

Announcement



- Midterm delays to 3/17
- Project I will be posted this weekend, which is due on 3/17

Last Time



- Transport Layer: logical communication between processes
- UDP & TCP: multiplexing, demultiplexing, error-detection code
- TCP: reliable data transfer, flow control, and congestion control
- Multiplexing & Demultiplexing
- Identifiers for UDP socket and TCP socket
- Reliable data transfer



rdt2.0: channel with bit errors

- ❖ underlying channel may flip bits in packet
 - checksum to detect bit errors
- ❖ *the question: how to recover from errors:*
 - *acknowledgements (ACKs)*: receiver explicitly tells sender that pkt received OK
 - *negative acknowledgements (NAKs)*: receiver explicitly tells sender that pkt had errors
 - sender retransmits pkt on receipt of NAK
- ❖ new mechanisms in `rdt2.0` (beyond `rdt1.0`):
 - error detection
 - feedback: control msgs (ACK,NAK) from receiver to sender
 - retransmission

rdt2.0 has a fatal flaw!

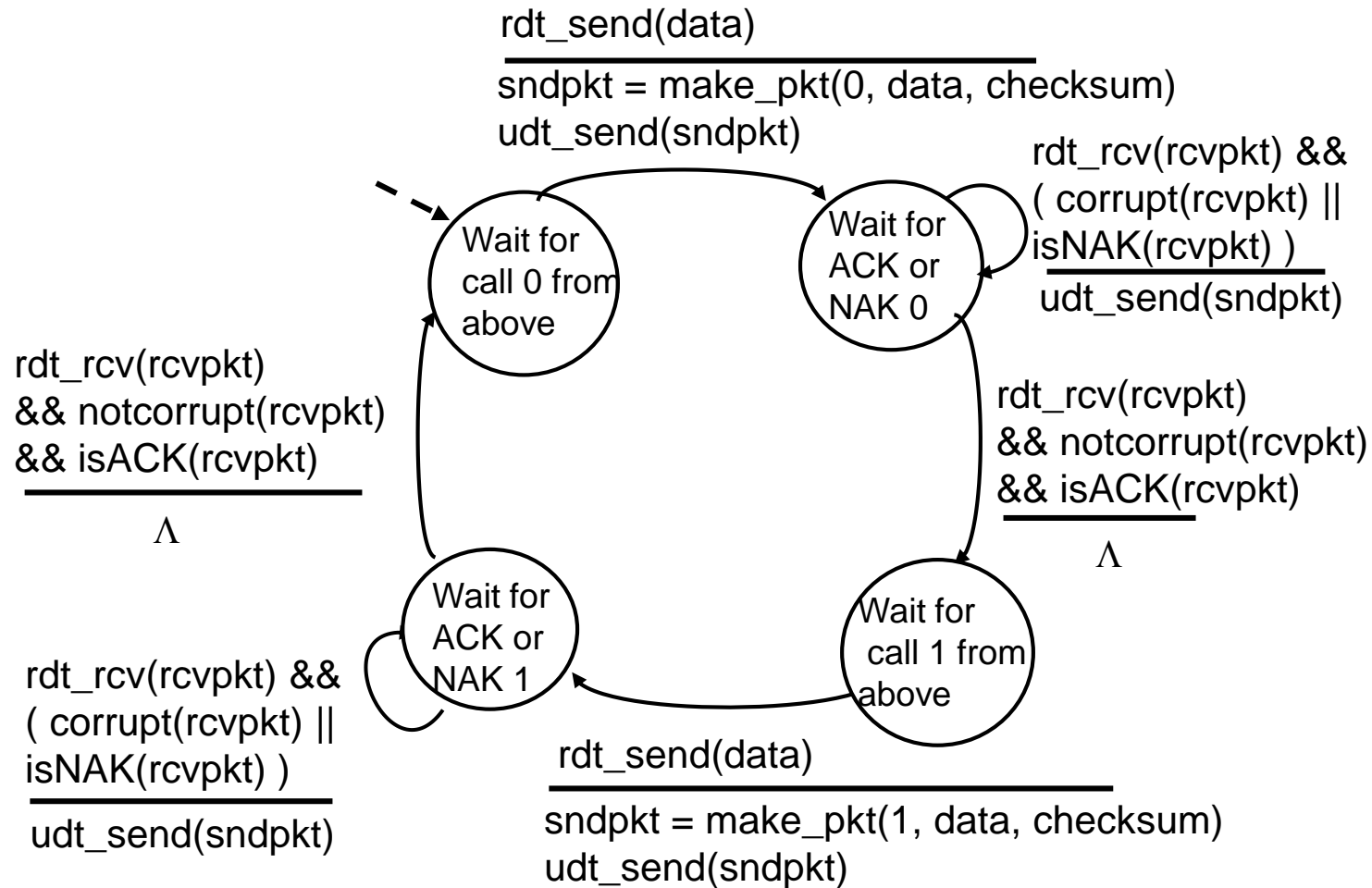
what happens if ACK/NAK corrupted?

- ❖ sender doesn't know what happened at receiver!
- ❖ can't just retransmit: possible duplicate

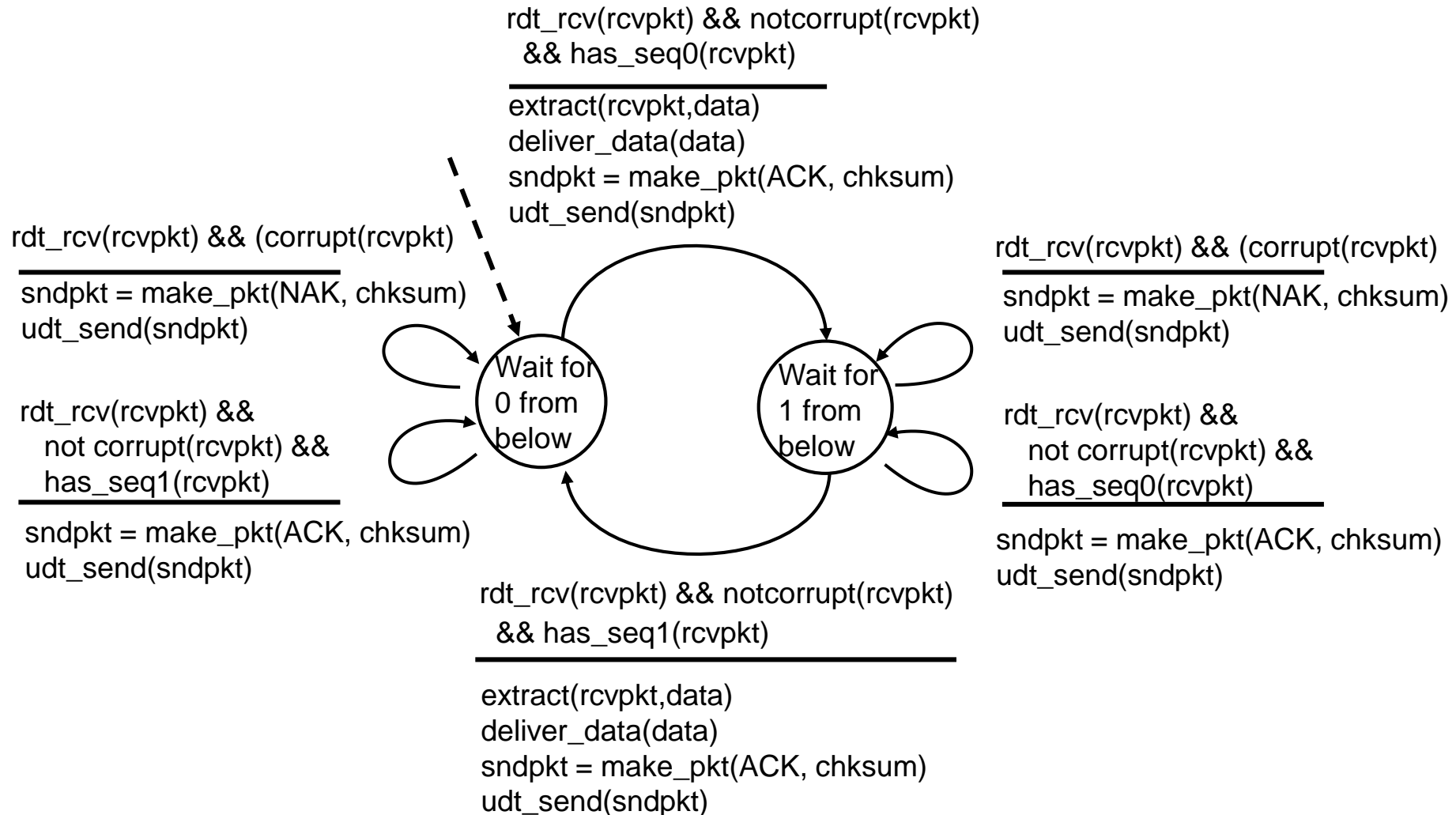
handling duplicates:

- ❖ sender retransmits current pkt if ACK/NAK corrupted
- ❖ sender adds *sequence number* to each pkt
- ❖ receiver discards (doesn't deliver up) duplicate pkt

rdt2.1: sender, handles garbled ACK/NAKs



rdt2.1: receiver, handles garbled ACK/NAKs



rdt2.2: a NAK-free protocol

- ❖ same functionality as rdt2.1, using ACKs only
- ❖ instead of NAK, receiver sends ACK for last pkt received OK
 - receiver must *explicitly* include seq # of pkt being ACKed
- ❖ duplicate ACK at sender results in same action as NAK: *retransmit current pkt*

rdt3.0: channels with errors and loss

new assumption: underlying channel can also lose packets (data, ACKs)

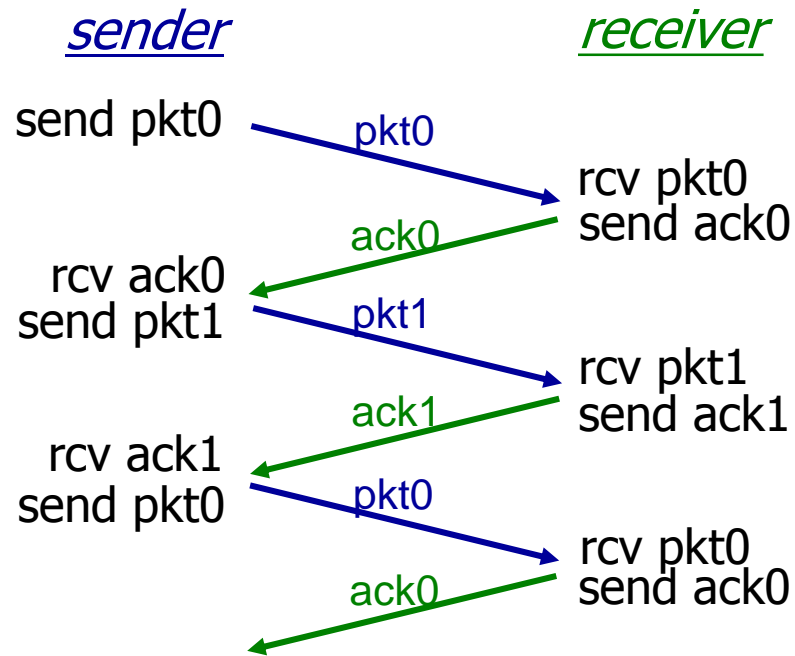
- checksum, seq. #, ACKs, retransmissions will be of help ... but not enough

new concerns: how to detect and address packet loss

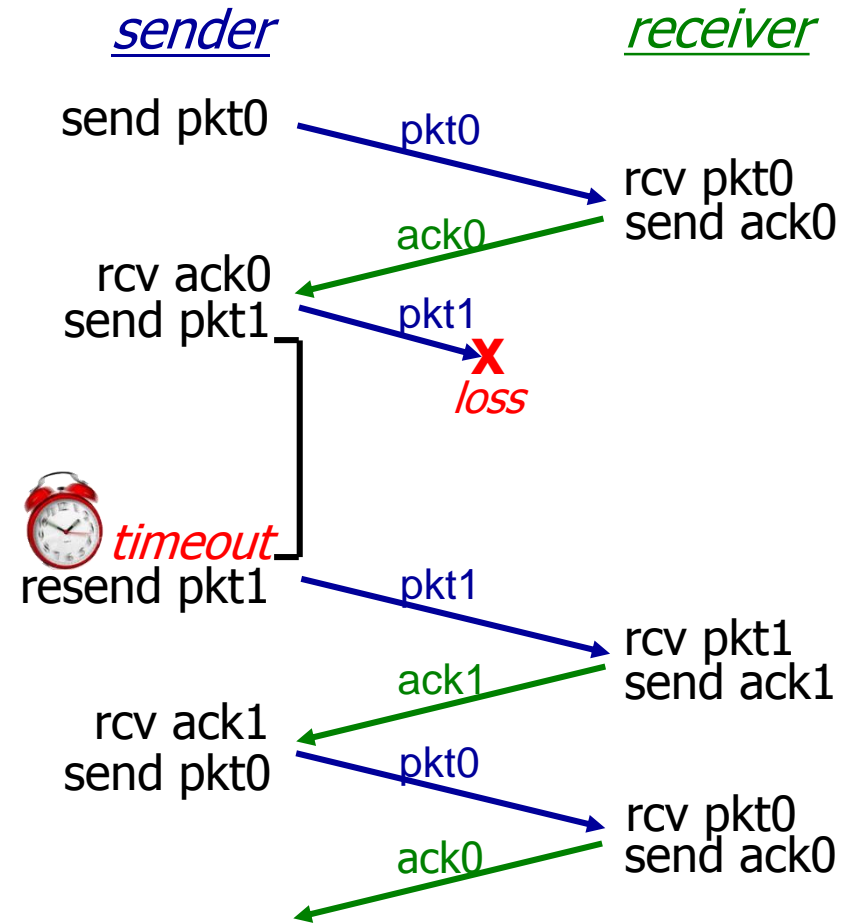
approach: sender waits “reasonable” amount of time for ACK

- ❖ retransmits if no ACK received in this time
- ❖ if pkt (or ACK) just delayed (not lost):
 - retransmission will be duplicate, but seq. #'s already handles this
 - receiver must specify seq # of pkt being ACKed
- ❖ requires countdown timer

rdt3.0 in action

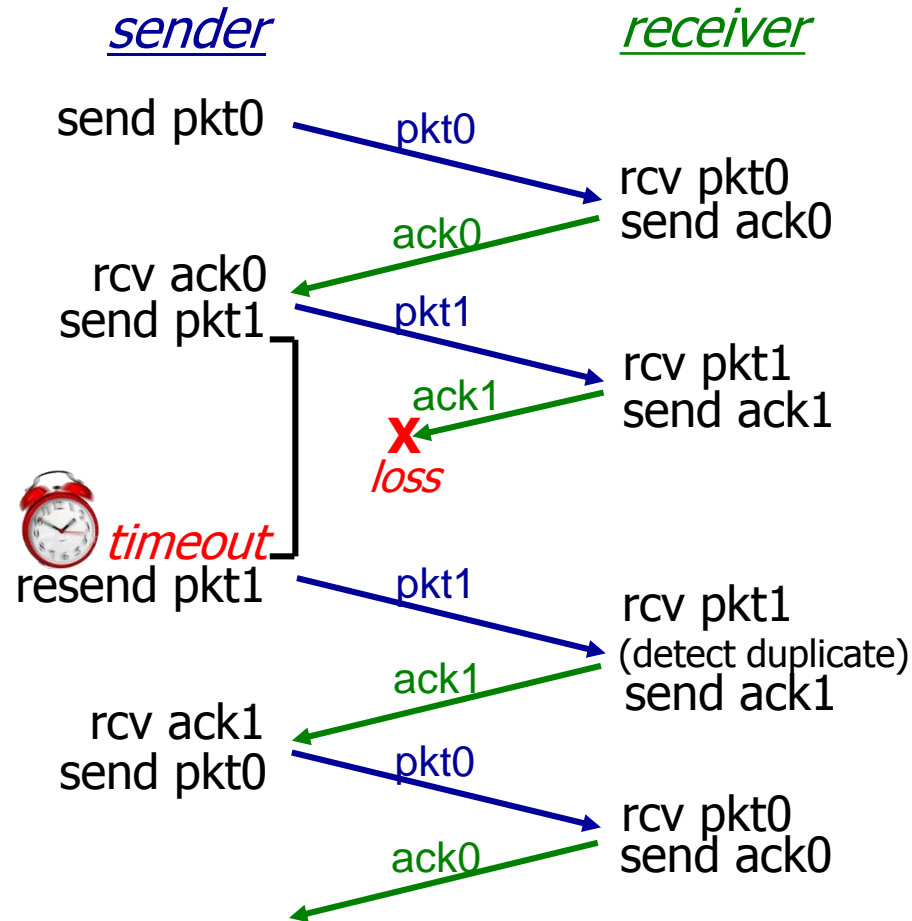


(a) no loss

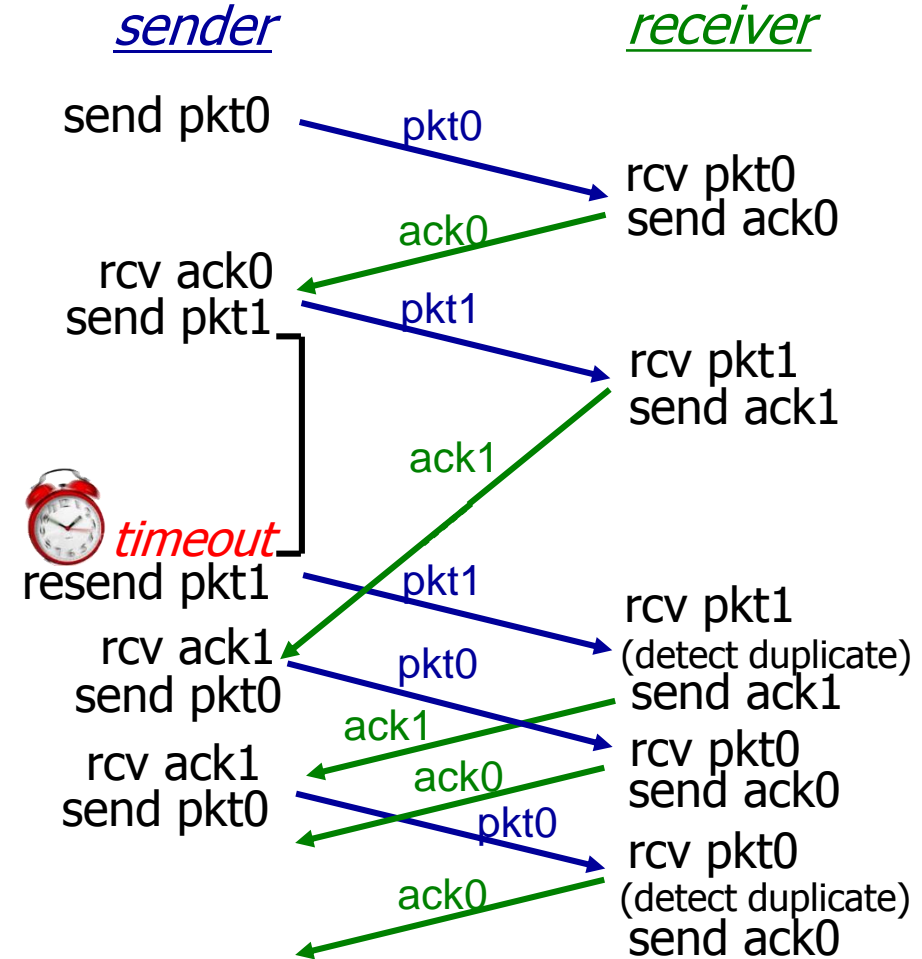


(b) packet loss

rdt3.0 in action



(c) ACK loss

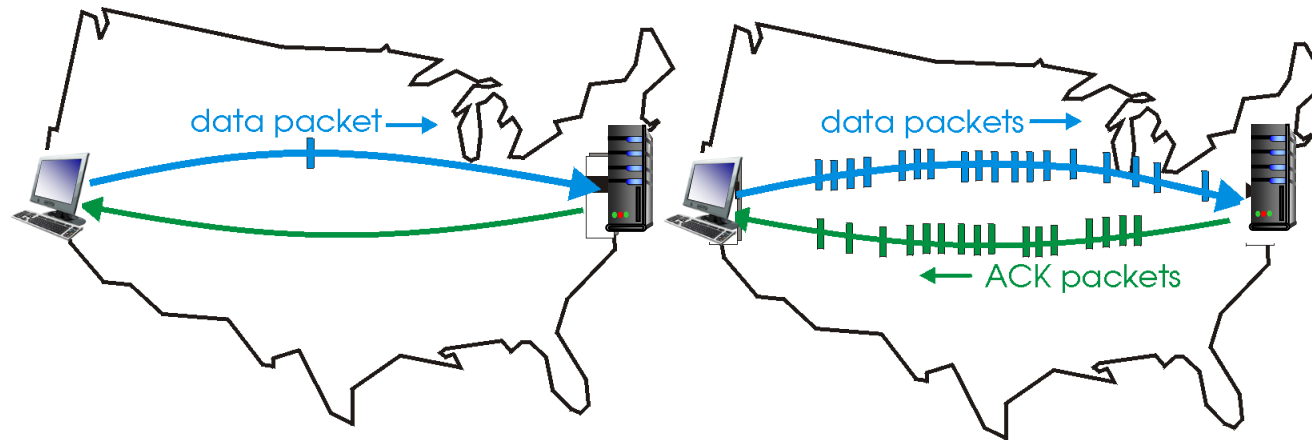


(d) premature timeout/ delayed ACK

Pipelined protocols

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

- 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 protocols: overview

Go-back-N:

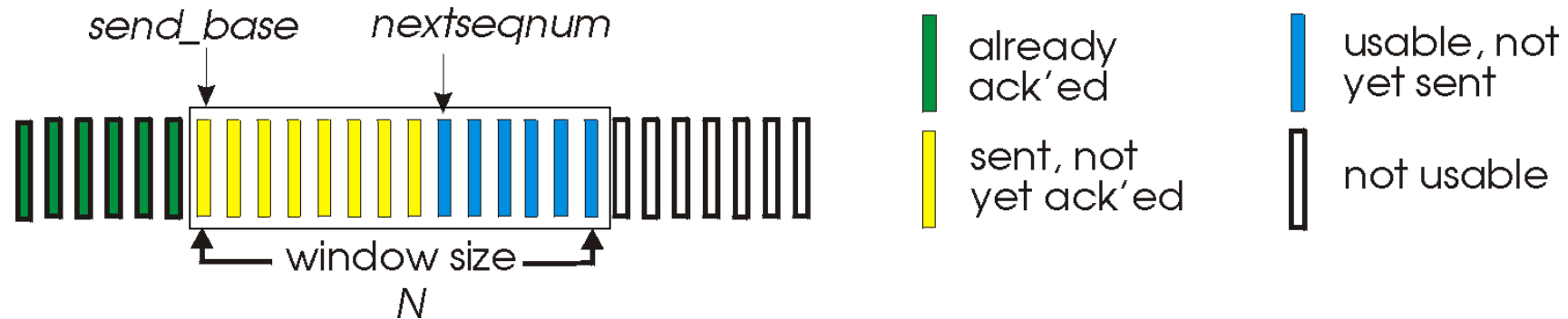
- ❖ sender can have up to N unacked packets in pipeline
- ❖ receiver only sends *cumulative ack*
 - doesn't ack packet if there's a gap
- ❖ sender has timer for oldest unacked packet
 - when timer expires, retransmit *all* unacked packets

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

- ❖ k-bit seq # in pkt header
- ❖ “window” of up to N, consecutive unack’ed pkts allowed



- ❖ ACK(n): ACKs all pkts up to, including seq # n - “*cumulative ACK*”
- ❖ timer for oldest in-flight pkt
- ❖ *timeout(n)*: retransmit packet n and all higher seq # pkts in window

GBN 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