National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 11

Chapter 3

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Nauman Moazzam Hayat

nauman.moazzam@lhr.nu.edu.pk

Office Hours: 11:30 am till 01:00 pm (Every Tuesday & Thursday)

Chapter 3
Transport Layer

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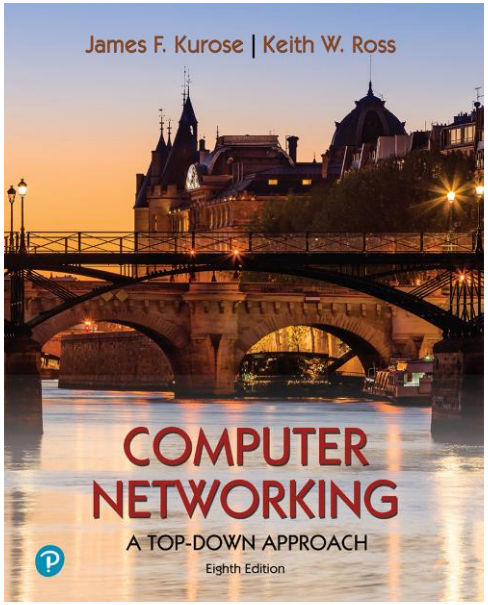


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

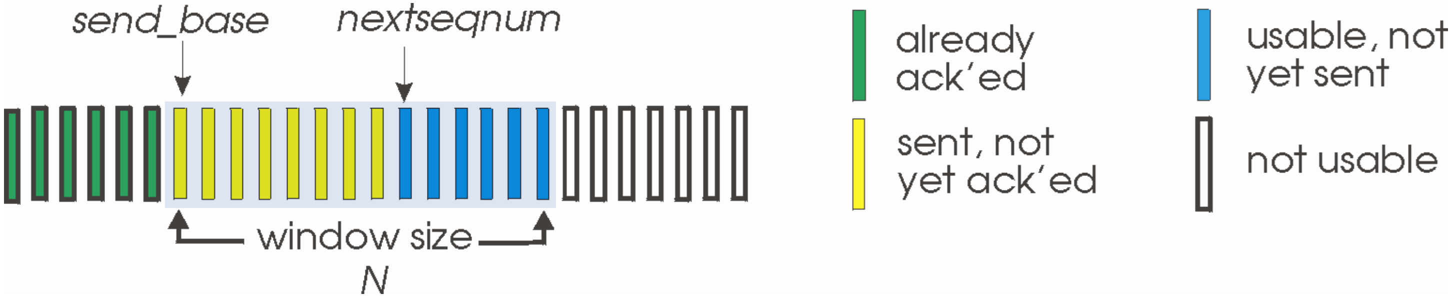
Two generic Forms of Pipelined Protocols are:

- *go-Back-N (**GBN**), also called the sliding window protocol &*

- *selective repeat **(SR**)*

Go-Back-N: sender (GBN , Sliding Window)

- sender: "window" of up to N, consecutive transmitted but unACKed pkts
- If N = 1, it becomes a Stop & Wait Protocol (thus N should always be greater than 1 to implement pipelining.)
  - k-bit seq # in pkt header, range of sequence numbers is [0, 2^k -1]

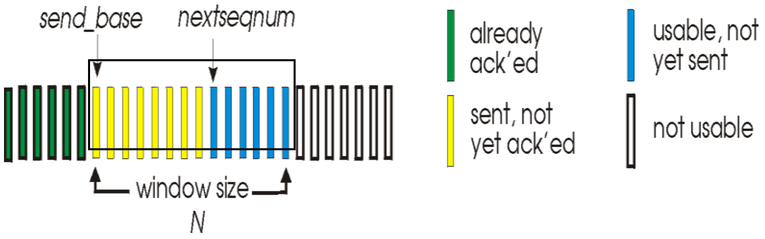


- *cumulative ACK:* ACK(*n*): ACKs all packets up to, including seq # *n*
  - on receiving ACK(*n*): move window forward to begin at *n+1* *(TCP uses cumulative ACKs)*
- timer for oldest in-flight packet
- *timeout(n):* retransmit packet n and all higher seq # packets in window

Go-Back-N: sender

- Invocation from above
  - When rdt_sent() is called, checks if window is full
  - If not full, a packet is created and sent
- Receipt of an ACK
  - Cumulative acknowledgement: ack with seq number n means all previous packets has been received at receiver
- A timeout event
  - All previous packets that have been sent, their acknowledgements have not been received will be resent

4 Ranges of Sequence Numbers

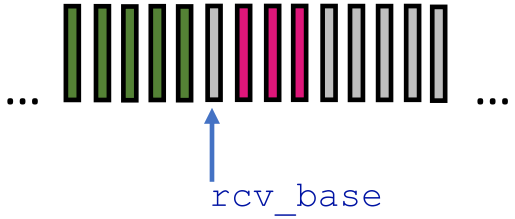


1. [0, base -1] → are packets with sequence numbers sent & ACKed.
2. [base, nextseqnum - 1] → are sequence numbers sent but not yet ACKed (inflight.)
3. [nextseqnum, base + N - 1] → are sequence numbers that can be sent immediately if more data arrives from the App layer.
4. [>=, base + N] → are sequence numbers that can't be used until an unACKed packet is ACKed.

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:

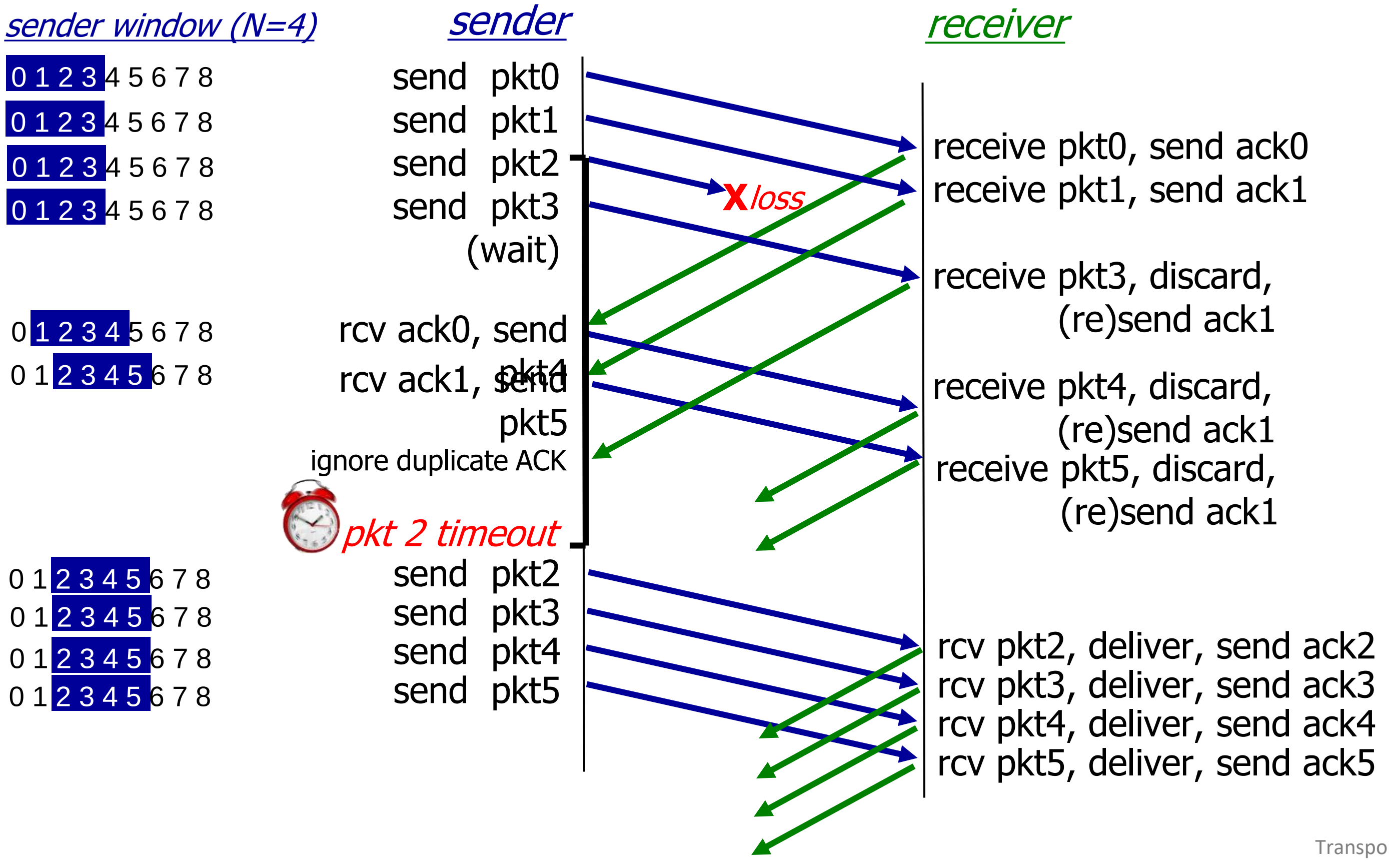


🟩 received and ACKed

🟥 Out-of-order: received but not ACKed

⬜ Not received

Go-Back-N in action



sender window (N=4)

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

sender

send pkt0
send pkt1
send pkt2
send pkt3
(wait)

rcv ack0, send pkt4
rcv ack1, send pkt5

ignore duplicate ACK

pkt 2 timeout

send pkt2
send pkt3
send pkt4
send pkt5

receiver

receive pkt0, send ack0
receive pkt1, send ack1

receive pkt3, discard,
(re)send ack1

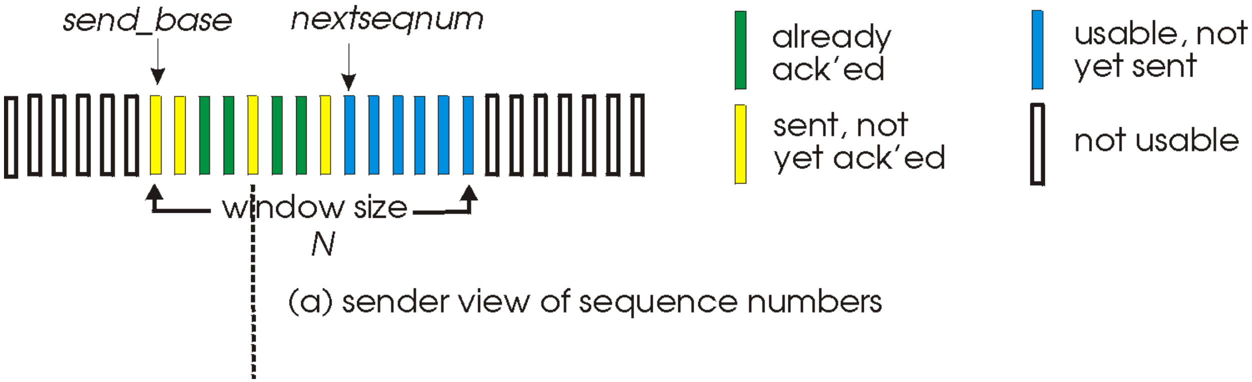
receive pkt4, discard,
(re)send ack1
receive pkt5, discard,
(re)send ack1

rcv pkt2, deliver, send ack2
rcv pkt3, deliver, send ack3
rcv pkt4, deliver, send ack4
rcv pkt5, deliver, send ack5

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



(a) sender view of sequence numbers

Sender window size = Receiver window size =N

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

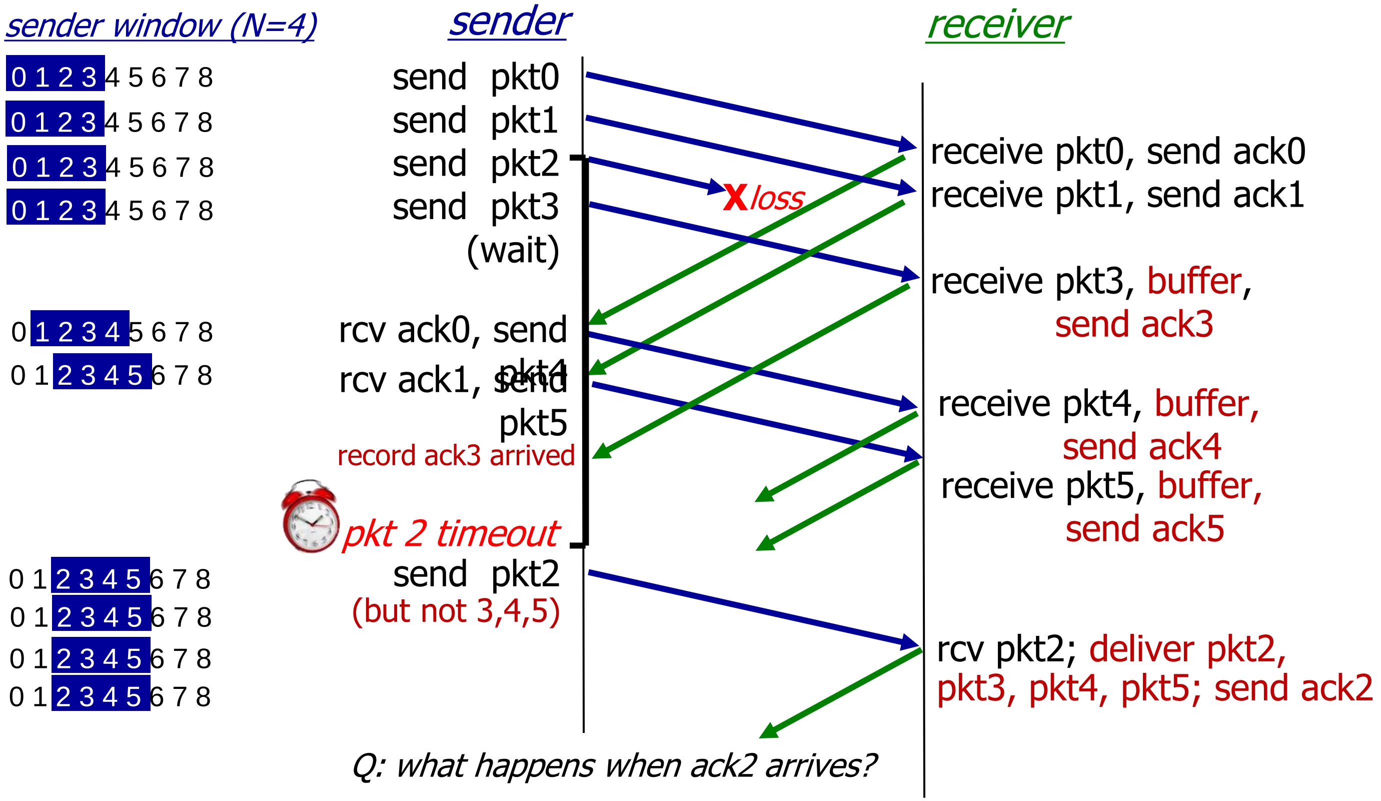
packet *n* in [rcvbase-N,rcvbase-1]

- ACK(*n*)

otherwise:

- ignore

Selective Repeat in action



sender window (N=4)

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

sender

send pkt0

send pkt1

send pkt2

send pkt3

(wait)

rcv ack0, send pkt4

rcv ack1, send pkt5

record ack3 arrived

pkt 2 timeout

send pkt2 (but not 3,4,5)

X *loss*

receiver

receive pkt0, send ack0

receive pkt1, send ack1

receive pkt3, buffer, send ack3

receive pkt4, buffer, send ack4

receive pkt5, buffer, send ack5

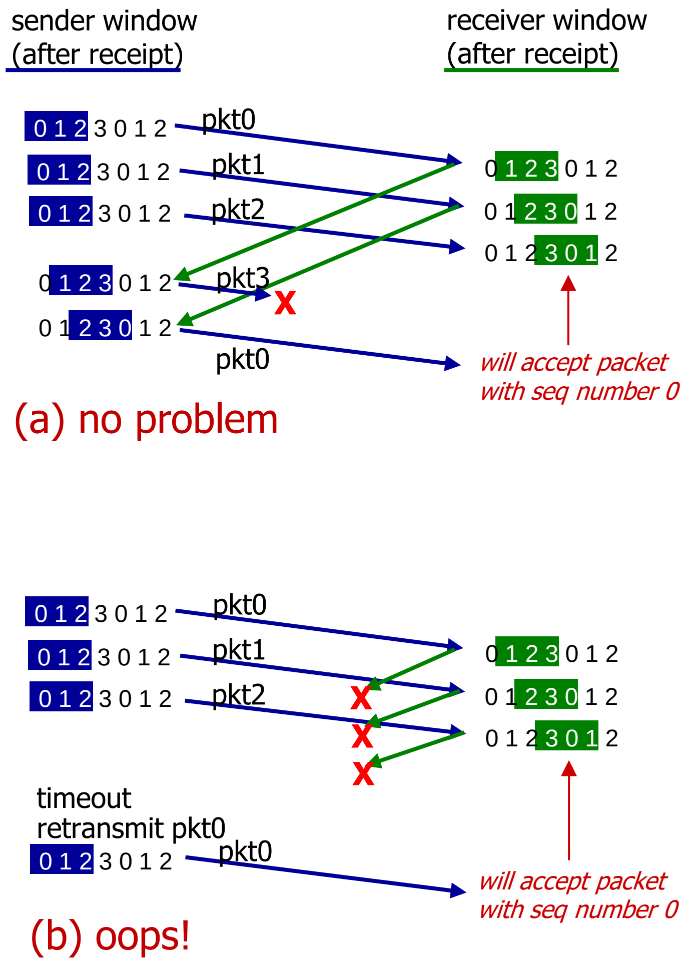
rcv pkt2; deliver pkt2, pkt3, pkt4, pkt5; send ack2

Q: what happens when ack2 arrives?

Selective repeat: a dilemma!

example:

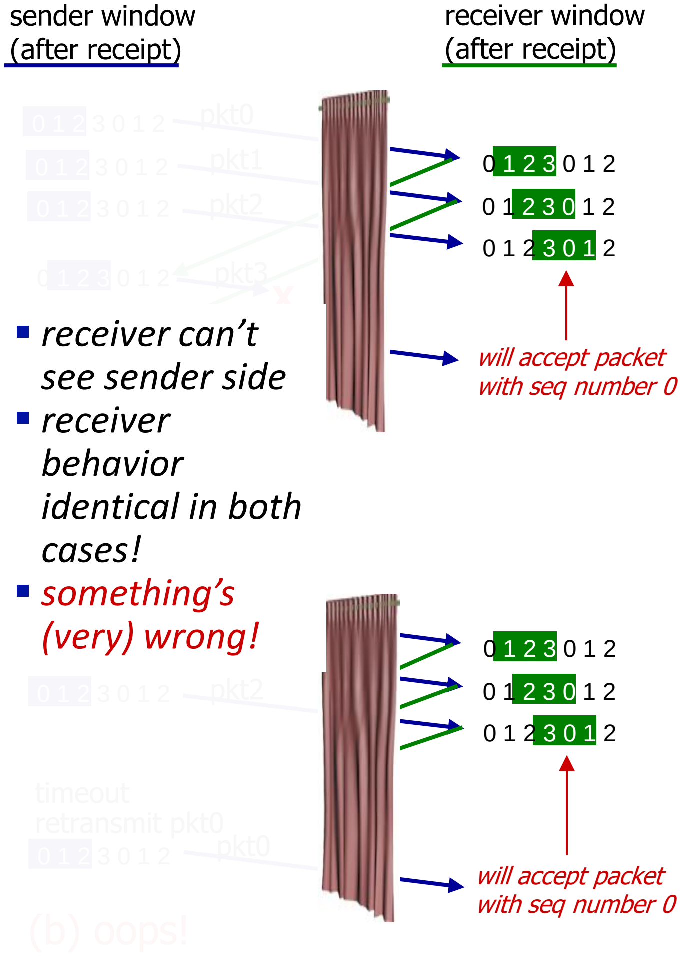
- seq #s: 0, 1, 2, 3 (base 4 counting)
- window size=3



Selective repeat: a dilemma!

example:

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



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

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

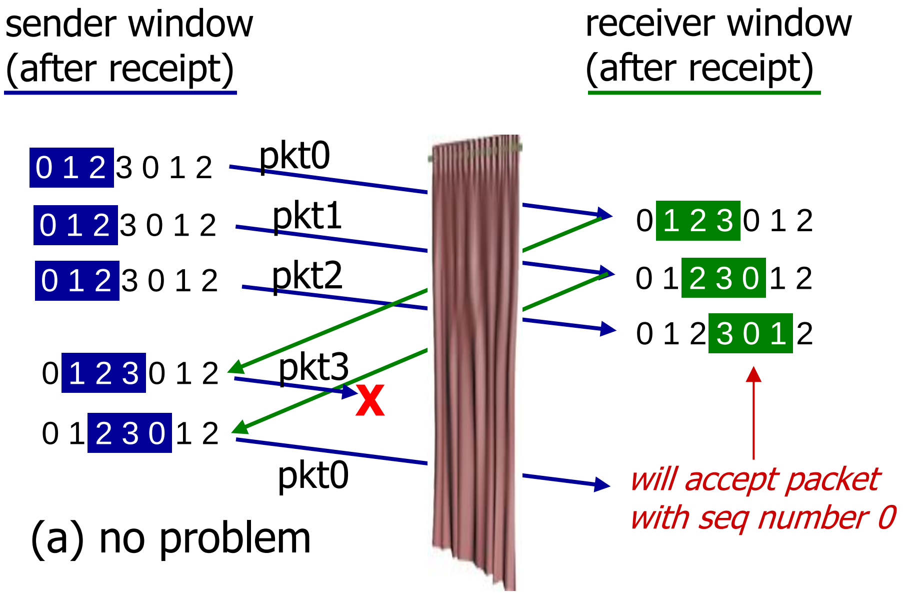
Selective repeat: dilemma

example:

- seq #' s: 0, 1, 2, 3
- window size=3
- receiver sees no difference in two scenarios!
- duplicate data accepted as new in (b) (new packet or retransmission?)

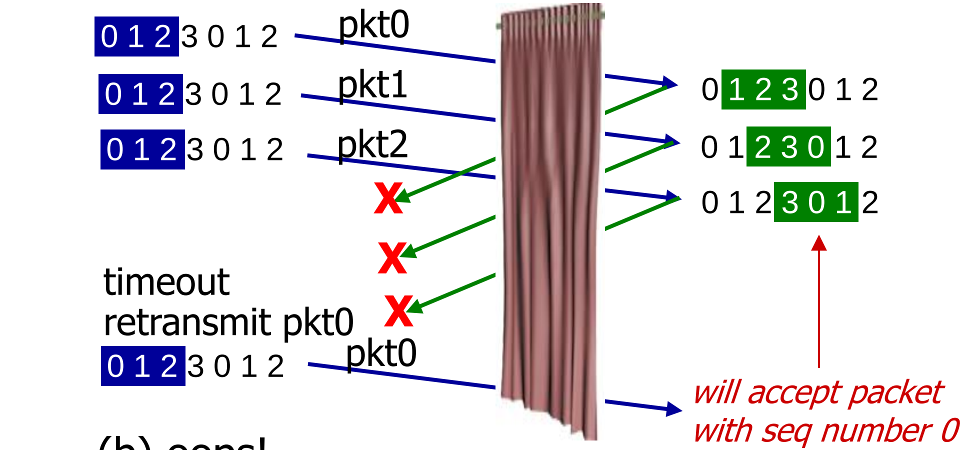
Q: what relationship between seq # size and window size to avoid problem in (b)?

Window size should be less than or equal to half the sequence number space in SR protocol. This is to avoid packets being recognized incorrectly. If the windows size is greater than half the sequence number space, then if an ACK is lost, the sender may send new packets that the receiver believes are retransmissions.



(a) no problem

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



(b) oops!

Major Differences between Stop & Wait, Go-Back-N (GBN) and Selective Repeat (SR) [1/2]

- Stop and Wait

The sender sends the packet and waits for the ACK (acknowledgement) of the packet. Once the ACK reaches the sender, it transmits the next packet in row. If the ACK is not received, it re-transmits the previous packet again.

- Go Back N

The sender sends N packets which is equal to the window size. Once the entire window is sent, the sender then waits for a cumulative ACK to send more packets. On the receiver end, it receives only in-order packets and discards out-of-order packets. As in case of packet loss, the entire window would be re-transmitted.

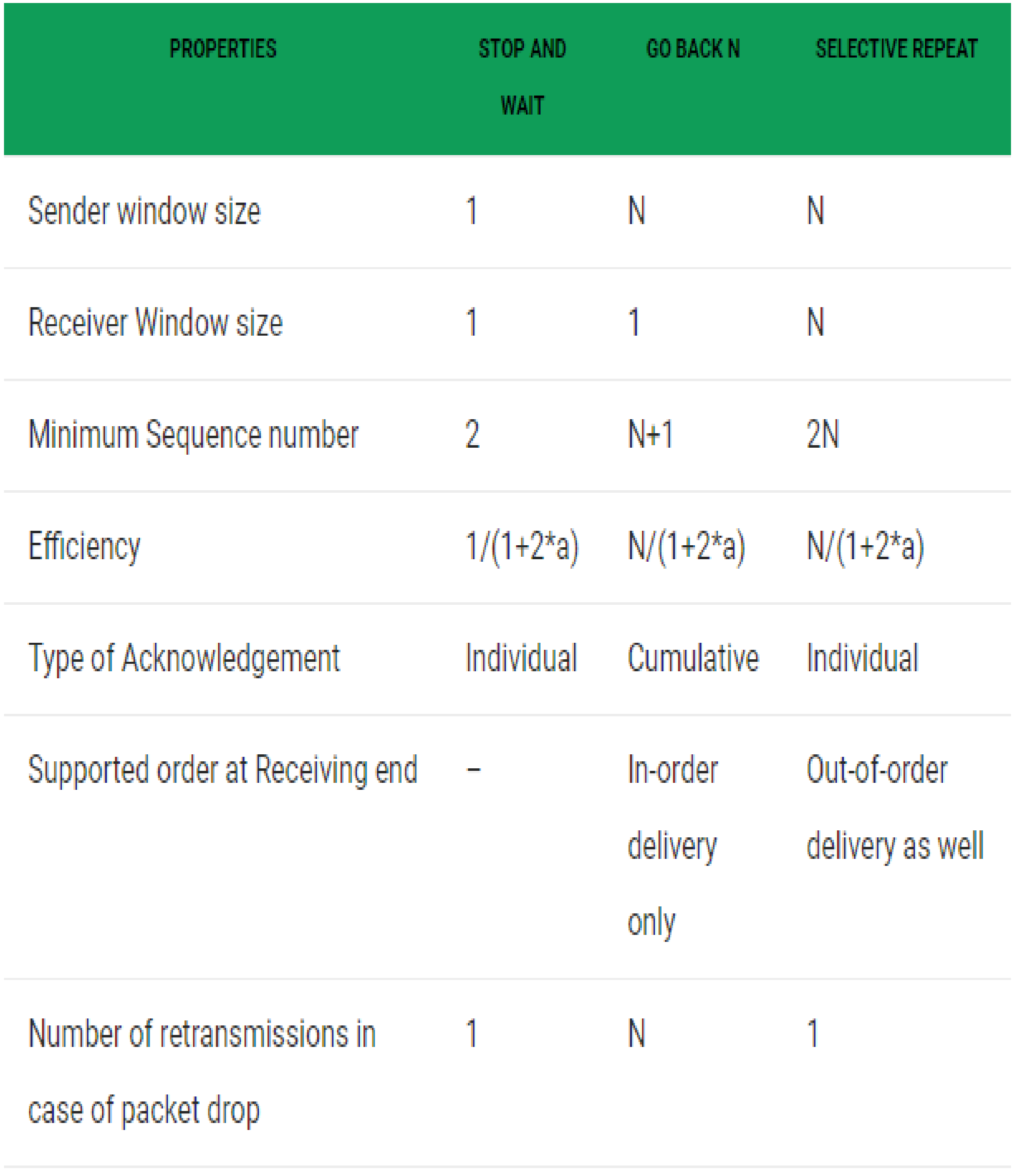
- Selective Repeat

The sender sends packet of window size N and the receiver acknowledges all packet whether they were received in order or not. In this case, the receiver maintains a buffer to contain out-of-order packets and sorts them. The sender selectively re-transmits the lost packet and moves the window forward.

URL for Interactive Animations:

https://wps.pearsoned.com/ecs_kurose_compnetw_6/216/55463/14198702.cw/index.html

Differences between Stop & Wait, Go-Back-N (GBN) and Selective Repeat (SR) [2/2]



PROPERTIES	STOP AND WAIT	GO BACK N	SELECTIVE REPEAT
Sender window size	1	N	N
Receiver Window size	1	1	N
Minimum Sequence number	2	N+1	2N
Efficiency	1/(1+2*a)	N/(1+2*a)	N/(1+2*a)
Type of Acknowledgement	Individual	Cumulative	Individual
Supported order at Receiving end	–	In-order delivery only	Out-of-order delivery as well
Number of retransmissions in case of packet drop	1	N	1

Where,

- *a = Ratio of Propagation delay and Transmission delay*
- *At N=1, Go Back N is effectively reduced to Stop and Wait*
- *As Go Back N acknowledges the packets cumulatively, it rejects out-of-order packets*
- *As Selective Repeat supports receiving out-of-order packets (it sorts the window after receiving the packets), it uses Independent Acknowledgement to acknowledge the packets.*