ECCS-3631
Networks and Data Communications

Module 5-3
Pipeline Protocols
Transmission Control Protocol
TCP Congestion and Flow Control

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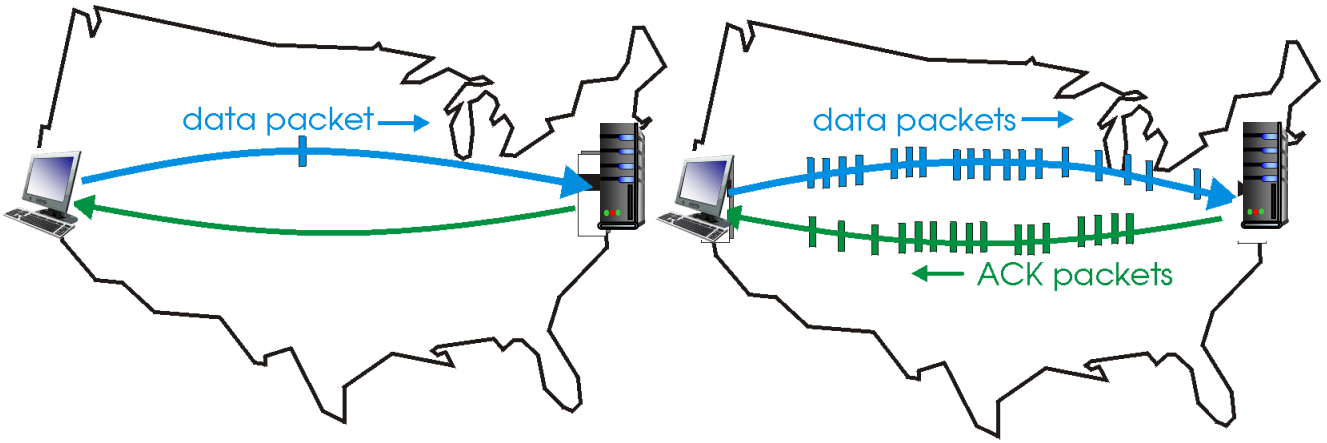
Pipelined Protocols

pipelining: sender allows multiple, "in-flight", yet-to-be-acknowledged packets

- range of sequence numbers must be increased
- buffering at sender and/or receiver



(a) a stop-and-wait protocol in operation

(b) a pipelined protocol in operation

- two generic forms of pipelined protocols: *go-Back-N, selective repeat*

Pipelined Protocol

The sender is allowed to send multiple packets without waiting for acknowledgments. Since the many in-transit sender-to-receiver packets can be visualized as filling a pipeline, this technique is known as pipelining.

Pipelining has the following consequences for reliable data transfer protocols:

- The range of sequence numbers must be increased, since each in-transit packet (not counting retransmissions) must have a unique sequence number and there may be multiple, in-transit, unacknowledged packets.
- The sender and receiver sides of the protocols may have to buffer more than one packet. Minimally, the sender will have to buffer packets that have been transmitted but not yet acknowledged. Buffering of correctly received packets may also be needed at the receiver.
- The range of sequence numbers needed and the buffering requirements will depend on the manner in which a data transfer protocol responds to lost, corrupted, and overly delayed packets.
- Two basic approaches toward pipelined error recovery can be identified: Go-Back-N and selective repeat.

Pipelined Protocol – Seq # and Ack

The sequence number is the byte number of the first byte of data in the TCP packet sent (also called a TCP segment).

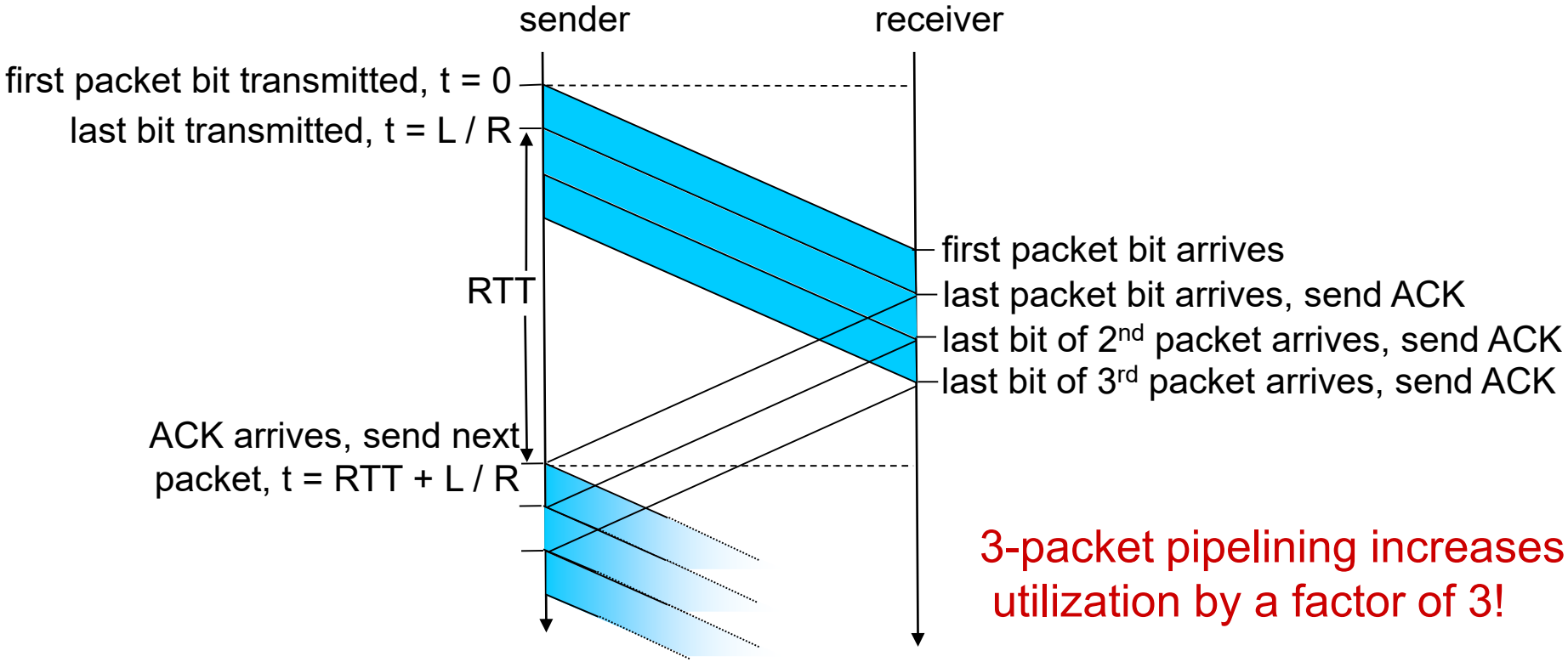
The acknowledgment number is the sequence number of the next byte the receiver expects to receive.

The receiver acknowledging sequence number ***x*** acknowledges receipt of all data bytes less than (but not including) byte number ***x***.

The sequence number is always valid. The acknowledgment number is only valid when the ACK flag is one.

The only time the ACK flag is not set, that is, the only time there is not a valid acknowledgment number in the TCP header, is during the first packet of connection set-up.

Pipelining: increased utilization



3-packet pipelining increases utilization by a factor of 3!

Pipelined Protocols: Overview

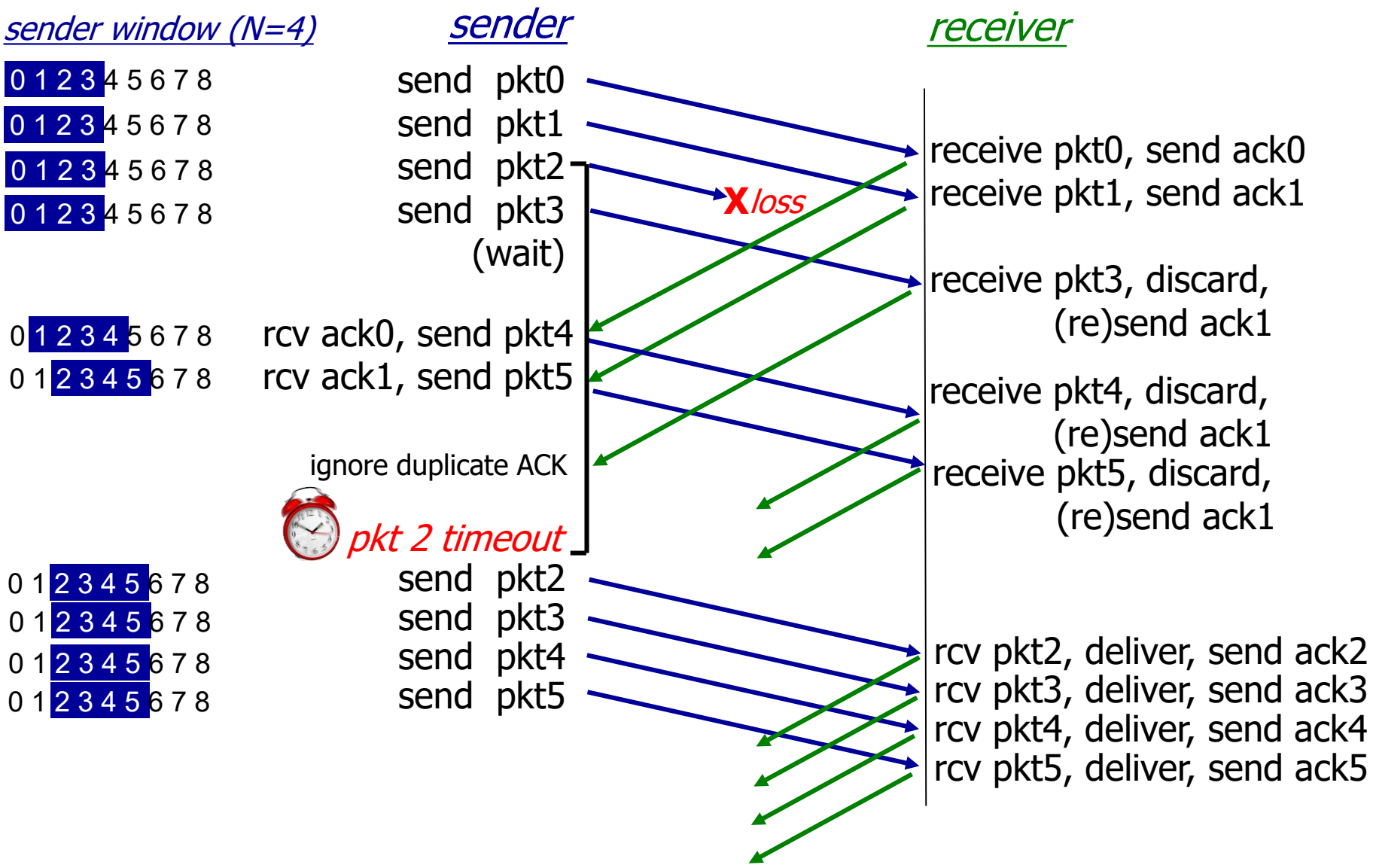
Go-back-N:

- Sender is allowed to transmit multiple packets without waiting for an acknowledgement.
- Receiver only sends cumulative acknowledgement, indicating that all packets with a sequence number up to and including n have been correctly received.
- Sender has timer for oldest unacked packet
- When timer expires, retransmit all unacked packets

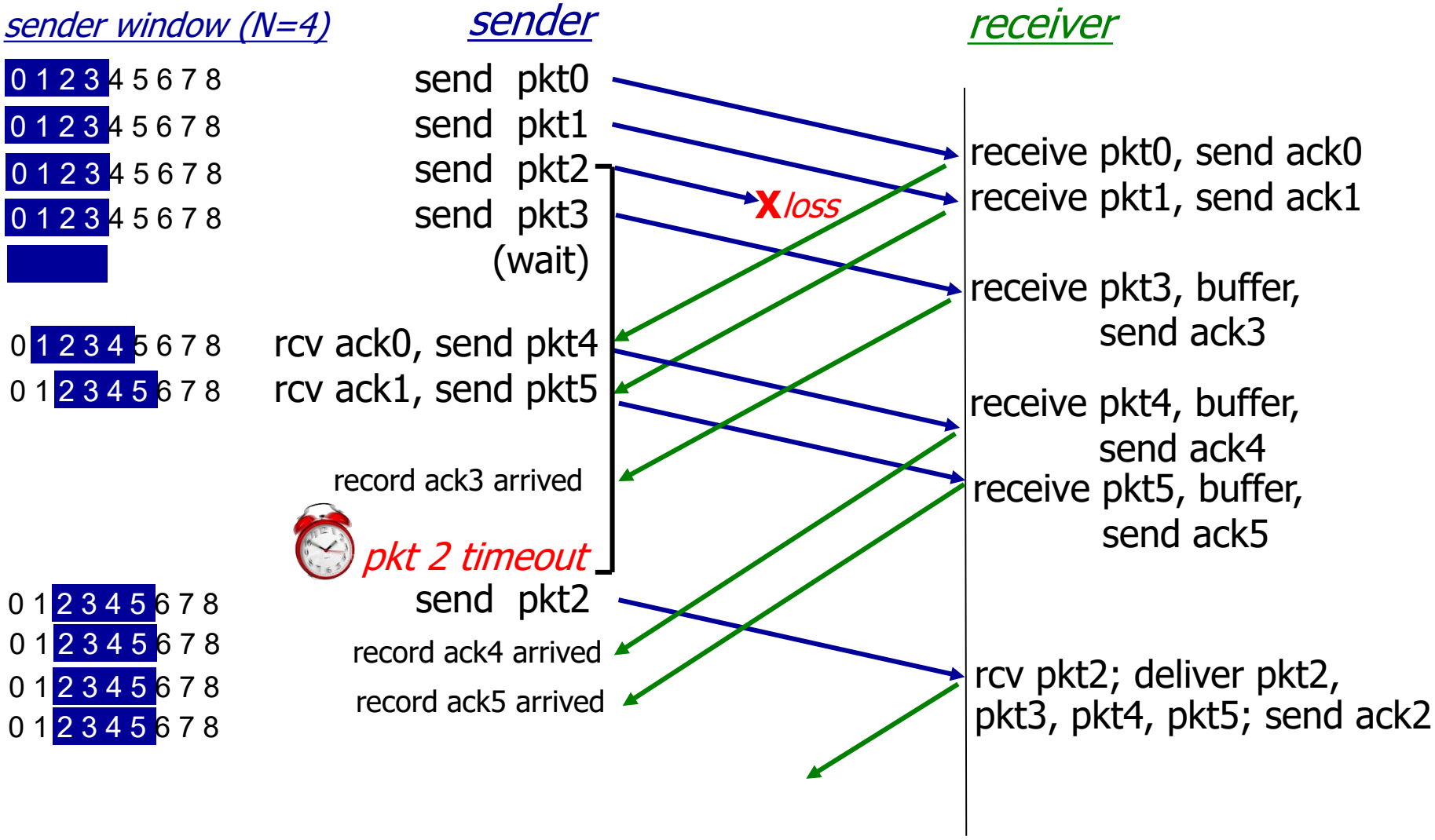
Selective Repeat:

- Sender is allowed to transmit up to N unacked packets in pipeline
- Receiver sends individual ack for each packet.
- Sender maintains timer for each unacked packet
- When timer expires, retransmit only that unacked packet

GBN in action



Selective Repeat in Action



Transmission Control Protocol (TCP)

point-to-point:

- one sender, one receiver

reliable, in-order *byte stream:*

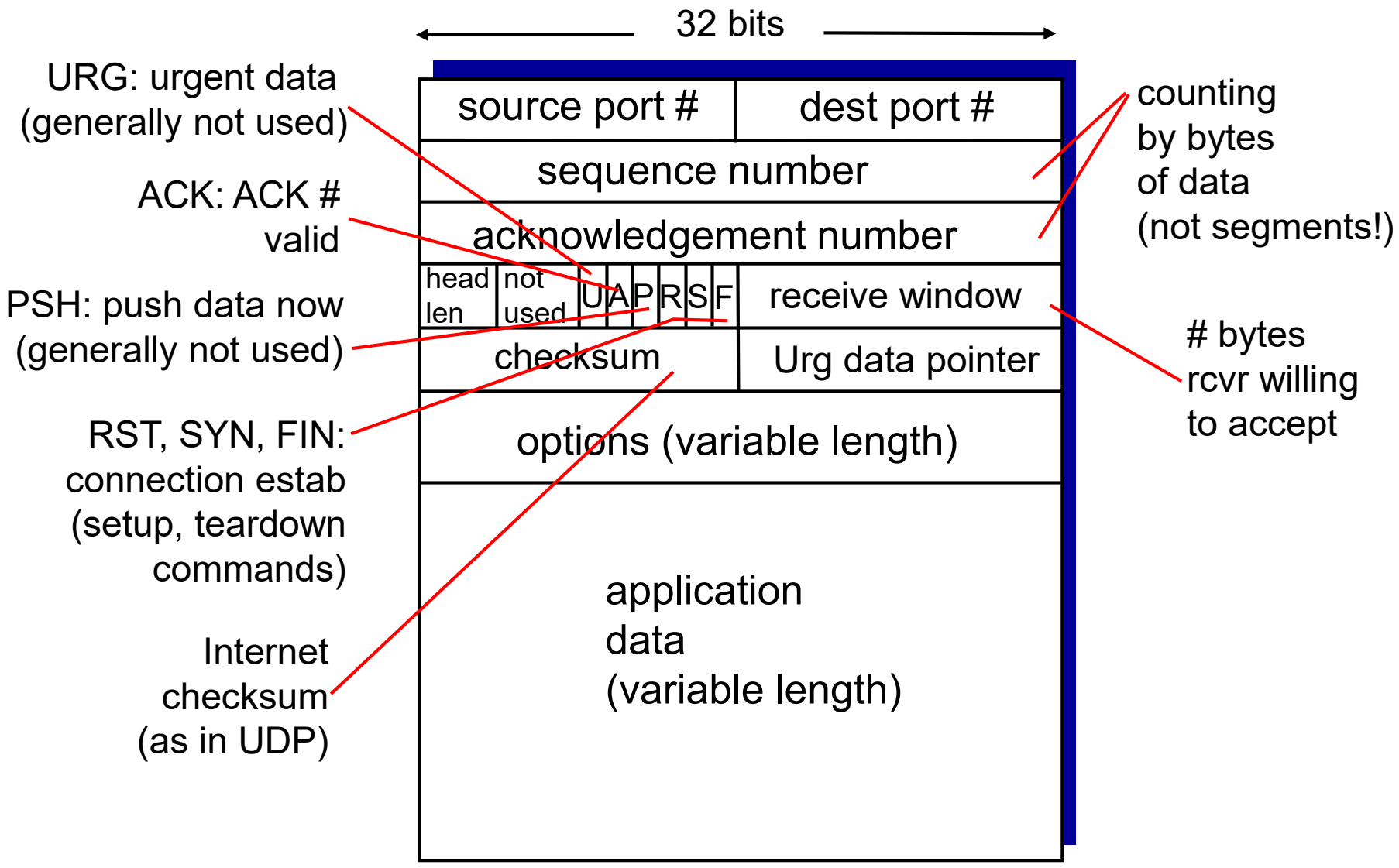
- Sequence number for a segment is the byte-stream number of the first byte in the segment.
- If file size to forward is 2000 bytes and MSS is 100, then first segment gets assigned sequence number 0, the second 100, the third 200, and so on. Total segments 2000/100=20

pipelined:

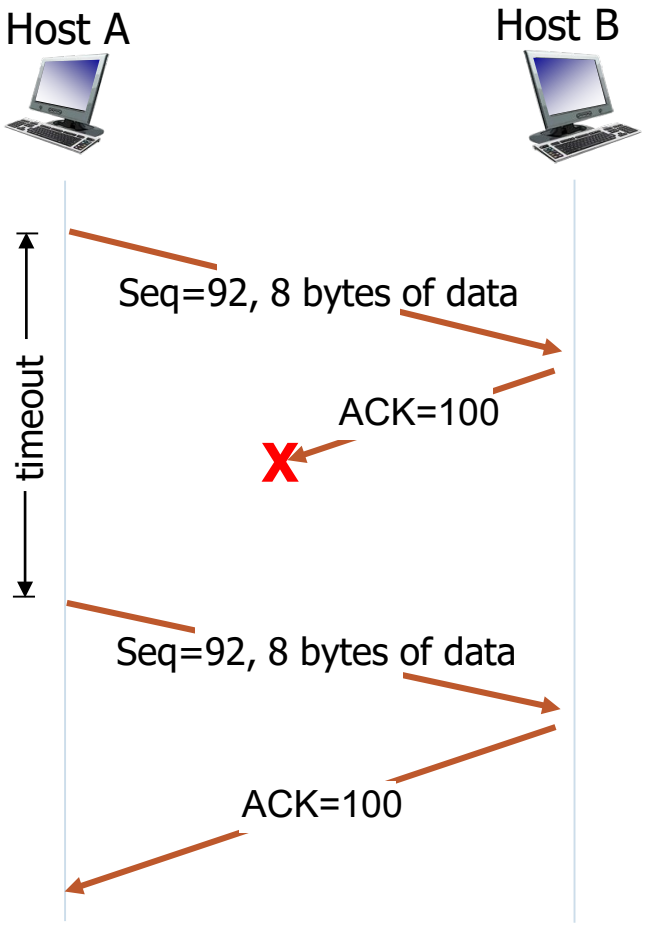
- TCP congestion and flow control set window size

- Full Duplex data:
  - Bi-directional data flow in same connection
  - MSS: maximum segment size. The maximum amount of data that can be grabbed and placed in a segment.
- connection-oriented:
  - handshaking (exchange of control messages) between sender and receiver before data exchange
- flow controlled:
  - sender will not overwhelm receiver

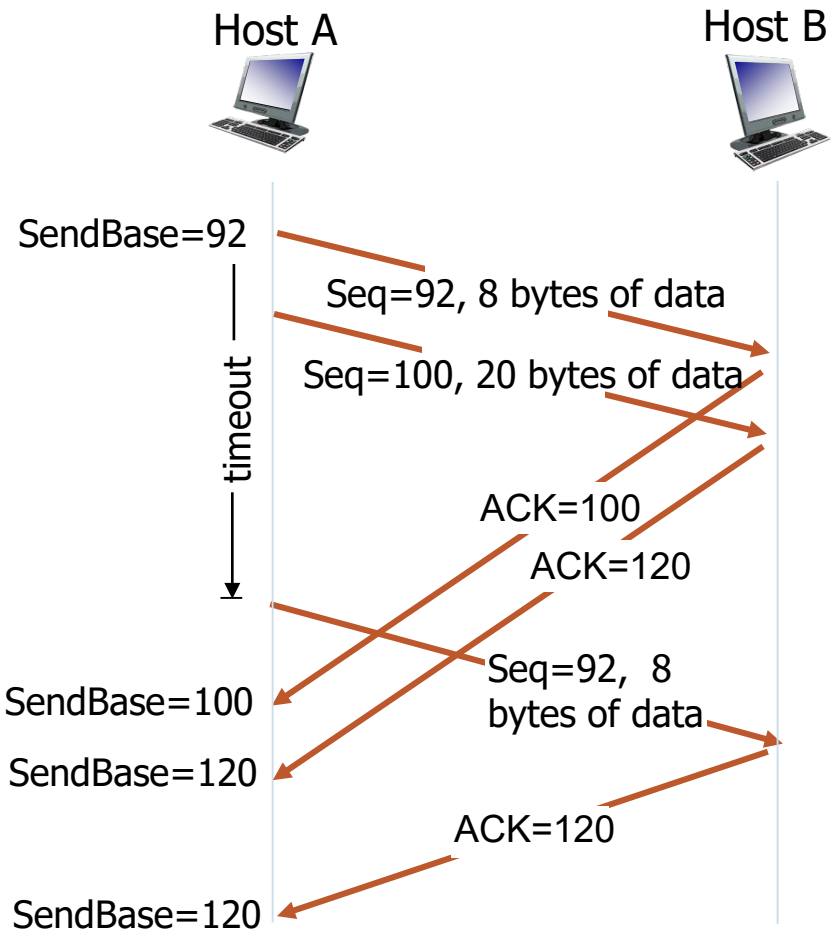
TCP Segment Structure



TCP Transmission Scenarios

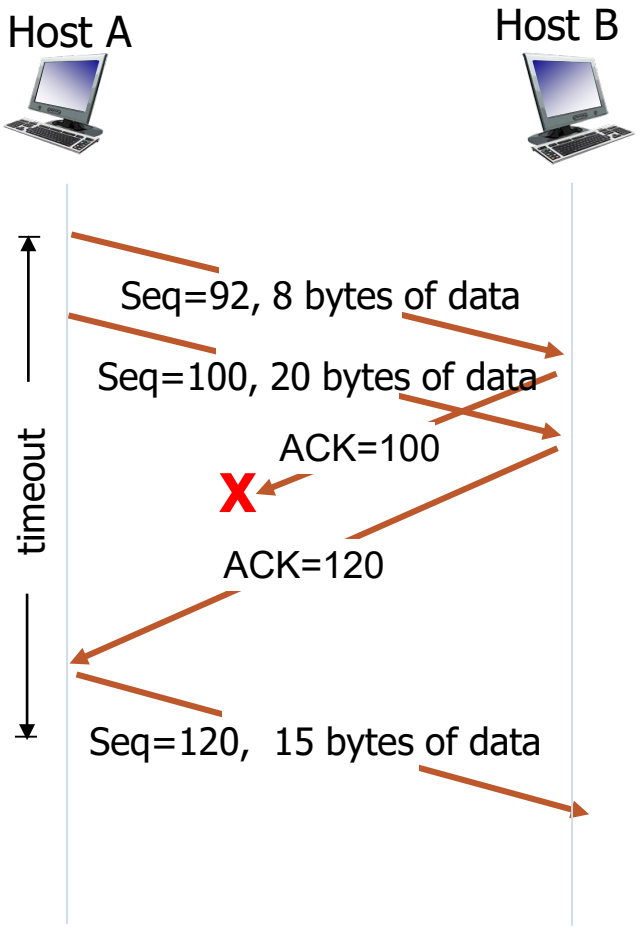


Lost ACK scenario



Premature timeout

TCP Transmission Scenarios



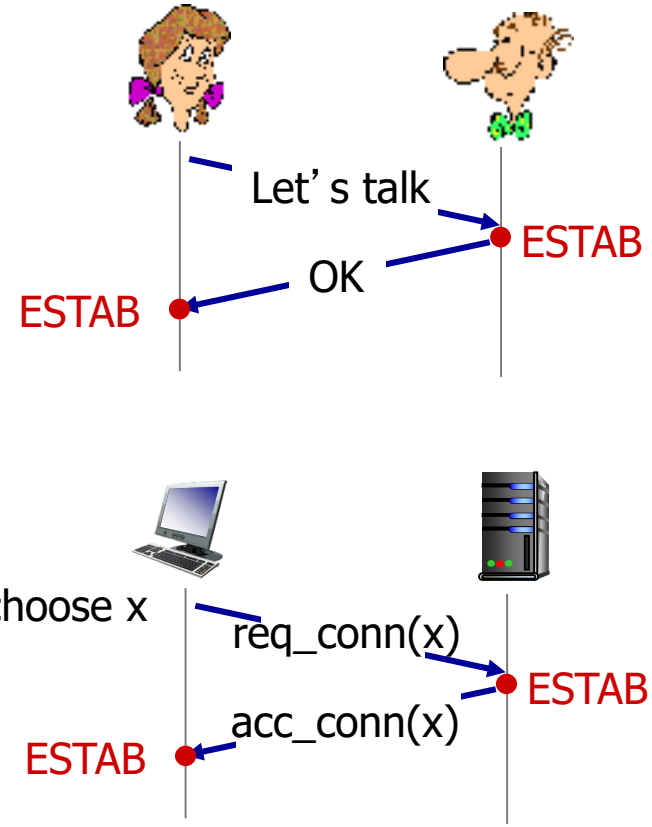
cumulative ACK

Connection Management

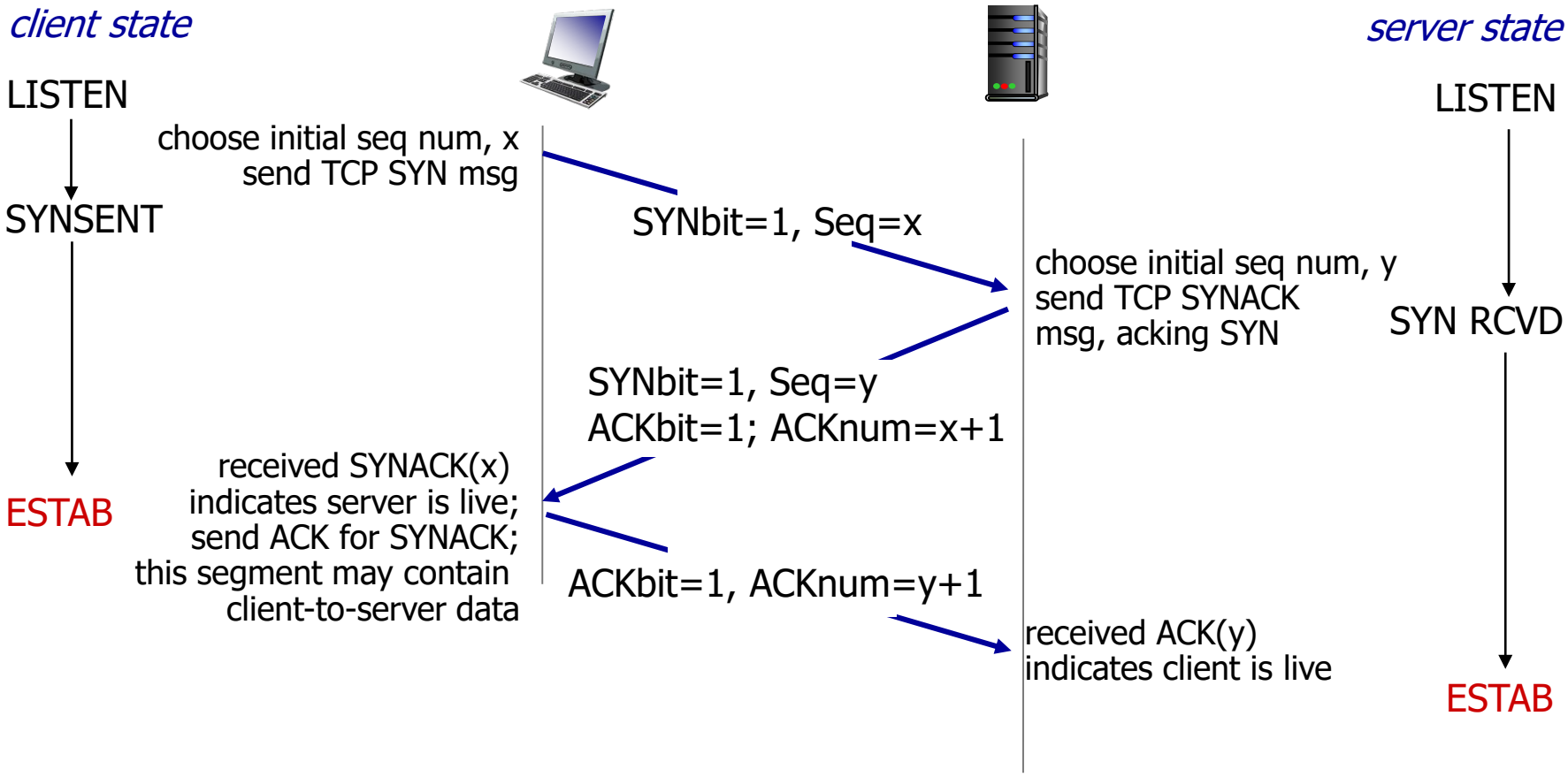
- before exchanging data, sender/receiver “handshake”:
- agree to establish connection (each knowing the other willing to establish connection)
- agree on connection parameters

2-way Handshake

2-way handshake:

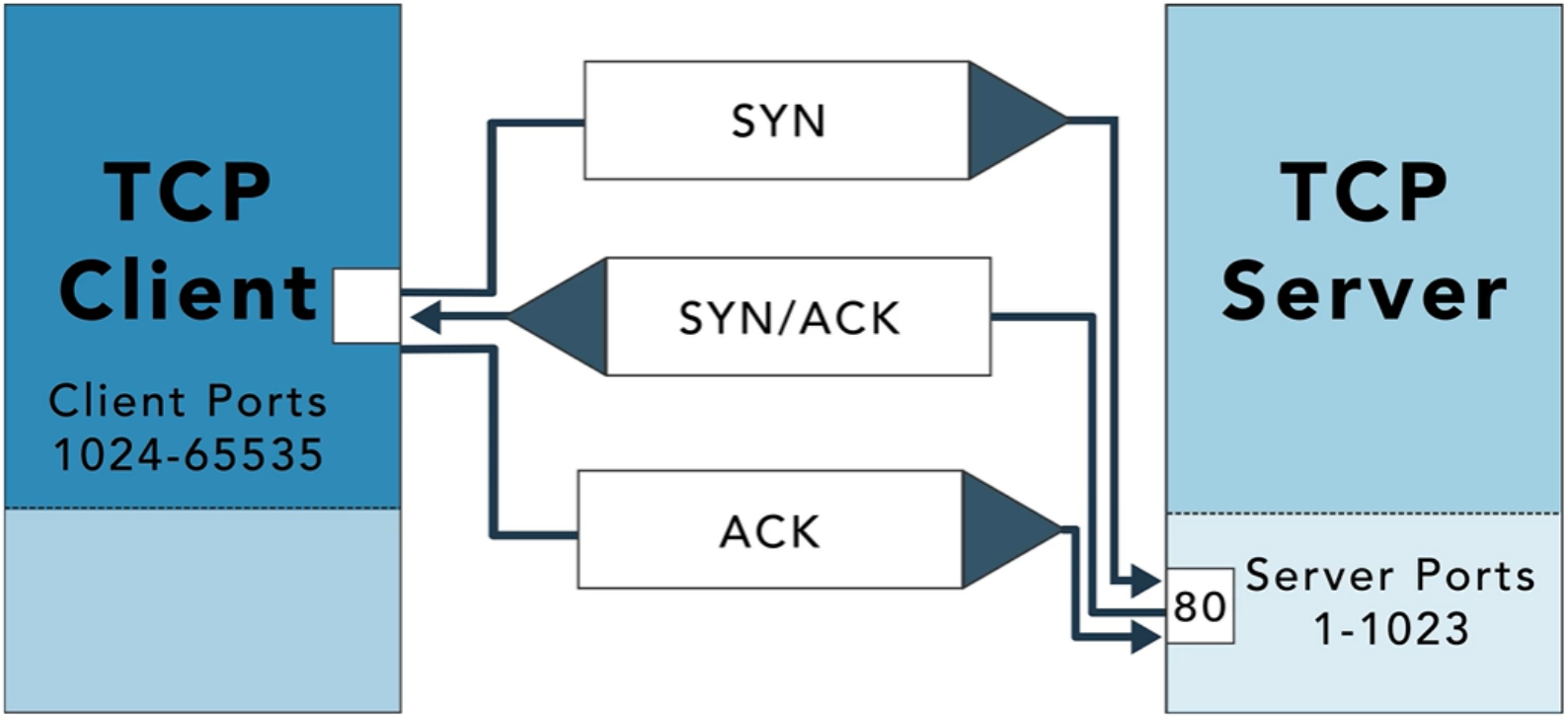


TCP 3-way handshake



TCP 3-way handshake

SYN, SYN-ACK, ACK Handshake



Principles of Congestion Control

congestion:

informally: "too many sources sending too much data too fast for *network* to handle"

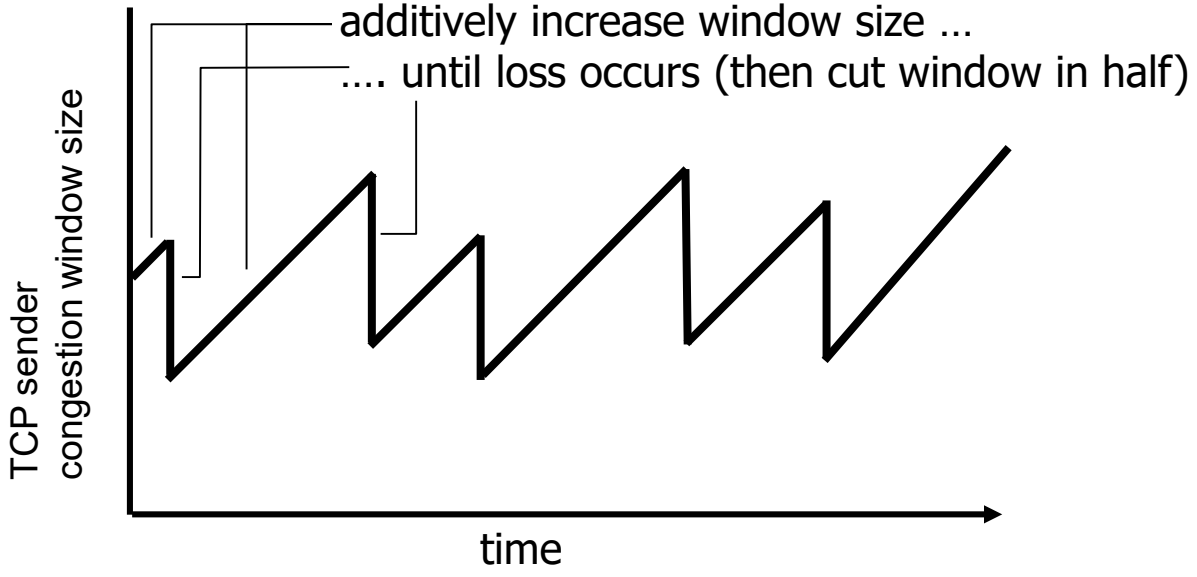
manifestations:

- lost packets (buffer overflow at routers)
- long delays (queueing in router buffers)

TCP Congestion Control

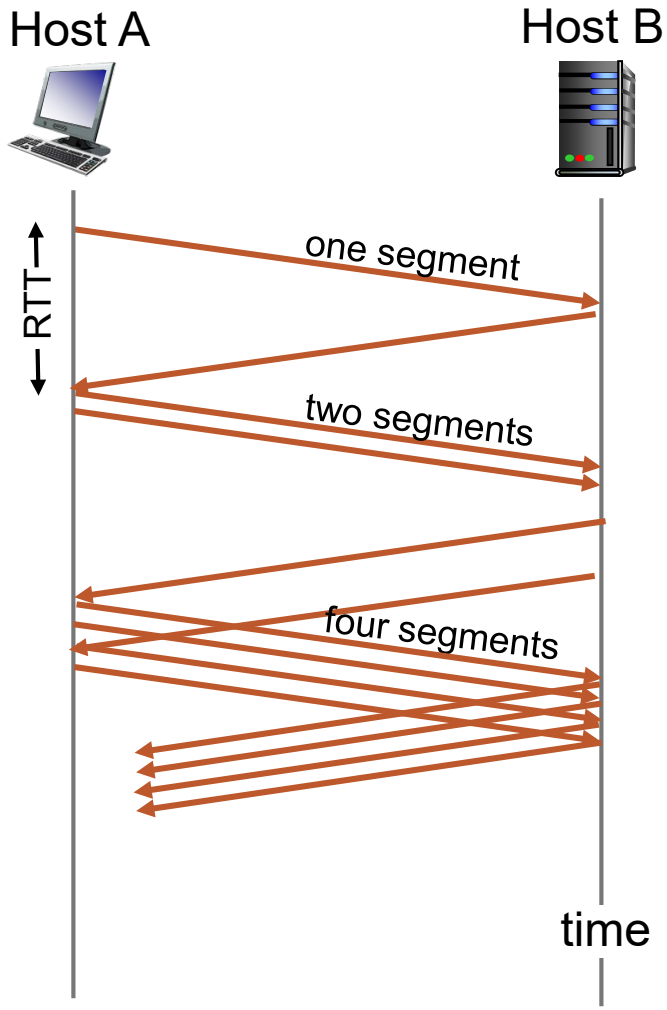
- *Additive-increase, Multiplicative-decrease (AIMD)*
- *approach:* sender increases transmission rate (window size), probing for usable bandwidth, until loss occurs
  - *additive increase:* increase congestion window by 1 MSS every RTT until loss detected
  - *multiplicative decrease*: cut congestion window in half after loss

AIMD saw tooth behavior: probing for bandwidth



TCP Slow Start

- when connection begins, increase rate exponentially until first loss event:
  - initially **cwnd** = 1 MSS
  - double **cwnd** every RTT
  - done by incrementing **cwnd** for every ACK received
- *summary:* initial rate is slow but ramps up exponentially fast



Practice Problem 1

Host A and B are communicating over a TCP connection, and Host B has already received from A all bytes up through byte 100. Suppose Host A then sends two segments to Host B back-to-back. The first and second segments contain 70 and 50 bytes of data, respectively. In the first segment, the sequence number is 101, the source port number is 225, and the destination port number is 80. Host B sends an acknowledgment whenever it receives a segment from Host A.

i. In the second segment sent from Host A to B, what are the sequence number, source port number, and destination port number?

ii. If the first segment arrives before the second segment, in the acknowledgment of the first arriving segment, what is the acknowledgment number, the source port number, and the destination port number?

iii. If the second segment arrives before the first segment, in the acknowledgment of the first arriving segment, what is the acknowledgment number?

iv. Suppose the two segments sent by A arrive in order at B. The first acknowledgment is lost and the second acknowledgment arrives after the first timeout interval. Draw a timing diagram, showing these segments and all other segments and acknowledgments sent. (Assume there is no additional packet loss.) For each segment in your figure, provide the sequence number and the number of bytes of data; for each acknowledgment that you add, provide the acknowledgment number.

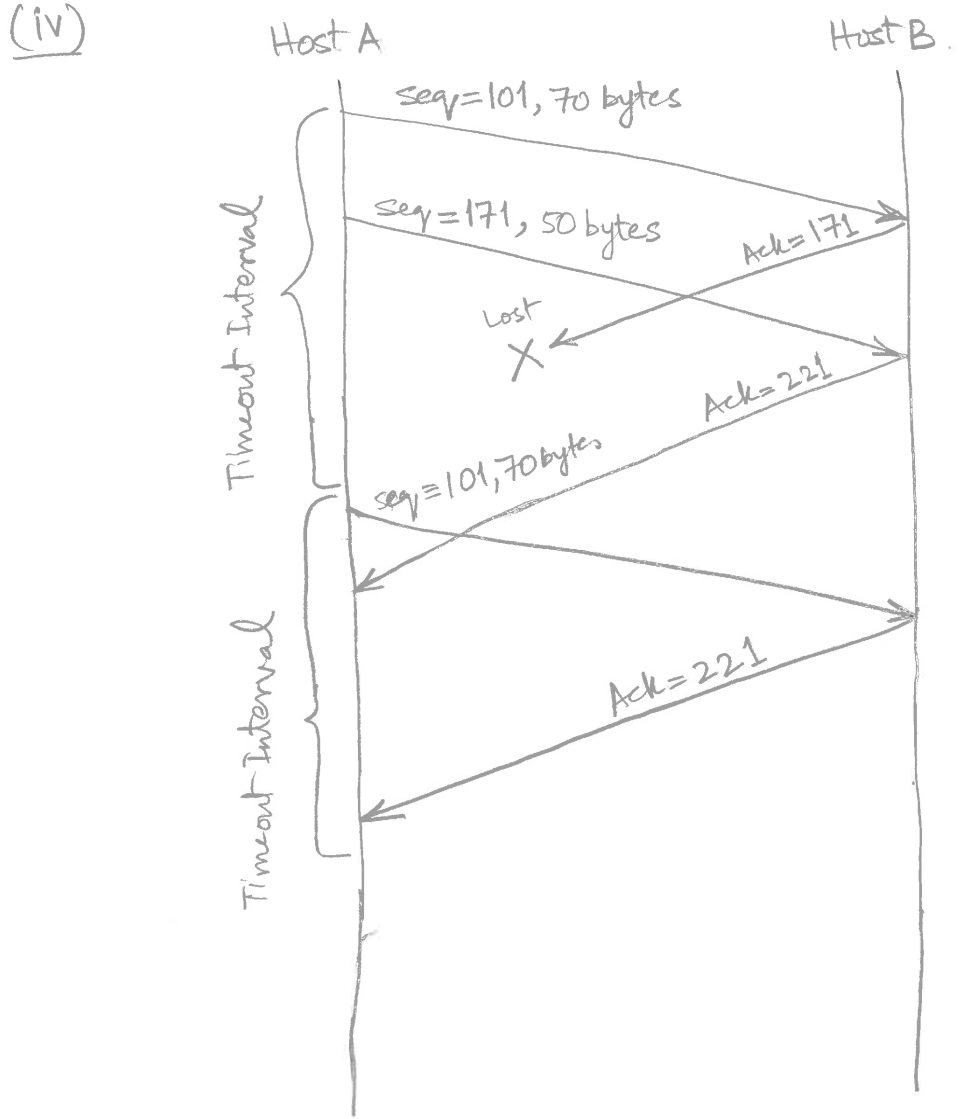
Practice Problem 1

(i) In the second segment sent from Host A to B: the sequence number is 171, the source port number is 225 and destination port number is 80.

(ii) If the first segment arrives before the second segment, in the acknowledgement of the first arriving segment, the acknowledgement number is 171,
the source port number is 80,
and the destination port number is 225.

(iii) If the second segment arrives before the first segment, in the acknowledgement of the first arriving segment, the acknowledgement number is 101, indicating that it is still waiting for bytes 101 and onwards.

Practice Problem 1



Practice Problem 2

Host A and B are communicating over a TCP connection, and Host B has already received from A all bytes up through byte 250. Suppose Host A then sends three segments to Host B back-to-back. The first, second and third segments contain 90, 70 and 50 bytes of data, respectively. Suppose all three segments sent by A arrive in order at B. The first acknowledgement arrives in time, while the second acknowledgment is lost and the third acknowledgment arrives after the second timeout interval.

Draw a timing diagram, showing these segments and all other segments and acknowledgments sent. (Assume there is no additional packet loss.) For each segment in your figure, provide the sequence number and the number of bytes of data; for each acknowledgment that you add, provide the acknowledgment number.

Practice Problem 2