

# Chapter 3

## Transport Layer

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# Chapter 3 Outline of Lecture 8

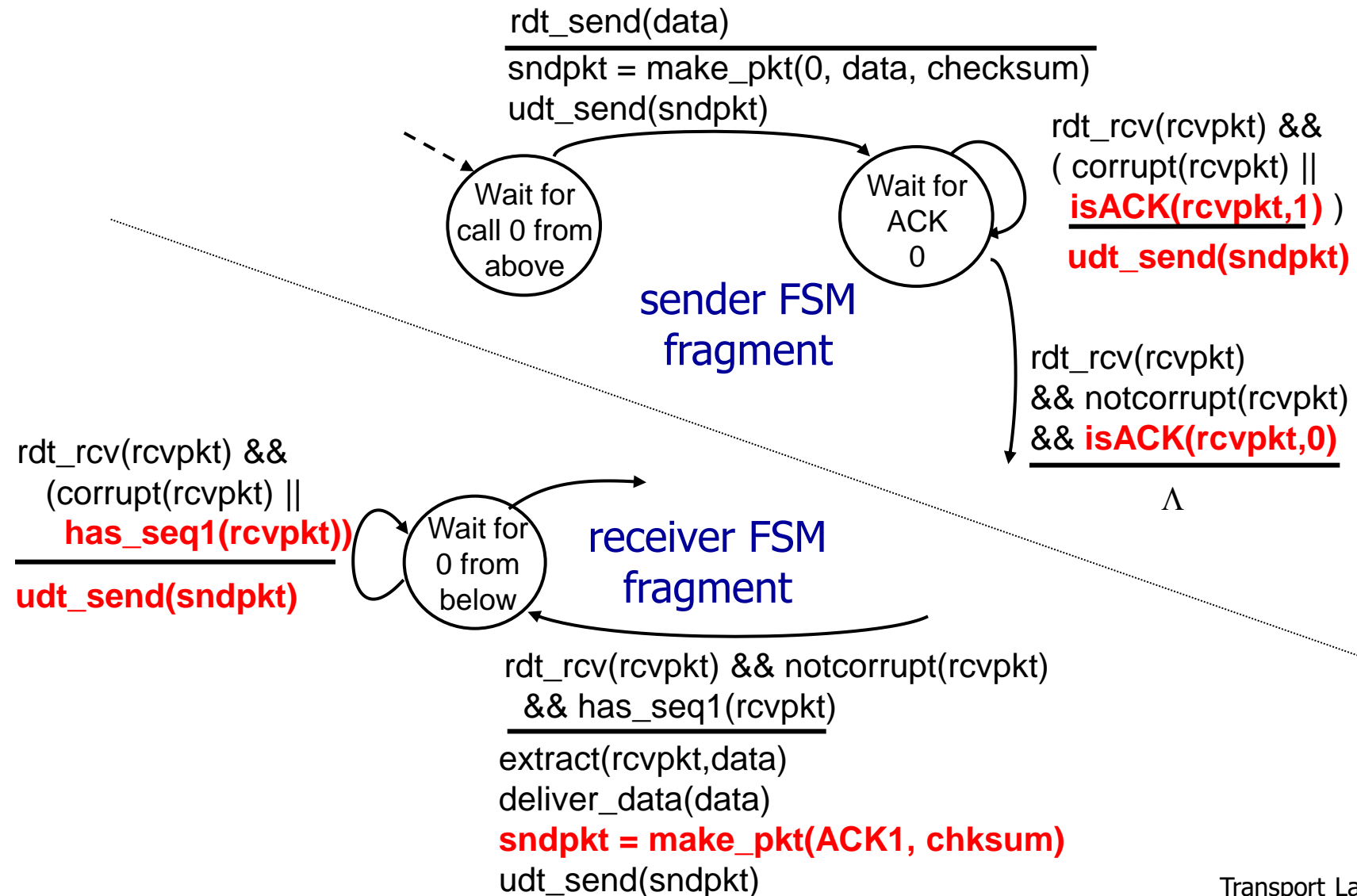
## 3.4 principles of reliable data transfer

- ❑ rdt2.2: a NAK-free protocol
- ❑ rdt3.0: channels with errors and loss
- ❑ Pipelined protocols

# 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*

# rdt2.2: sender, receiver fragments



# rdt3.0: channels with errors *and* loss

## new assumption:

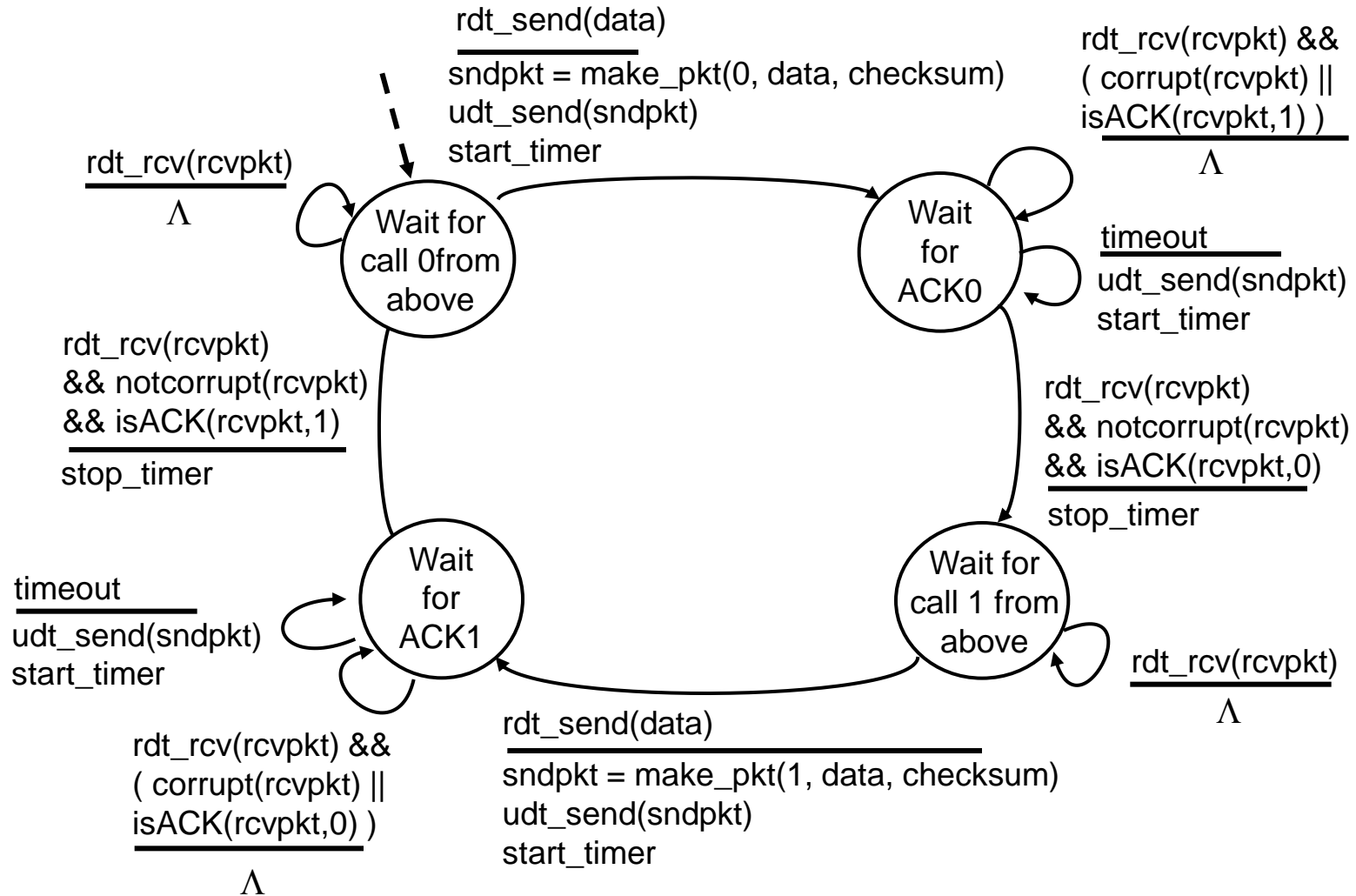
underlying channel can also lose packets (data, ACKs)

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

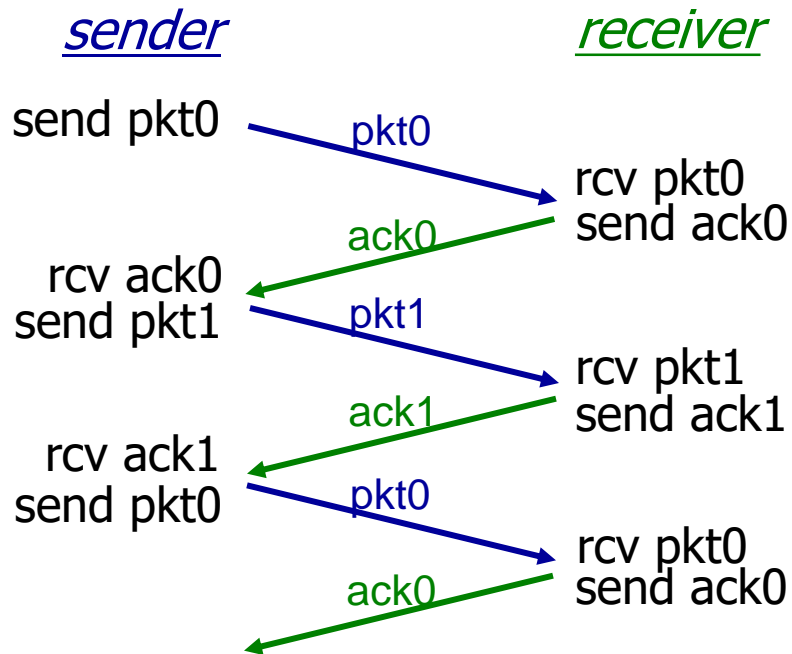
approach: sender waits “reasonable” amount of time for ACK

- ❖ 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

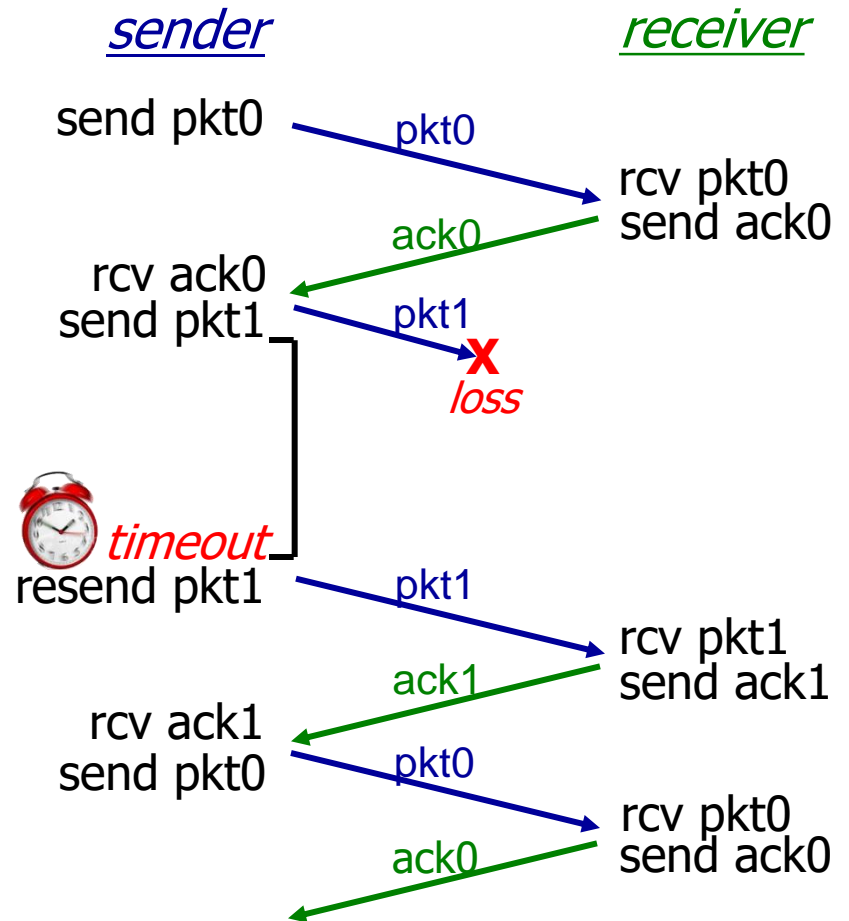
# rdt3.0 sender



# rdt3.0 in action

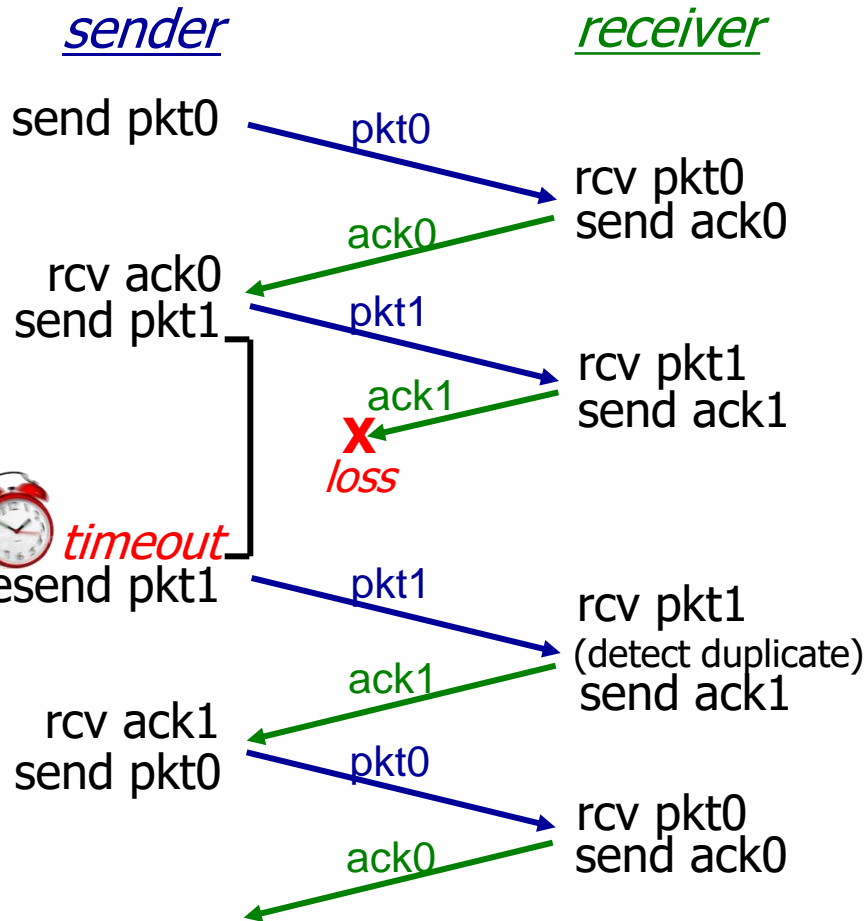


(a) no loss

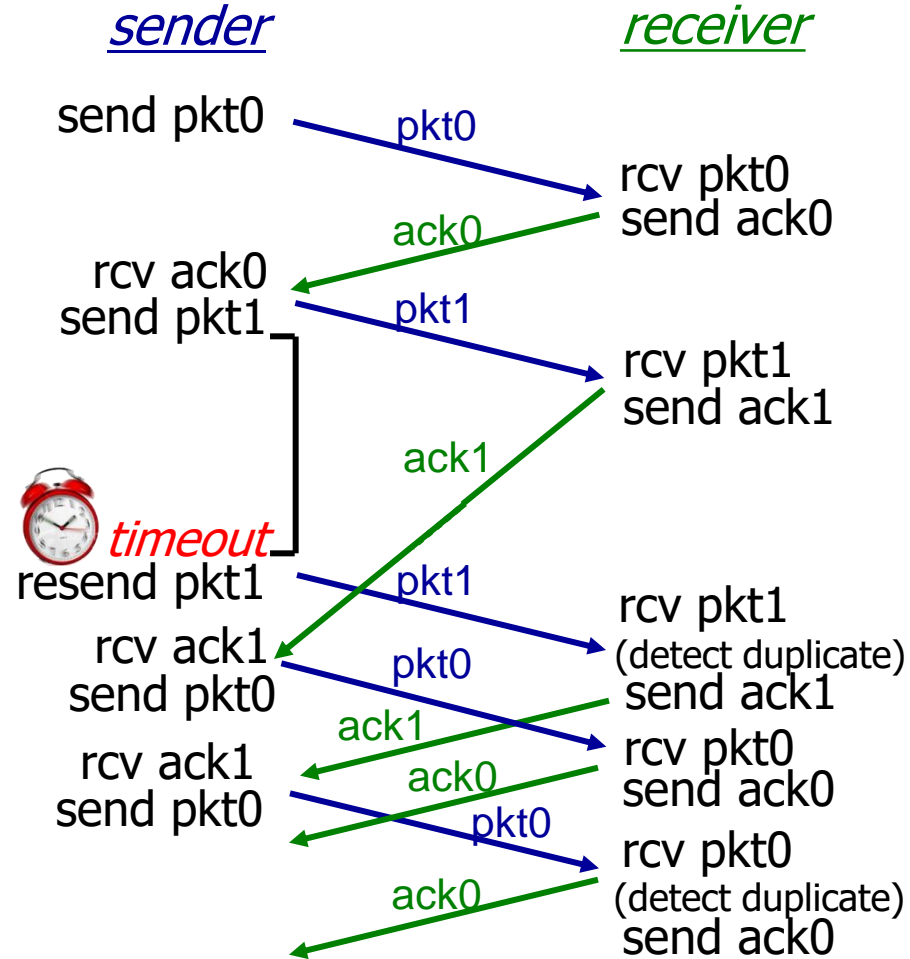


(b) packet loss

# rdt3.0 in action



(c) ACK loss



(d) premature timeout/ delayed ACK



# Performance of rdt3.0

- ❖ rdt3.0 is correct, but performance stinks
- ❖ e.g.: 1 Gbps link, 15 ms prop. delay, 8000 bit packet:

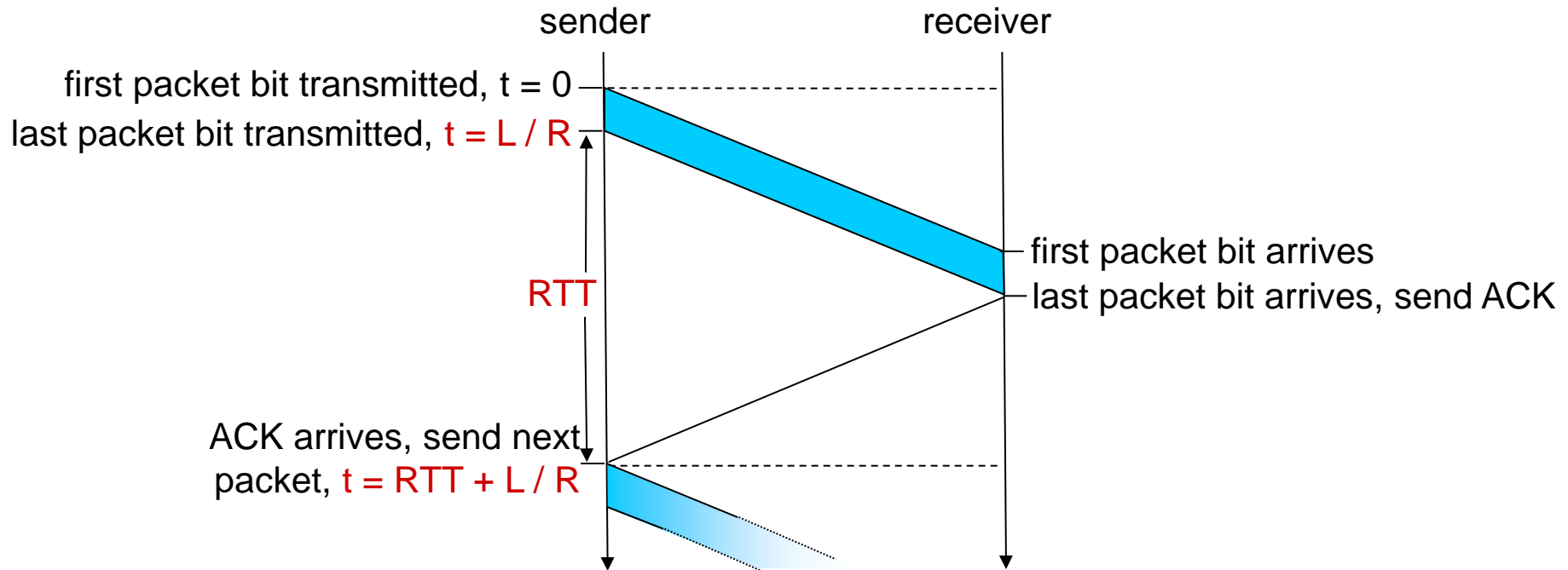
$$D_{trans} = \frac{L}{R} = \frac{8000 \text{ bits}}{10^9 \text{ bits/sec}} = 8 \text{ microseconds}$$

- $U_{sender}$ : **utilization** – fraction of time sender busy sending

$$U_{sender} = \frac{L / R}{RTT + L / R} = \frac{.008}{30.008} = 0.00027$$

- if RTT=30 msec, 1KB pkt every 30 msec: 33kB/sec thruput over 1 Gbps link
- ❖ network protocol limits use of physical resources!

# rdt3.0: stop-and-wait operation

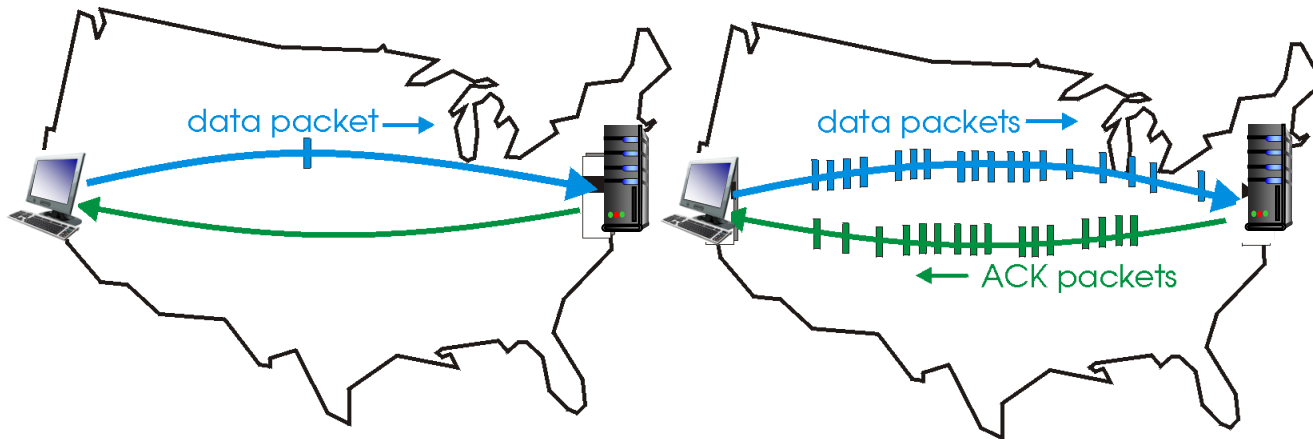


$$U_{\text{sender}} = \frac{L / R}{RTT + L / R} = \frac{.008}{30.008} = 0.00027$$

# 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

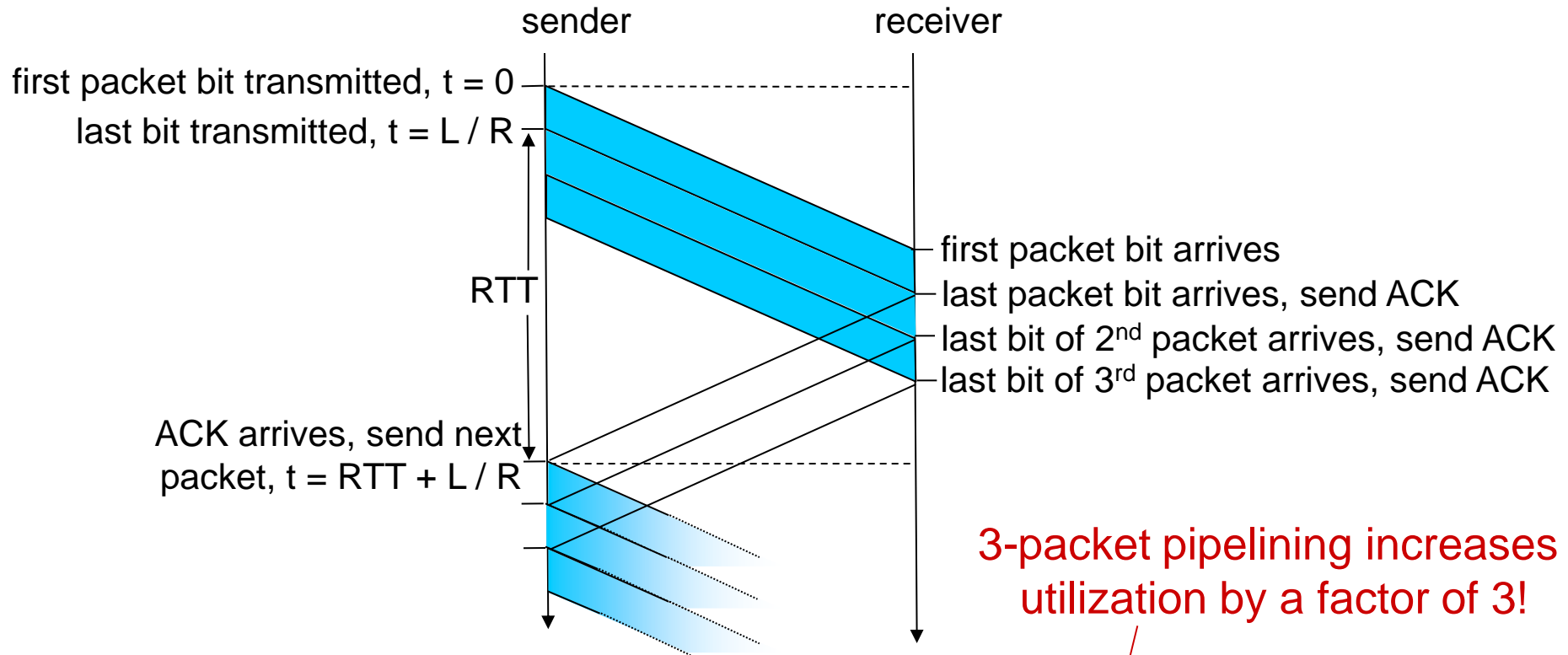


(a) a stop-and-wait protocol in operation

(b) a pipelined protocol in operation

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

# 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:

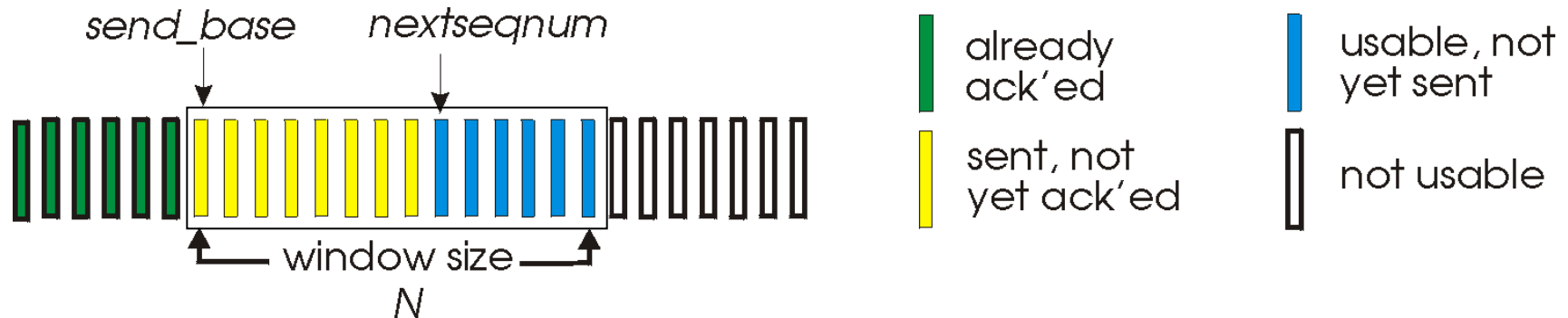
- ❖ sender can have up to N unacked packets in pipeline
- ❖ receiver only sends *cumulative ack*
  - doesn't ack packet if there's a gap
- ❖ sender has timer for oldest unacked packet
  - when timer expires, retransmit *all* unacked packets

## 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

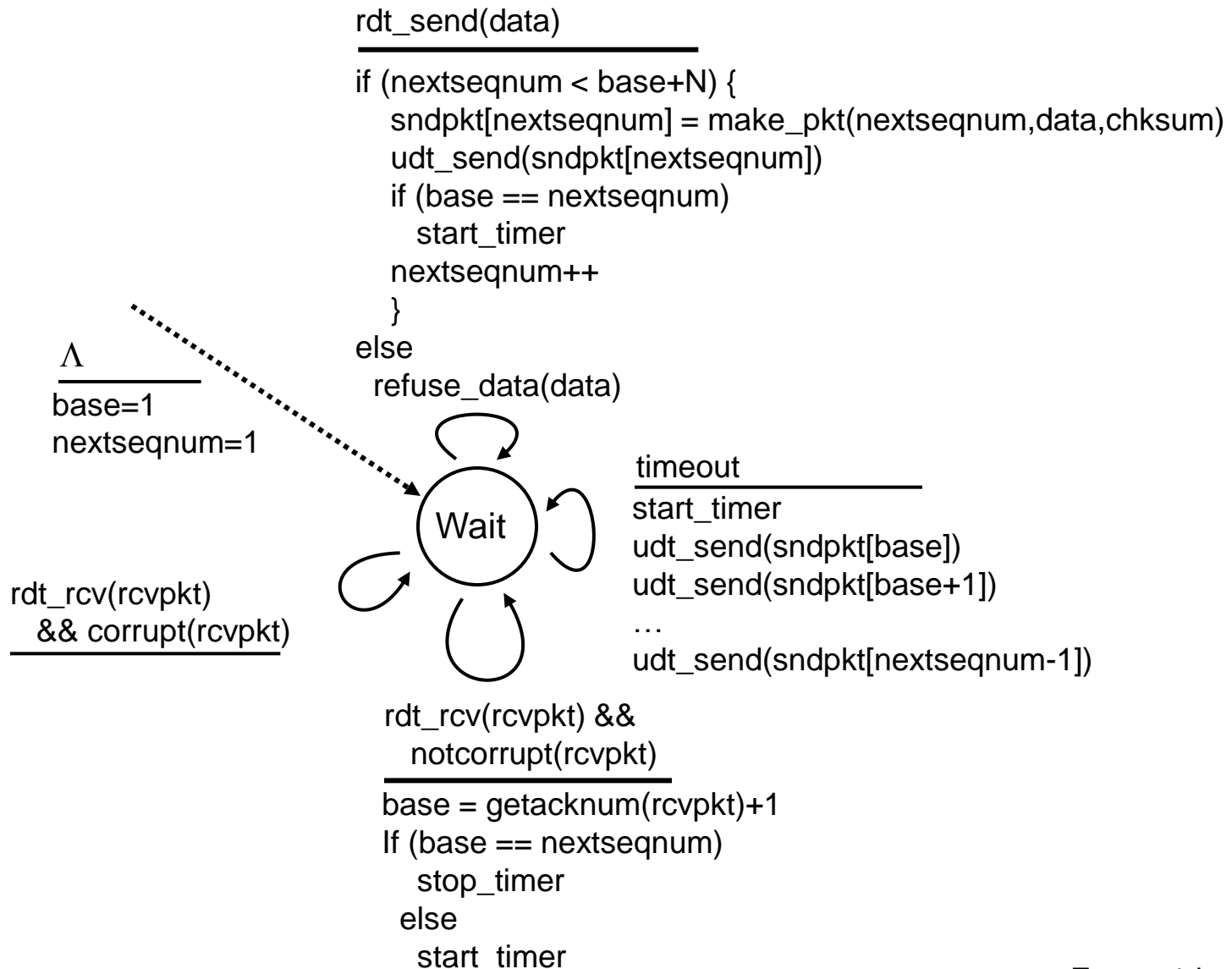
# Go-Back-N: sender

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

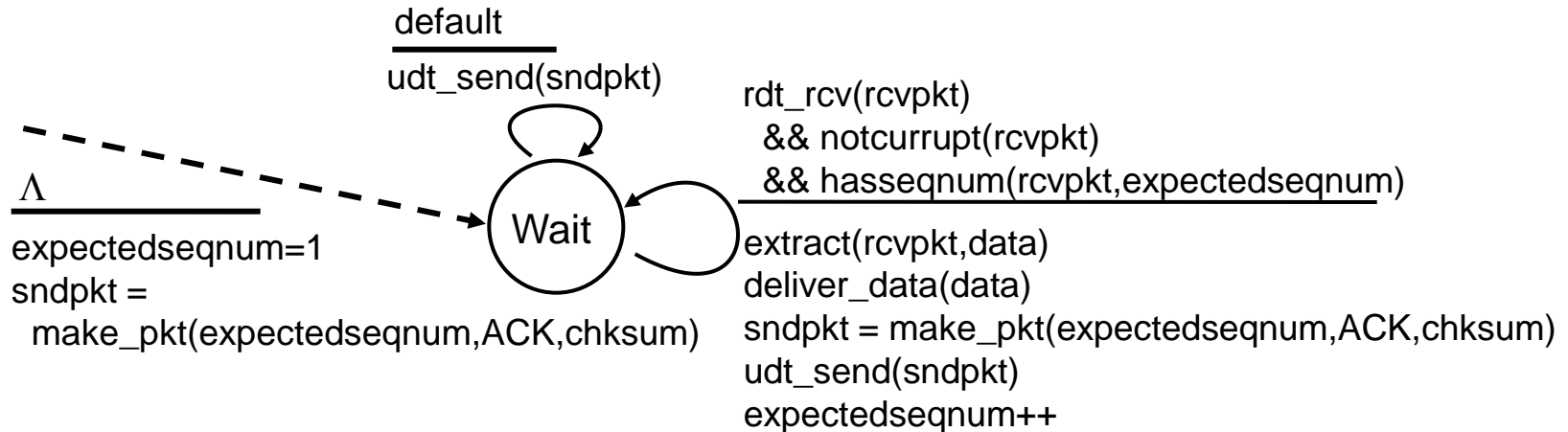


- ❖ ACK(n): ACKs all pkts up to, including seq # n - “cumulative ACK”
  - may receive duplicate ACKs (see receiver)
- ❖ timer for oldest in-flight pkt
- ❖ timeout(n): retransmit packet n and all higher seq # pkts in window

# GBN: sender extended FSM



# GBN: receiver extended FSM



ACK-only: always send ACK for correctly-received pkt with highest *in-order* seq #

- may generate duplicate ACKs
- need only remember **expectedseqnum**

❖ out-of-order pkt:

- discard (don't buffer): *no receiver buffering!*
- re-ACK pkt with highest in-order seq #



# 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

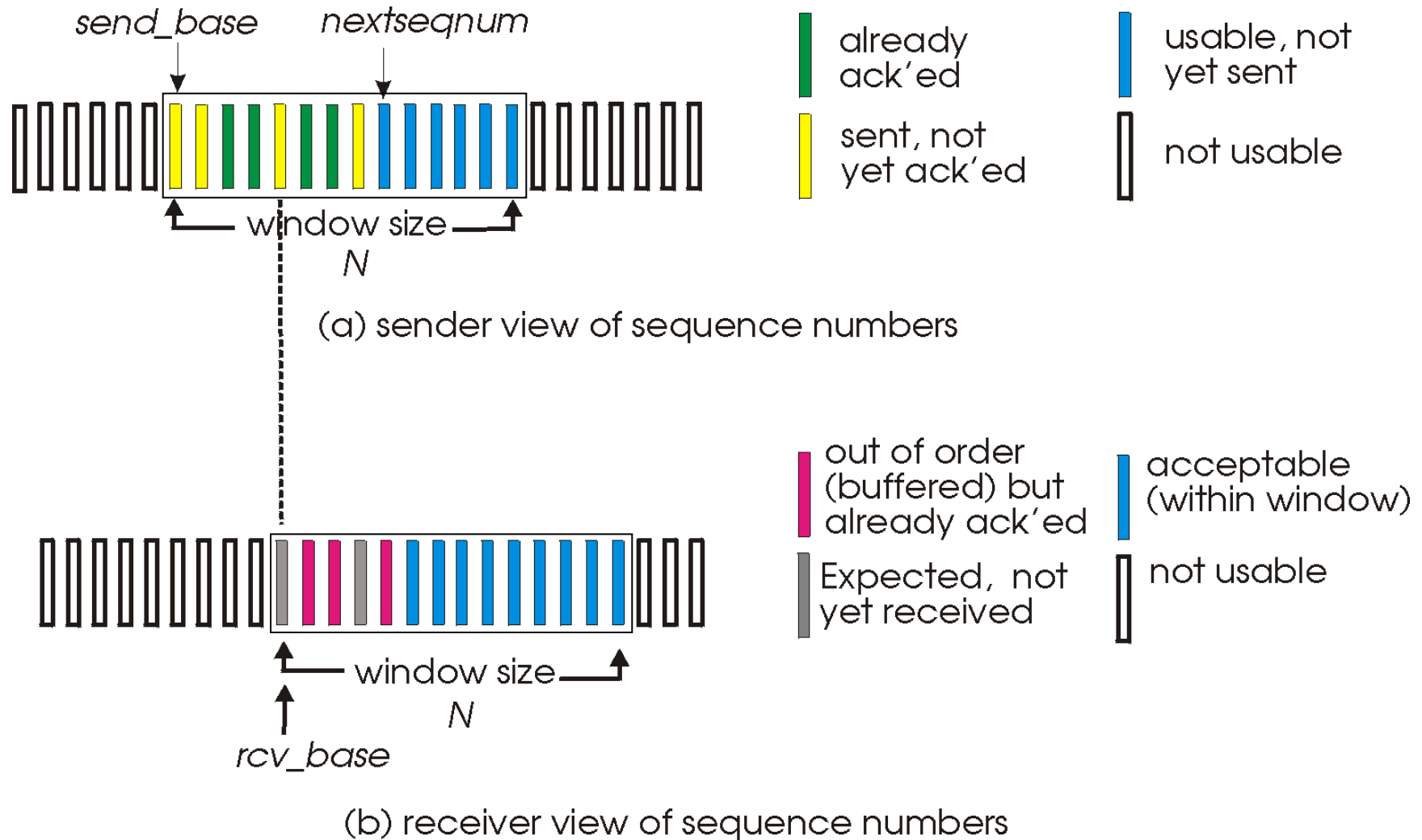
receive pkt5, discard,  
(re)send ack1

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

# Selective repeat

- ❖ receiver *individually* acknowledges all correctly received pkts
  - buffers pkts, as needed, for eventual in-order delivery to upper layer
- ❖ sender only resends pkts for which ACK not received
  - sender timer for each unACKed pkt
- ❖ sender window
  - $N$  consecutive seq #'s
  - limits seq #s of sent, unACKed pkts

# Selective repeat: sender, receiver windows



# Selective repeat

## sender

### data from above:

- ❖ if next available seq # in window, send pkt

### timeout(n):

- ❖ resend pkt n, restart timer

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

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

## receiver

### pkt n in [rcvbase, rcvbase+N-1]

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

### pkt 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

record ack4 arrived

record ack5 arrived

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: dilemma

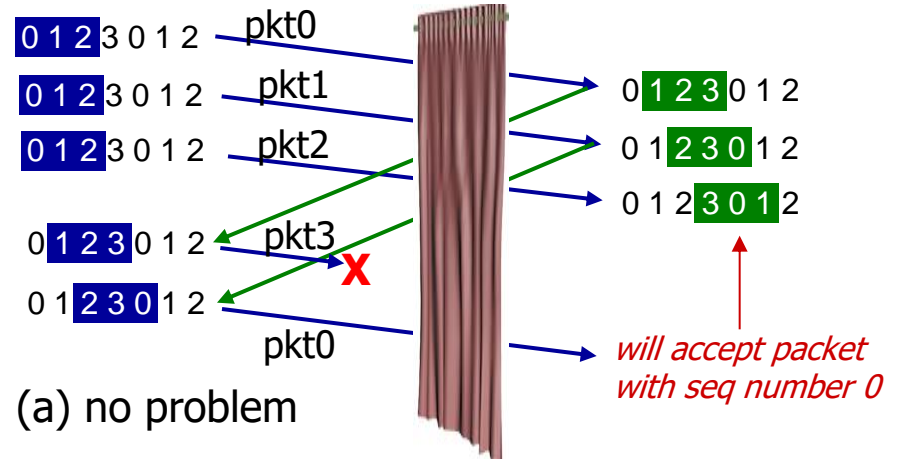
example:

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

**Q:** what relationship between seq # size and window size to avoid problem in (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!*

