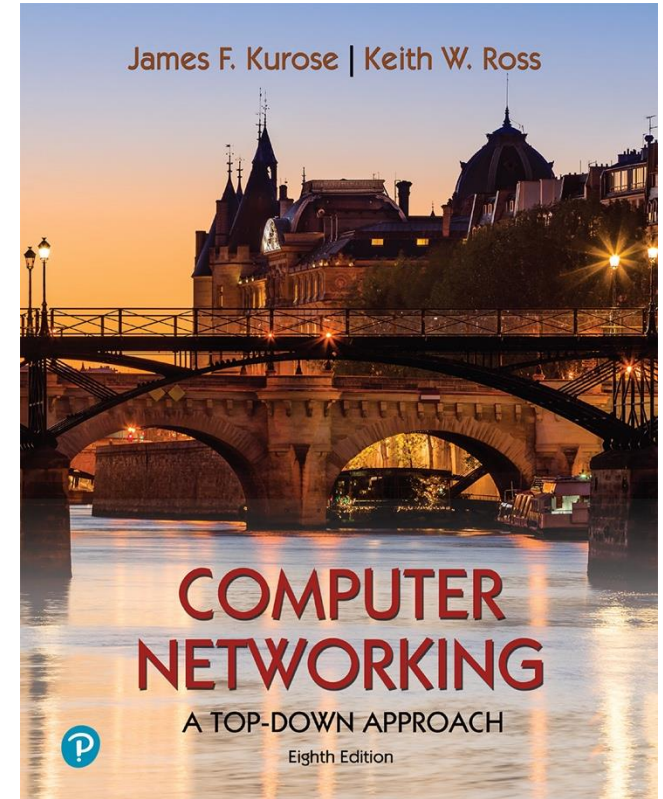


Chapter 3

Transport Layer



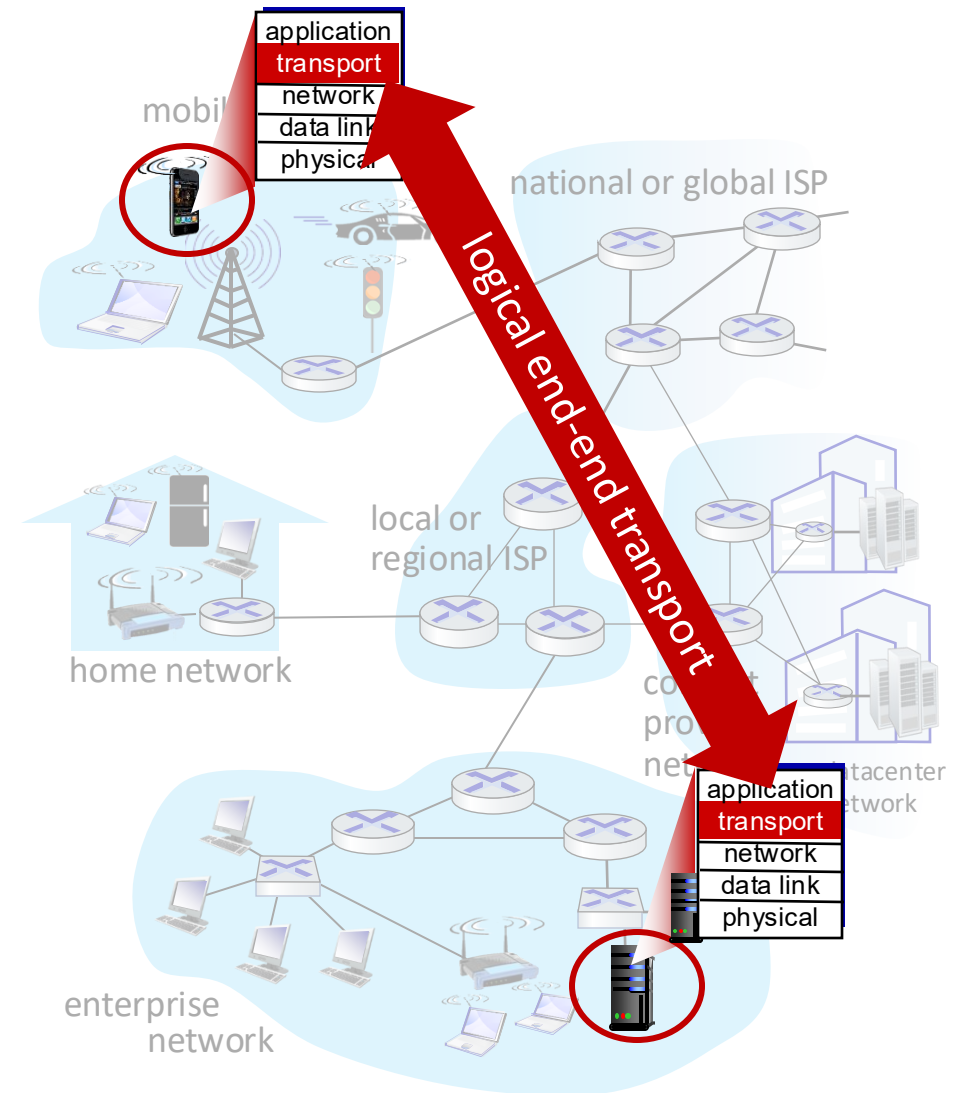
Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

Transport services and protocols

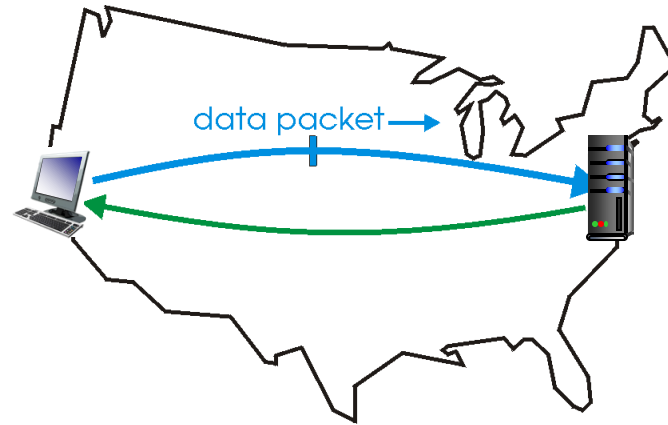
- provide *logical communication* between application processes running on different hosts
- transport protocols actions in end systems:
 - sender: breaks application messages into *segments*, passes to network layer
 - receiver: reassembles segments into messages, passes to application layer
- two transport protocols available to Internet applications
 - TCP, UDP



rdt3.0: pipelined protocols operation

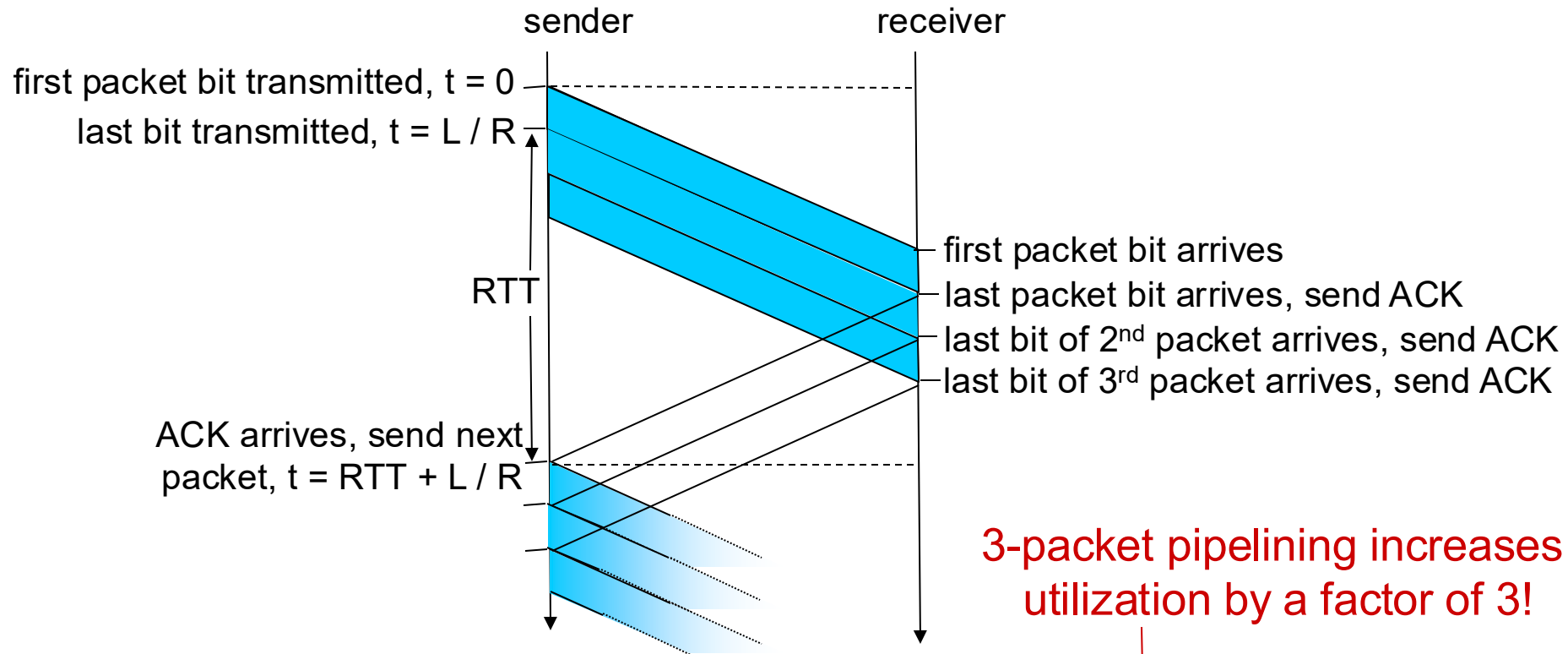
pipelining: sender allows multiple, “in-flight”, yet-to-be-acknowledged packets

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



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

Pipelining: increased utilization



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

$$U_{\text{sender}} = \frac{3L / R}{RTT + L / R} = \frac{.0024}{30.008} = 0.00081$$

Pipelined protocols: overview

Go-back-N:

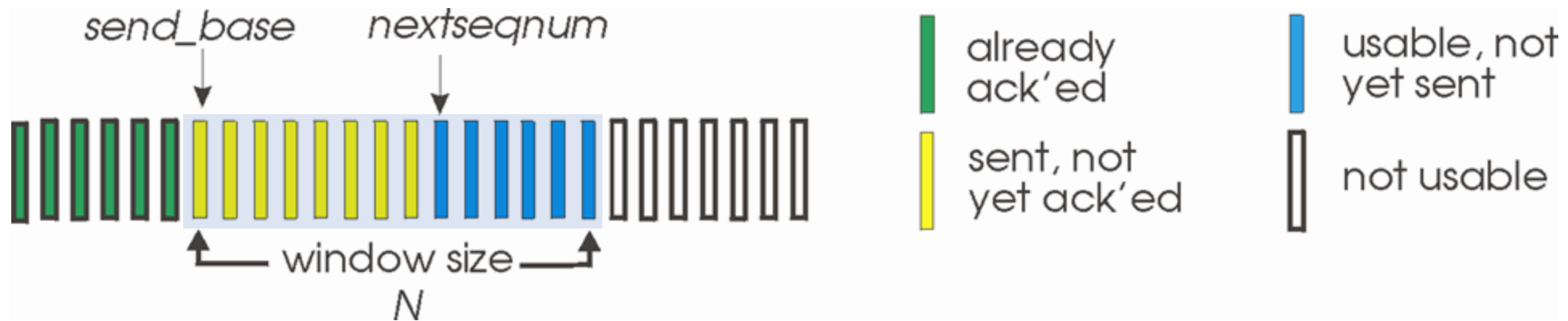
- sender can have up to N unacked packets in pipeline
- receiver only sends *cumulative ack*
 - doesn't ack packet if there's a gap
- sender has timer for oldest unacked packet
 - when timer expires, retransmit *all* unacked packets

Selective Repeat:

- sender can have up to N unack'ed packets in pipeline
- rcvr sends *individual ack* for each packet
- sender maintains timer for each unacked packet
 - when timer expires, retransmit only that unacked packet

Go-Back-N: sender

- sender: “window” of up to N , consecutive transmitted but unACKed pkts
 - k -bit seq # in pkt header

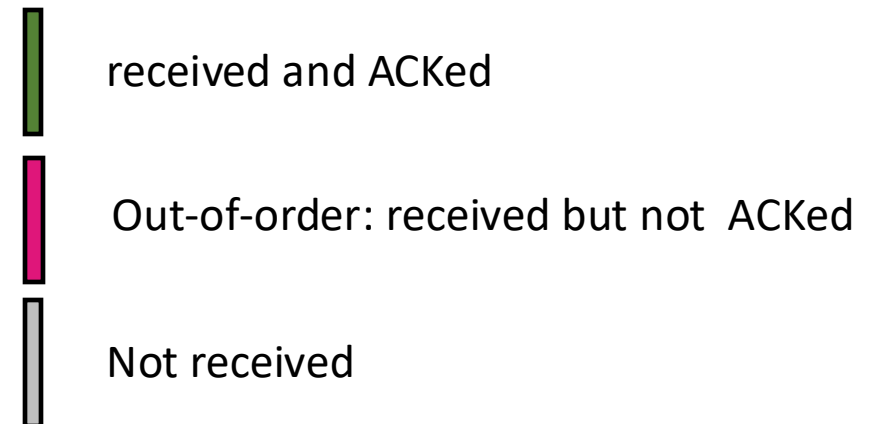
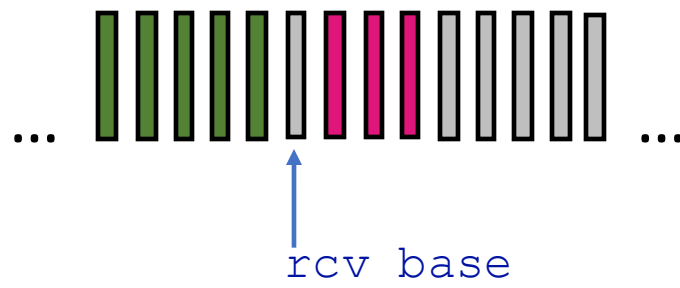


- ***cumulative ACK***: $ACK(n)$: ACKs all packets up to, including seq # n
 - on receiving $ACK(n)$: move window forward to begin at $n+1$
- timer for oldest in-flight packet
- *timeout*(n): retransmit packet n and all higher seq # packets in window

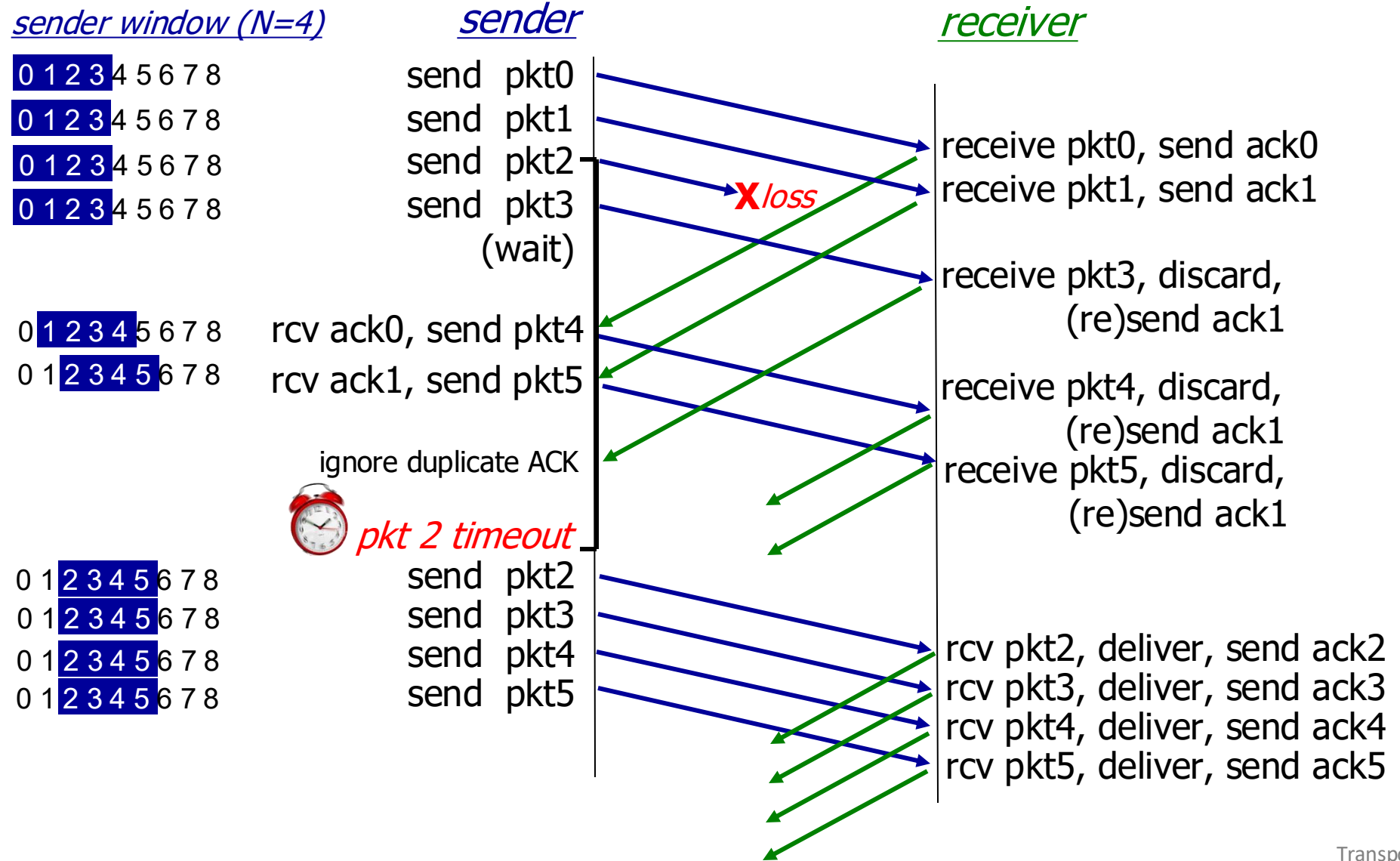
Go-Back-N: receiver

- ACK-only: always send ACK for correctly-received packet so far, with highest *in-order* seq #
 - may generate duplicate ACKs
 - need only remember `rcv_base`
- on receipt of out-of-order packet:
 - can discard (don't buffer) or buffer: an implementation decision
 - re-ACK pkt with highest in-order seq #

Receiver view of sequence number space:



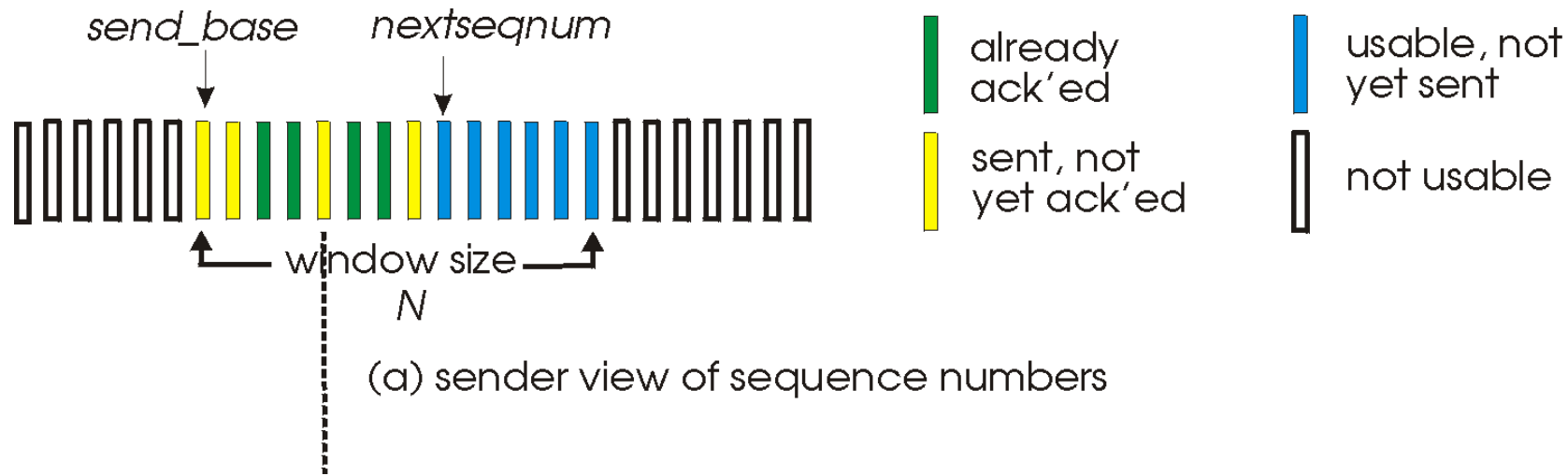
Go-Back-N in action



Selective repeat: the approach

- *pipelining*: multiple packets in flight
- *receiver individually ACKs* all correctly received packets
 - buffers packets, as needed, for in-order delivery to upper layer
- sender:
 - maintains (conceptually) a timer for each unACKed pkt
 - timeout: retransmits single unACKed packet associated with timeout
 - maintains (conceptually) “window” over *N* consecutive seq #s
 - limits pipelined, “in flight” packets to be within this window

Selective repeat: sender, receiver windows



Selective repeat: sender and receiver

sender

data from above:

- if next available seq # in window, send packet

timeout(n):

- resend packet n , restart timer

ACK(n) in [sendbase, sendbase+N-1]:

- mark packet n as received
- if n smallest unACKed packet, advance window base to next unACKed seq #

receiver

packet n in [rcvbase, rcvbase+N-1]

- send ACK(n)
- out-of-order: buffer
- in-order: deliver (also deliver buffered, in-order packets), advance window to next not-yet-received packet

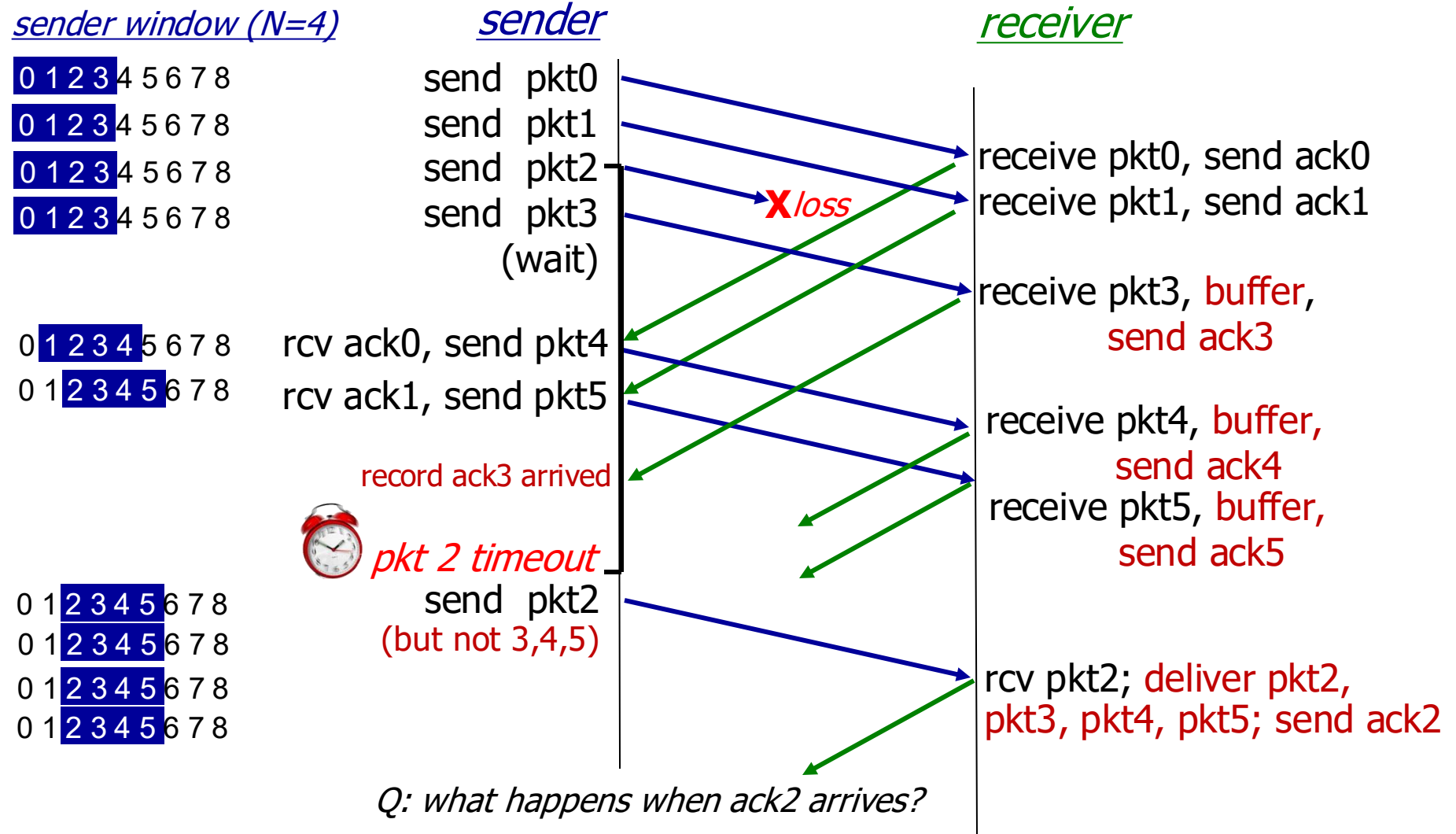
packet n in [rcvbase-N, rcvbase-1]

- ACK(n)

otherwise:

- ignore

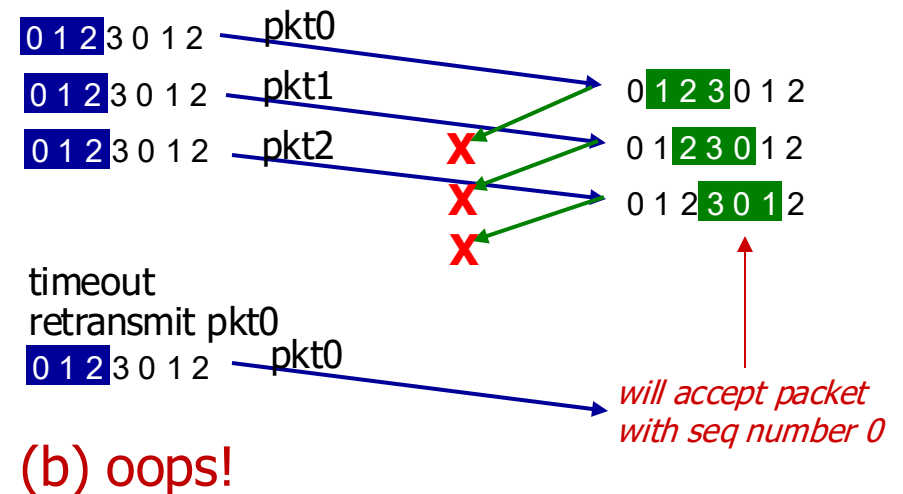
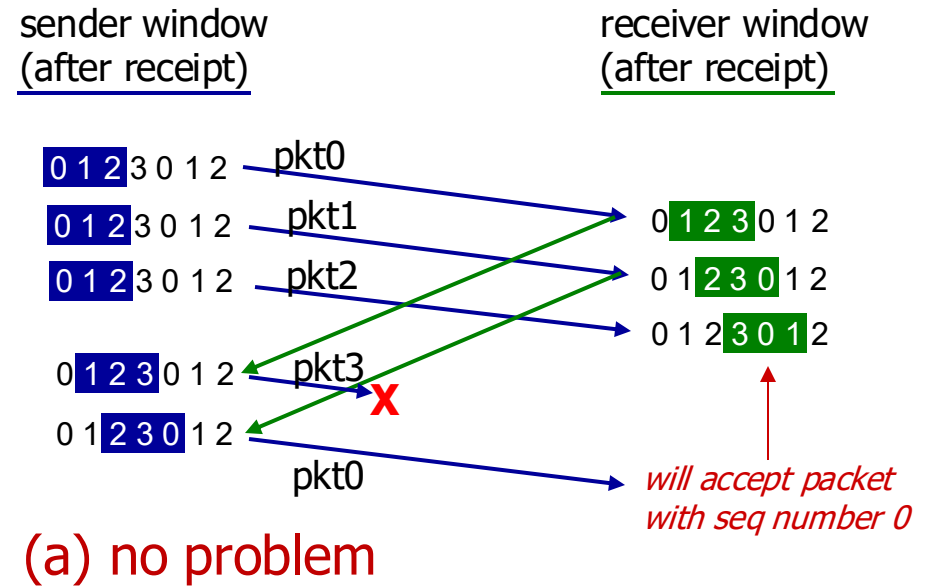
Selective Repeat in action



Selective repeat: a dilemma!

example:

- seq #s: 0, 1, 2, 3 (base 4 counting)
- window size=3



Selective repeat: a dilemma!

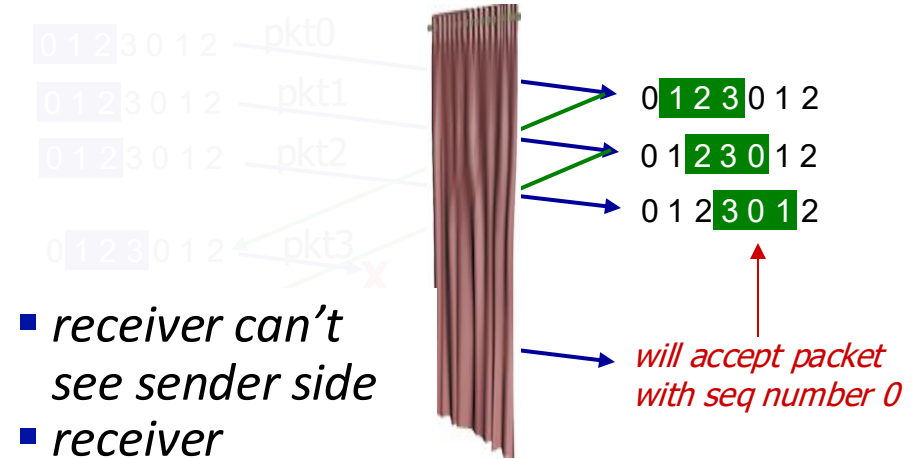
example:

- seq #s: 0, 1, 2, 3 (base 4 counting)
- window size=3

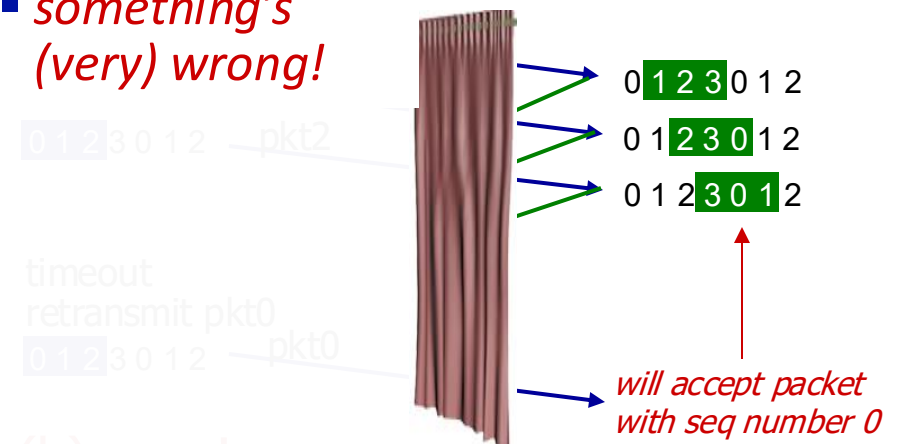
Q: what relationship is needed between sequence # size and window size to avoid problem in scenario (b)?

sender window
(after receipt)

receiver window
(after receipt)



- receiver can't see sender side
- receiver behavior identical in both cases!
- *something's (very) wrong!*



Chapter 3: roadmap

- Transport-layer services
- Multiplexing and demultiplexing
- Connectionless transport: UDP
- Principles of reliable data transfer
- **Connection-oriented transport: TCP**
 - segment structure
 - reliable data transfer
 - flow control
 - connection management
- Principles of congestion control
- TCP congestion control

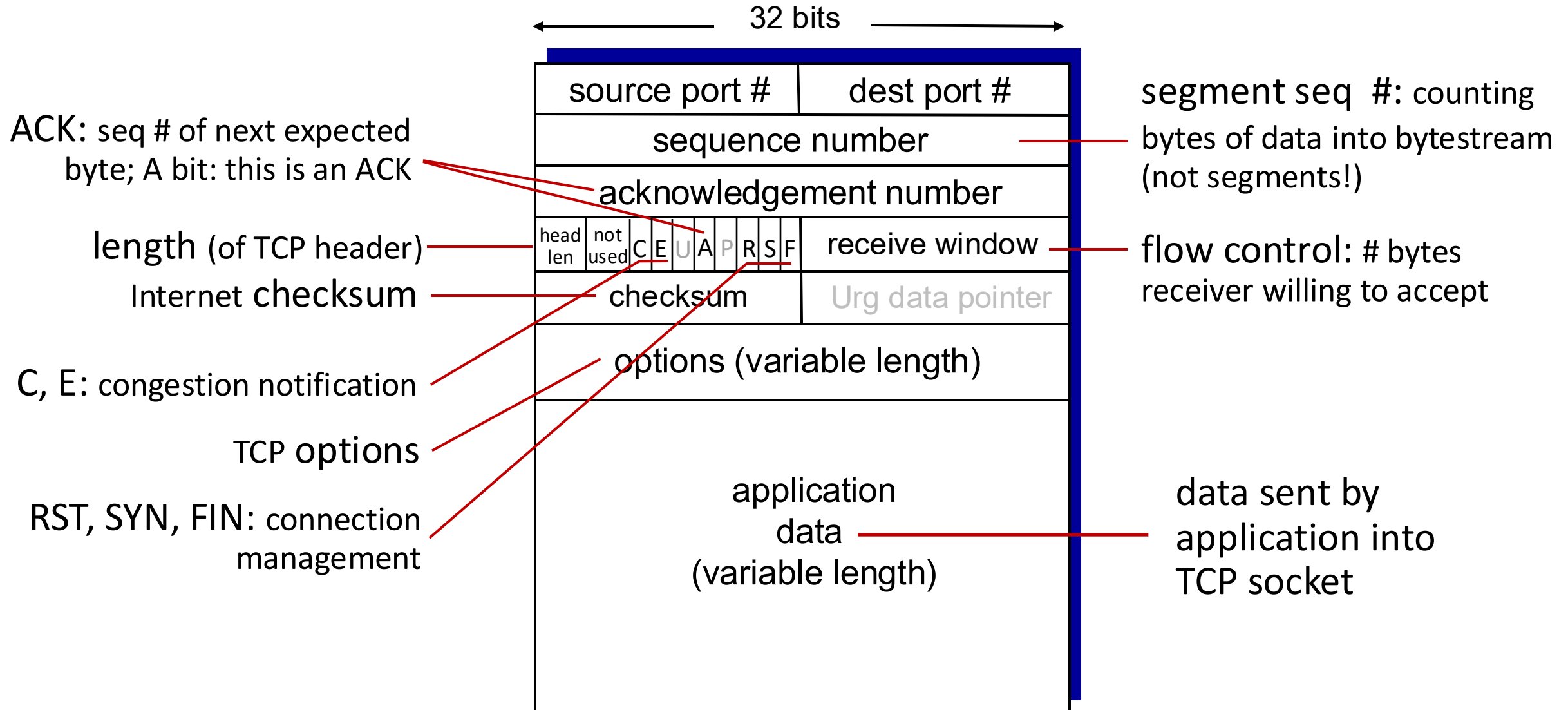


TCP: overview

RFCs: 793, 1122, 2018, 5681, 7323

- **point-to-point:**
 - one sender, one receiver
- **reliable, in-order *byte stream*:**
 - no “message boundaries”
- **full duplex data:**
 - bi-directional data flow in same connection
 - MSS: maximum segment size
- **cumulative ACKs**
- **pipelining:**
 - TCP congestion and flow control set window size
- **connection-oriented:**
 - handshaking (exchange of control messages) initializes sender, receiver state before data exchange
- **flow controlled:**
 - sender will not overwhelm receiver

TCP segment structure



TCP sequence numbers, ACKs

Sequence numbers:

- byte stream “number” of first byte in segment’s data

Acknowledgements:

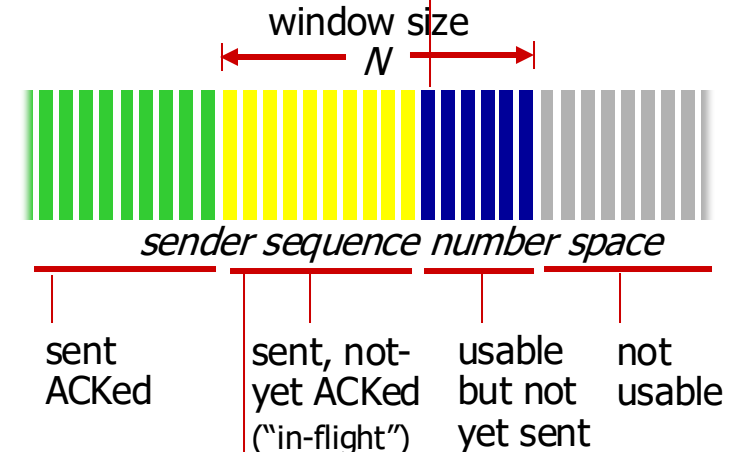
- seq # of next byte expected from other side
- cumulative ACK

Q: how receiver handles out-of-order segments

- A: TCP spec doesn’t say, - up to implementor

outgoing segment from sender

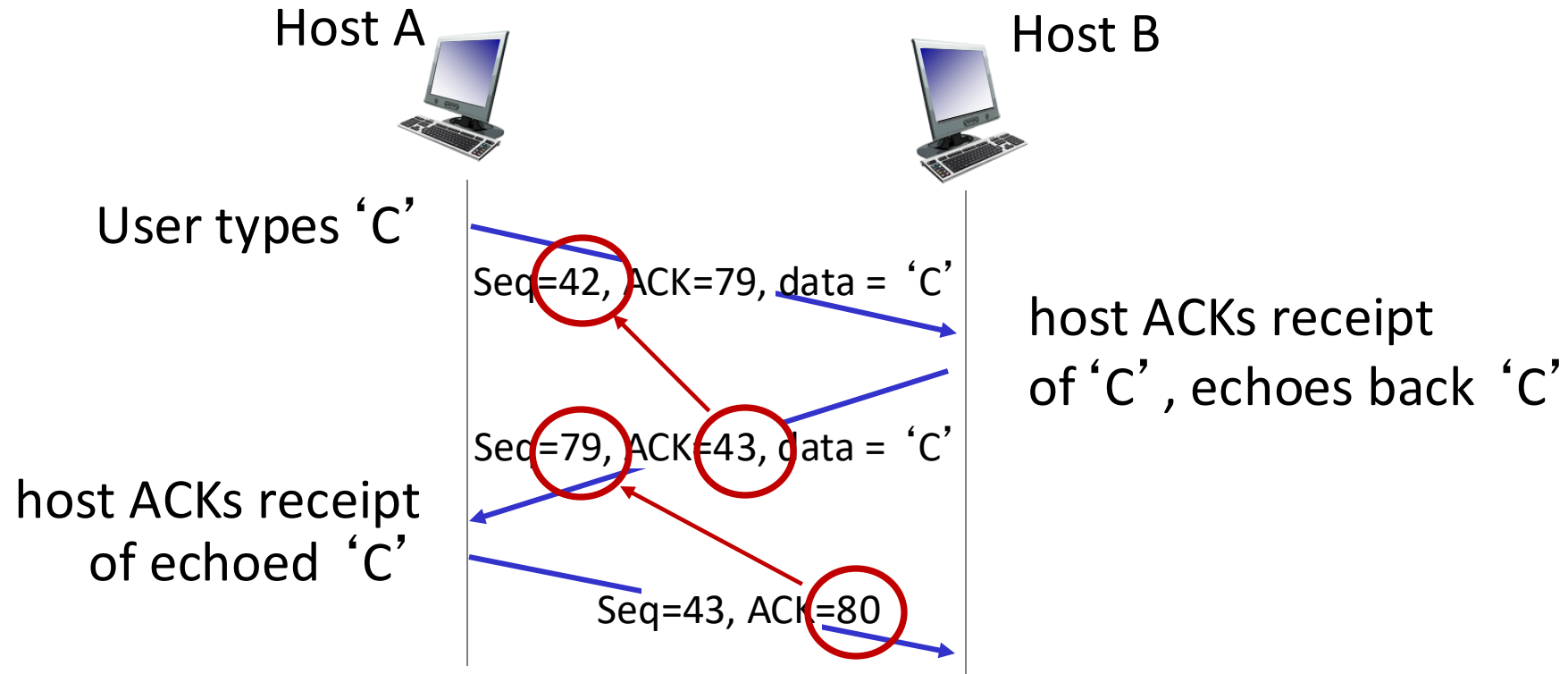
| | |
|------------------------|-------------|
| source port # | dest port # |
| sequence number | |
| acknowledgement number | |
| | rwnd |
| checksum | urg pointer |



outgoing segment from receiver

| | |
|------------------------|---------------|
| source port # | dest port # |
| sequence number | |
| acknowledgement number | |
| | A rwnd |
| checksum | urg pointer |

TCP sequence numbers, ACKs



simple telnet scenario