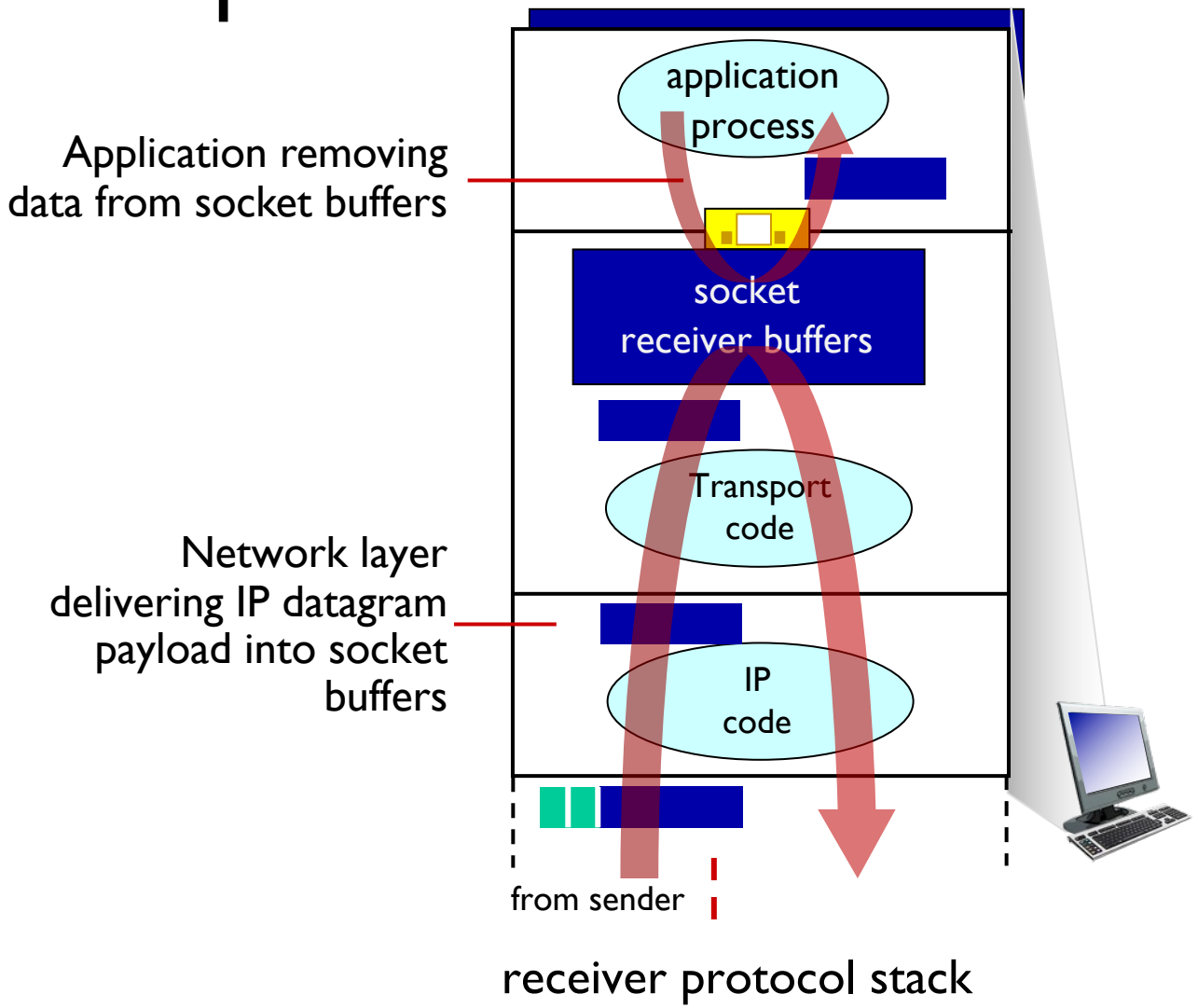
Doubles the timeout interval each time TCP retransmits upon timeout!

Outline

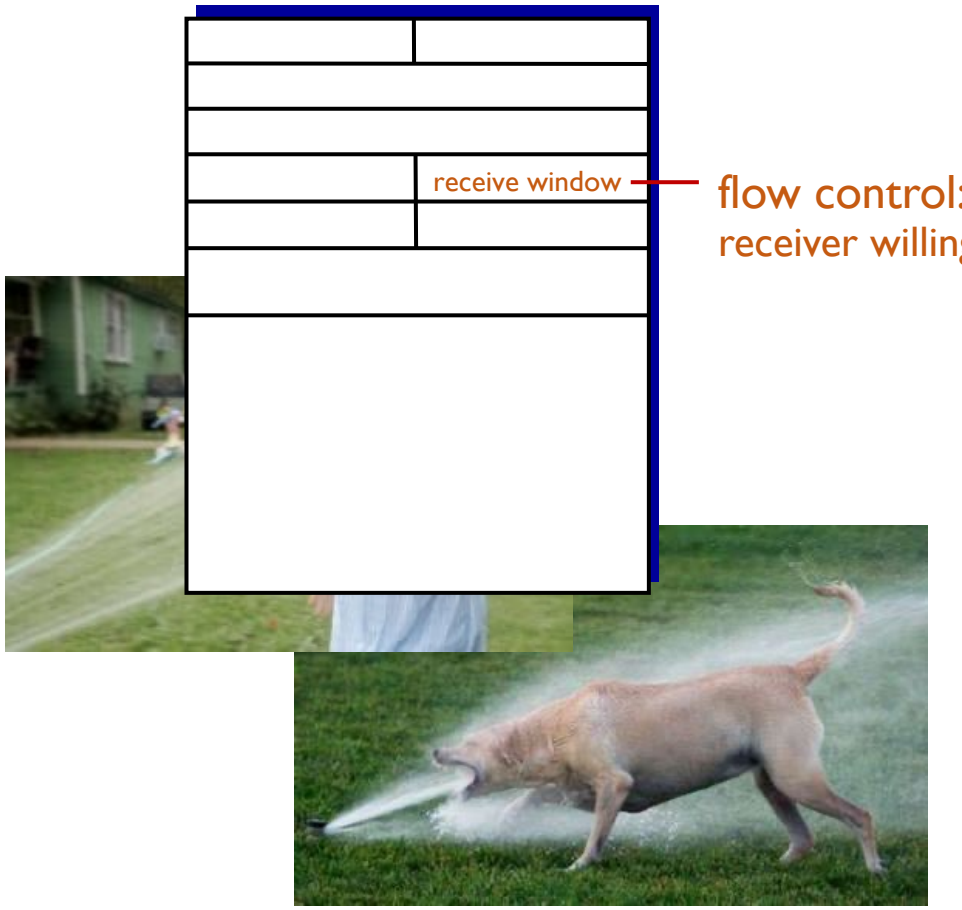
1. TCP overview
2. TCP timeout
3. TCP interesting scenarios
4. TCP flow control

Loss happens if network delivers faster than what application layer can process

Loss was happening in the socket buffer of the receiver!



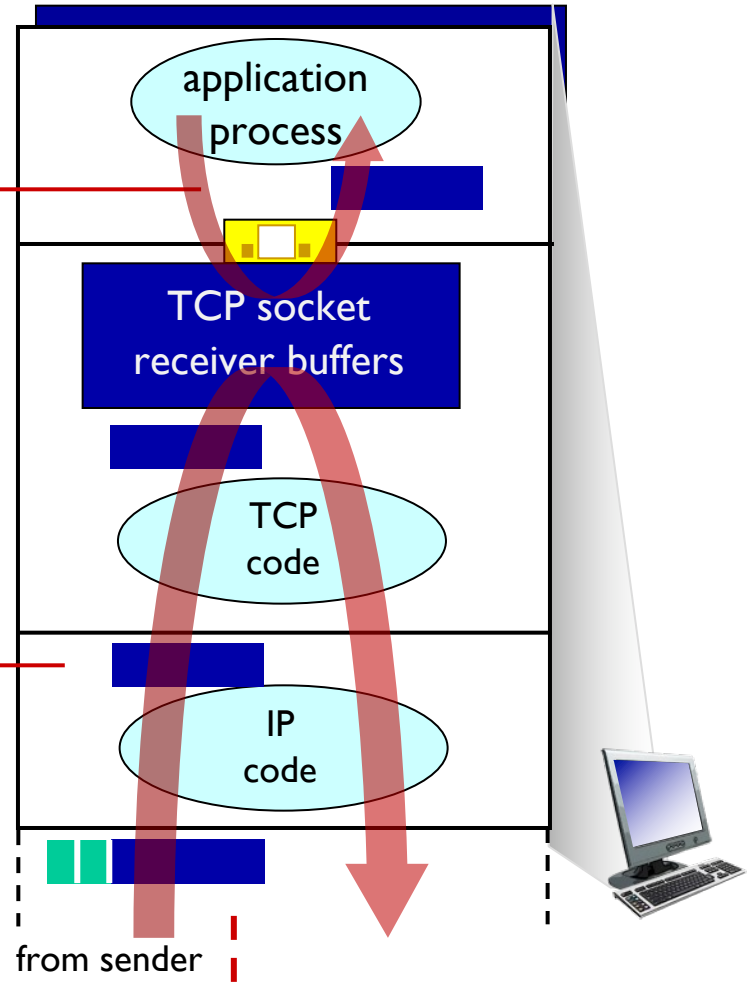
TCP flow control ensures NOT to overflow receiver socket buffer



flow control: # bytes receiver willing to accept

Application removing data from TCP socket buffers

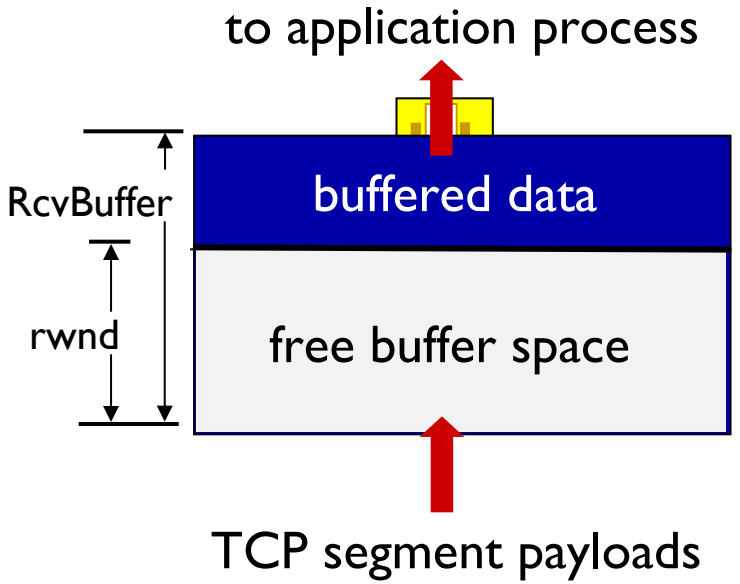
Network layer delivering IP datagram payload into TCP socket buffers



receiver protocol stack

TCP sender limits in-flight packets smaller than rwnd

- TCP receiver "advertises" free buffer space in rwnd field in TCP header
  - RcvBuffer size set via socket options (default 4096 bytes)



TCP receiver-side buffering

Guarantees receiver buffer will not overflow!

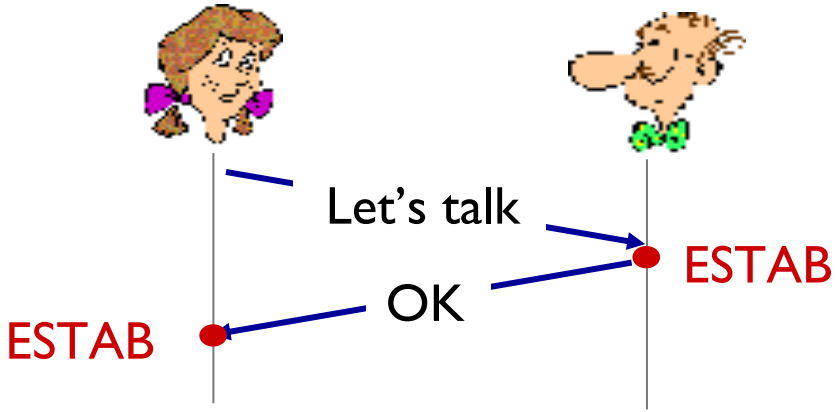
Outline

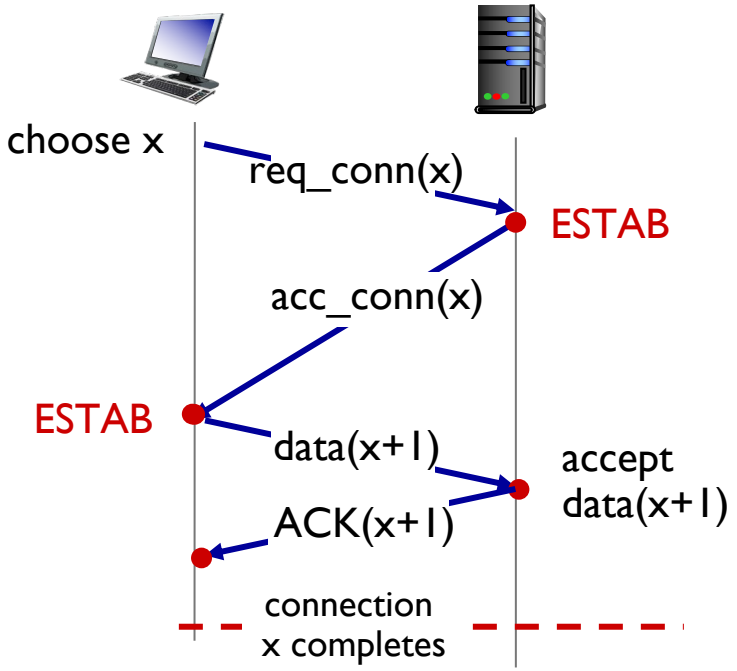
1. TCP overview
2. TCP timeout
3. TCP interesting scenarios
4. TCP flow control
5. TCP connection management

TCP has “handshake” prior to actual data exchange

- agree to establish connection
- agree on connection parameters (e.g., starting seq #s, rwnds)

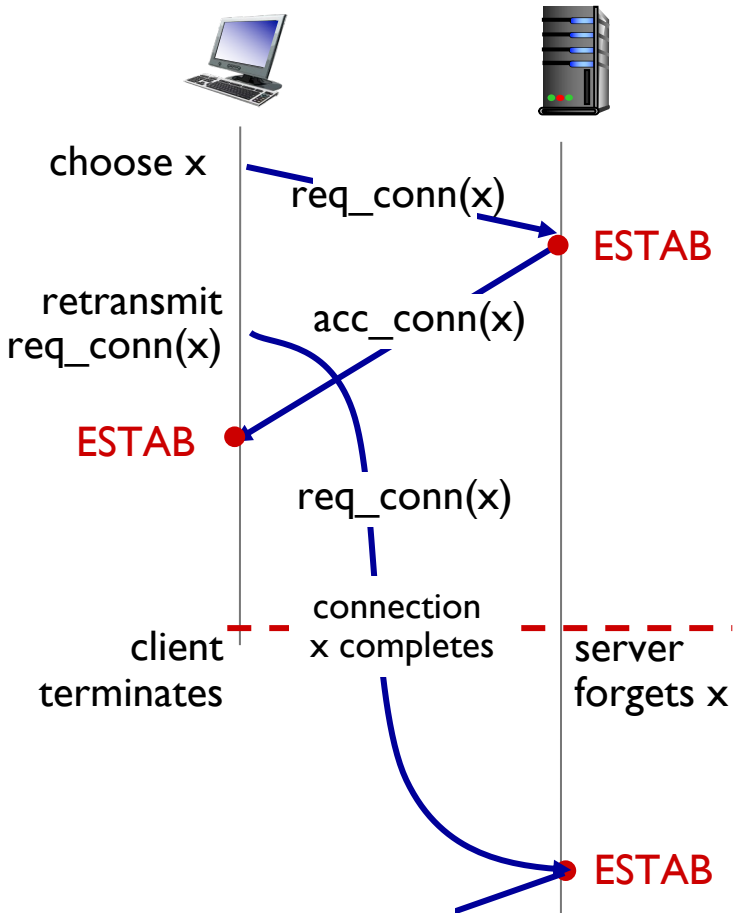
We could use 2-way handshake





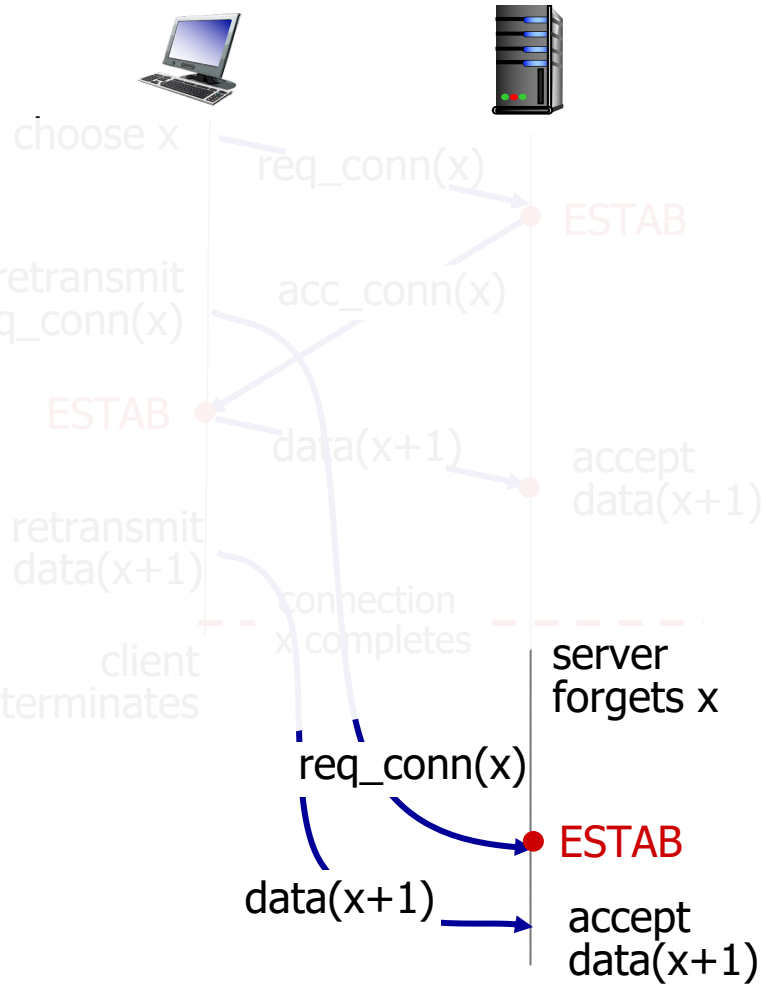
No problem!

2-way handshake is not enough!



Problem: half open connection! (no client)

2-way handshake is not enough!



Problem: dup data accepted!

TCP 3-way handshake

Client state

clientSocket = socket(AF_INET, SOCK_STREAM)

LISTEN

clientSocket.connect((serverName,serverPort))

SYNSENT

ESTAB

Server state

serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind((",serverPort))
serverSocket.listen(1)
connectionSocket, addr = serverSocket.accept()

LISTEN

SYN RCVD

ESTAB

choose init seq num, x
send TCP SYN msg

SYNbit=1, Seq=x

choose init seq num, y
send TCP SYNACK
msg, acking SYN

SYNbit=1, Seq=y
ACKbit=1; ACKnum=x+1

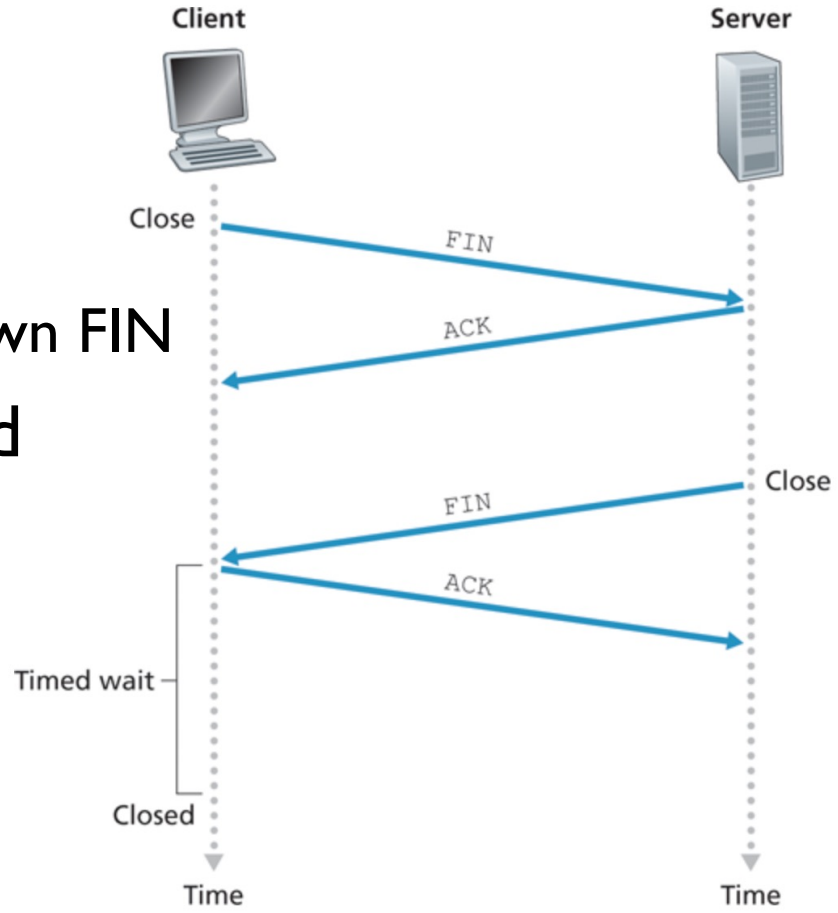
received SYNACK(x)
indicates server is live;
send ACK for SYNACK;
this segment may contain
client-to-server data

ACKbit=1, ACKnum=y+1

received ACK(y)
indicates client is live

Closing a TCP connection

- Send TCP segment with FIN bit = 1
- respond to received FIN with ACK
  - on receiving FIN, ACK can be combined with own FIN
- simultaneous FIN exchanges can be handled



Backup slides

Acknowledgements

Slides are adopted from Kurose' Computer Networking Slides