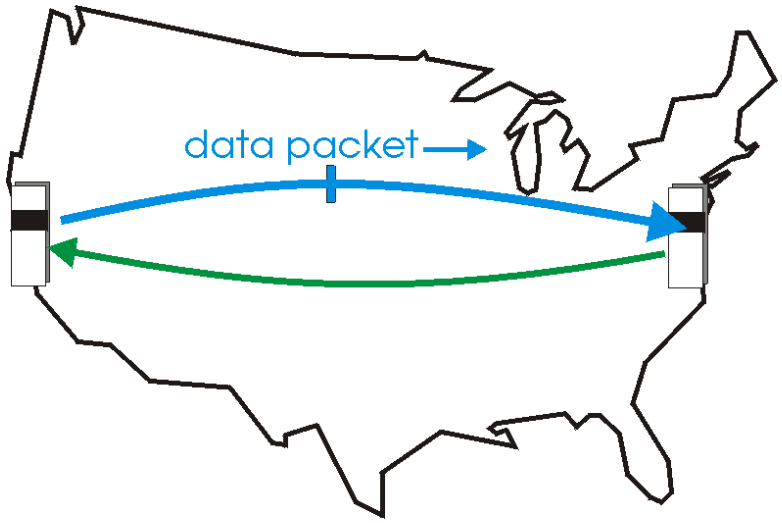
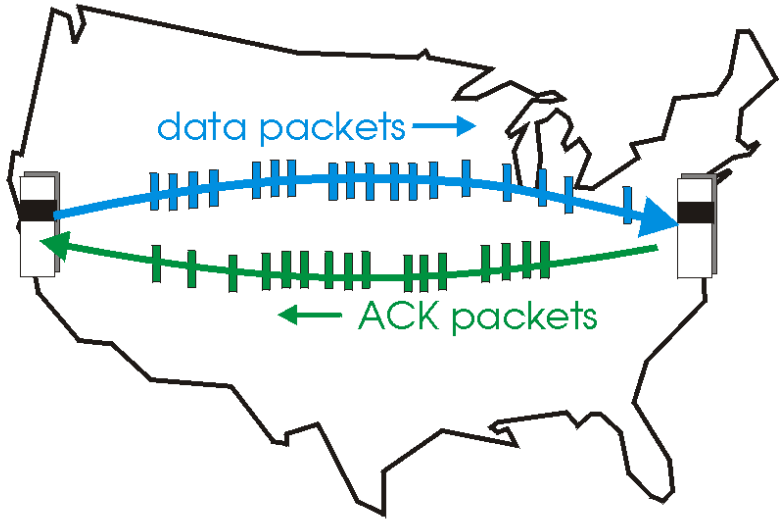
# Pipelined reliable transport



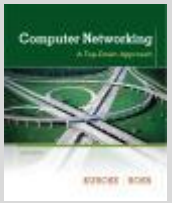

(a) a stop-and-wait protocol in operation




(b) a pipelined protocol in operation







# Chapter 3 outline

3.1 Transport-layer services

3.2 Multiplexing and demultiplexing

3.3 Connectionless transport: UDP

3.4 Principles of reliable data transfer

3.5 Connection-oriented transport: TCP

- Segment structure
- Reliable data transfer
- Flow control
- Connection management

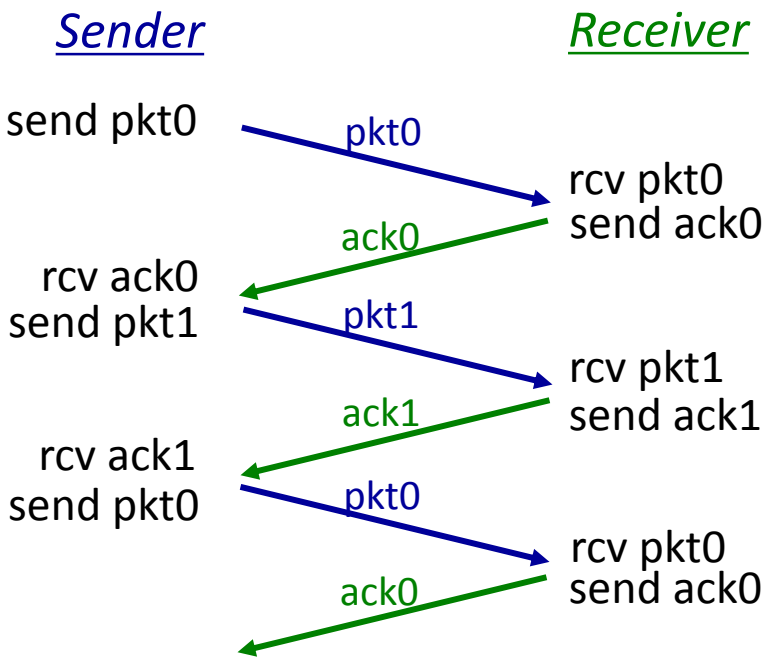
3.6 Principles of congestion control

3.7 TCP congestion control

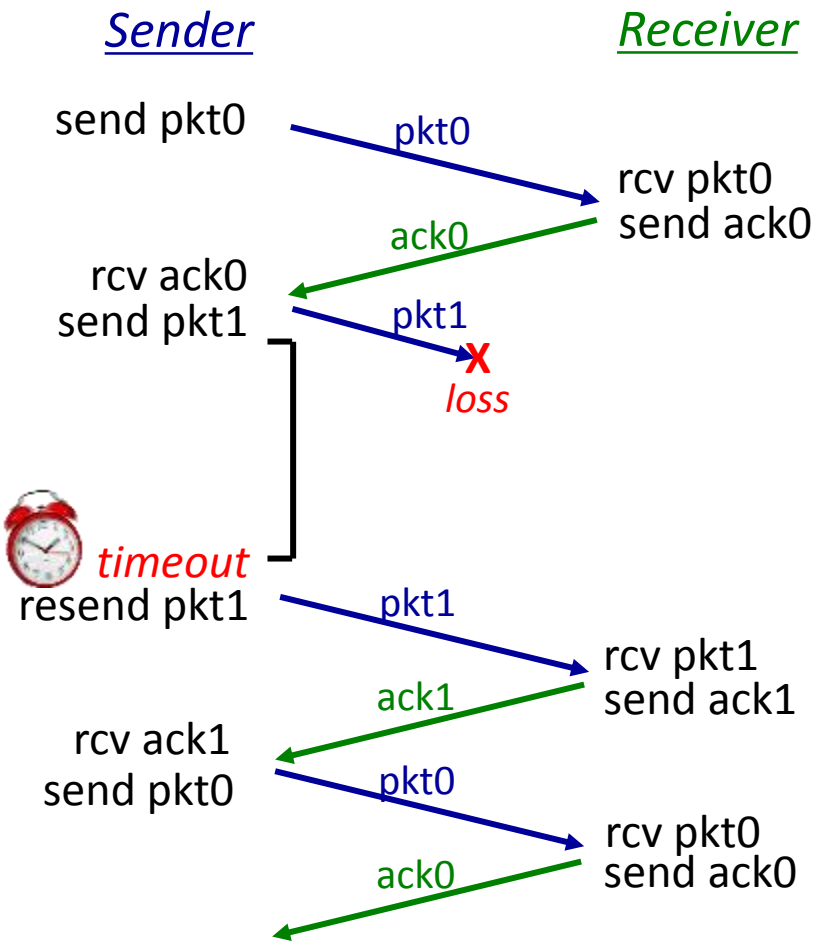
# Overview

- Reliable data transfer
  - Real networks, packets get corrupted, lost or delayed
  - Use ACKs, sequences numbers, timers to make reliable
  - e.g. rdt3.0 using stop-and-wait-protocol
  - Problem: way to slow for fat long pipes
- Pipelined reliable data transfer
  - Good-Back-N (GBN) protocol
  - Selective Repeat (SR) protocol

# rdt3.0 in action

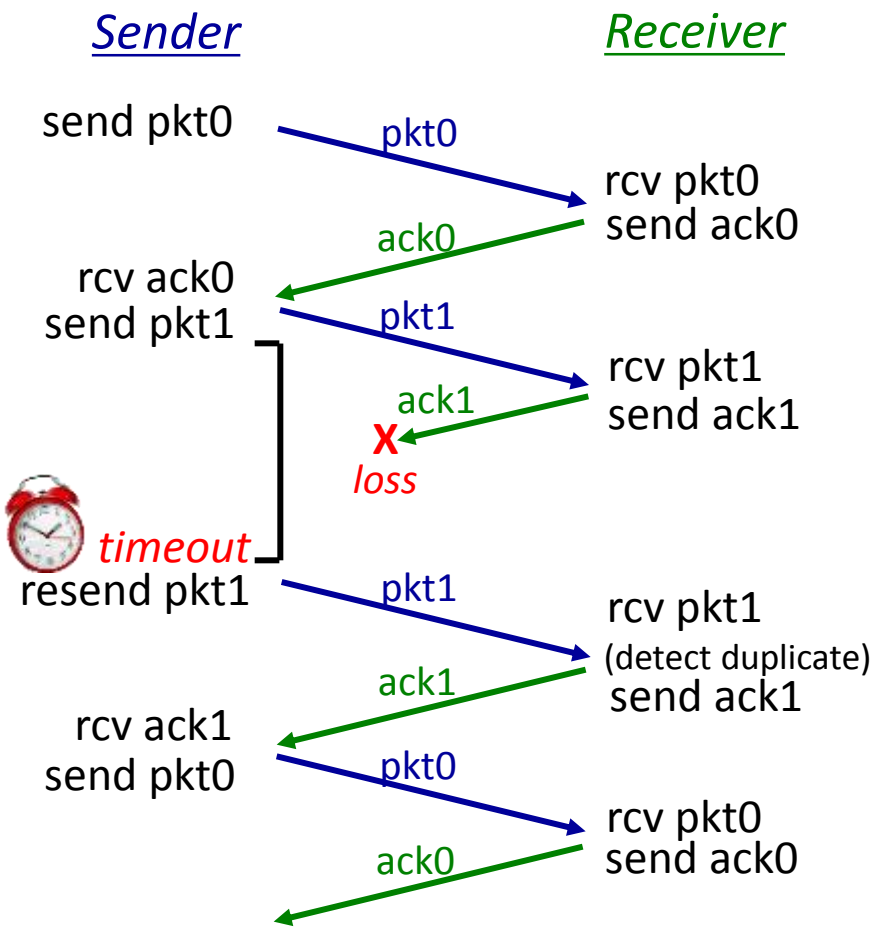



(a) no loss

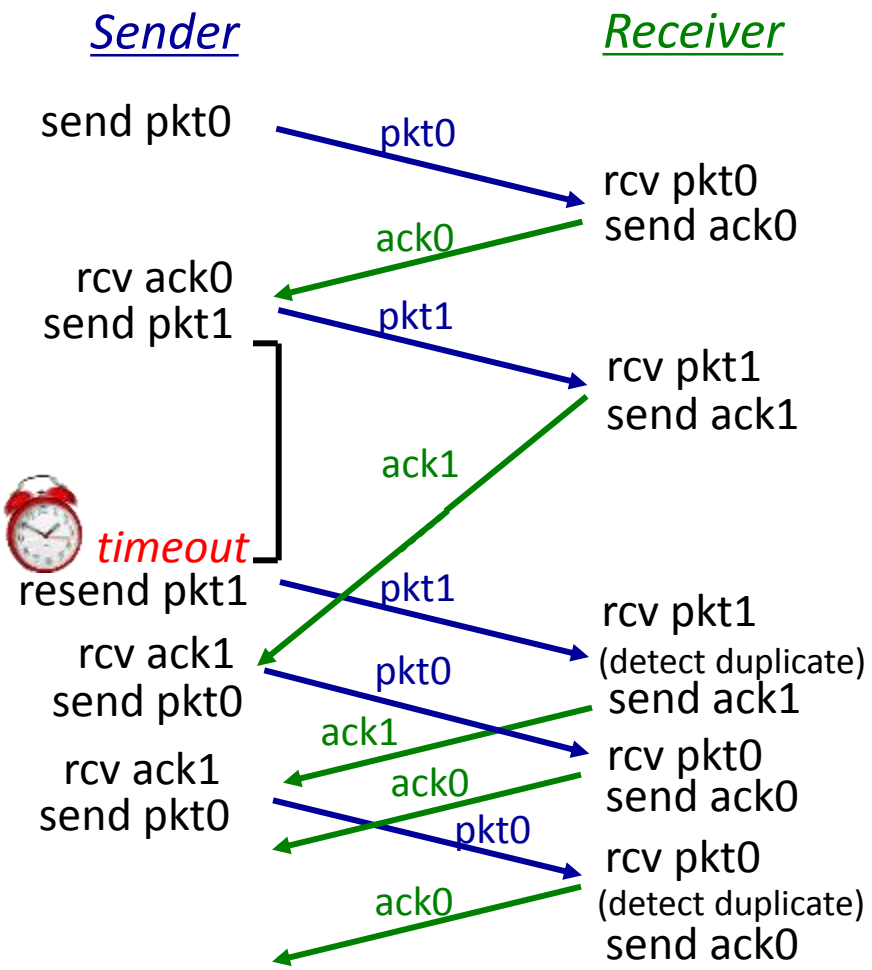



(b) packet loss

# rdt3.0 in action

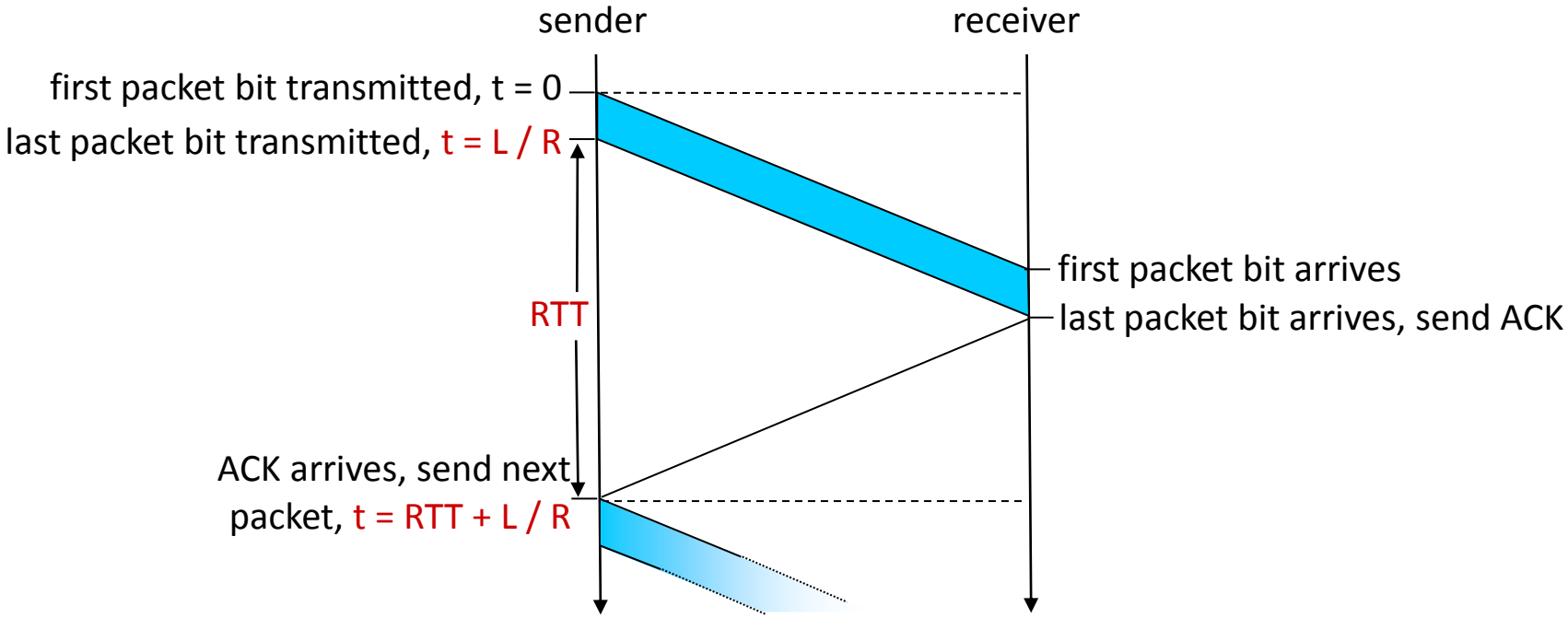



(c) ACK loss




(d) premature timeout / delayed ACK

# rdt3.0: stop-and-wait operation

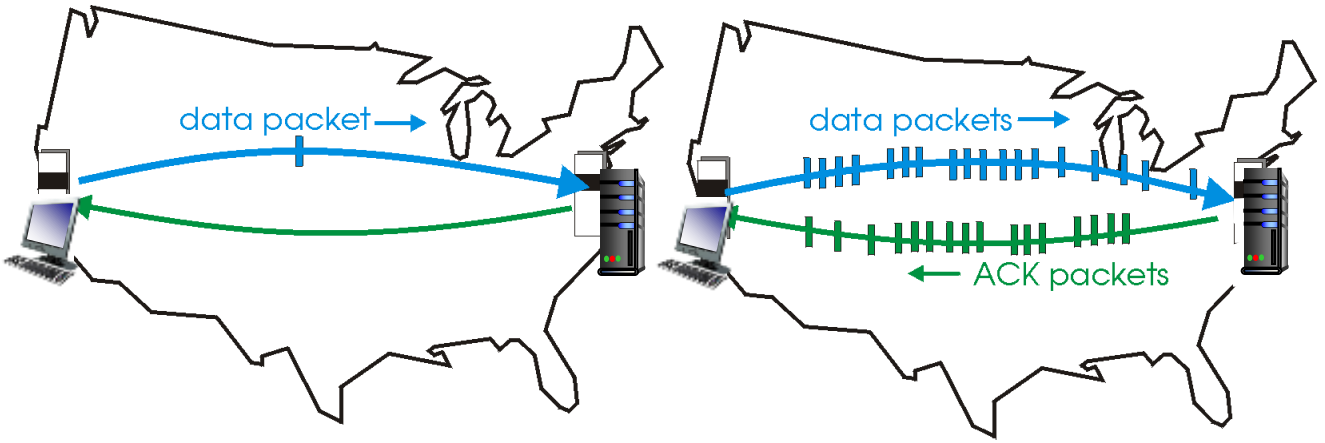



$$U_{sender} = \frac{L/R}{RTT + L/R} = \frac{.008}{30.008} = 0.00027$$

# Pipelined protocols

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

- Range of sequence numbers must be increased
- Buffering at sender and/or receiver



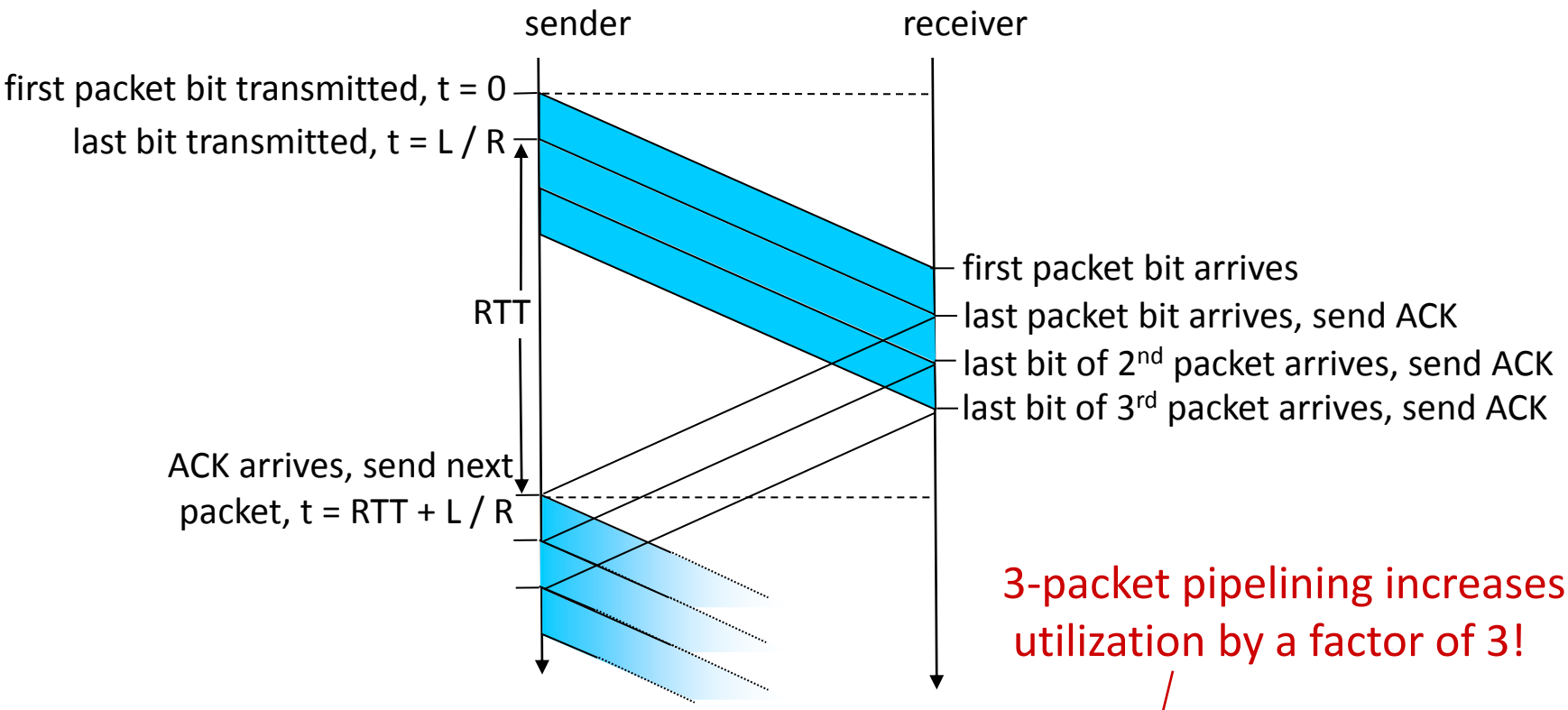

(a) a stop-and-wait protocol in operation

(b) a pipelined protocol in operation

❖ Two generic forms of pipelined protocols:

- *Go-Back-N (GBN)*
- *Selective Repeat (SR)*

# Pipelining: increased utilization




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

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

# 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

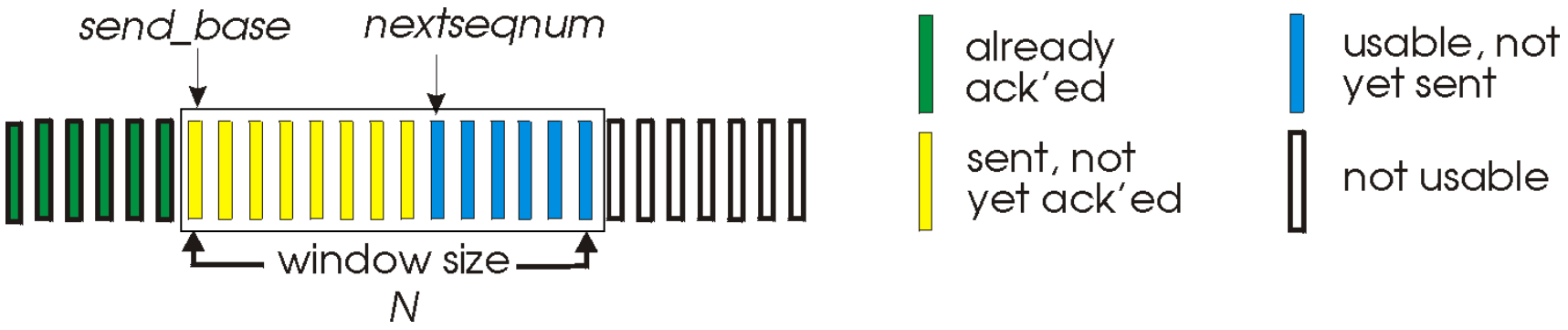
## Selective Repeat:

- Sender can have up to N 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

N = window size
sliding-window protocol

# Go-Back-N: sender

- k-bit sequence # in packet header
- Window of up to N, consecutive unACKed packets allowed




- ACK(n): ACKs all packets up to, including sequence # n
  - *Cumulative ACK*
  - May receive duplicate ACKs (see receiver)
- Timer for oldest in-flight packet
- *timeout(n):* retransmit packet n and all higher sequence # packets in window

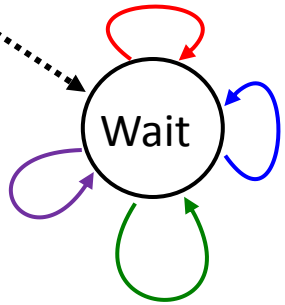
# GBN sender

```
rdt_send(data)
if (nextseqnum < base+N) {
   sndpkt[nextseqnum] = make_pkt(nextseqnum,data,chksum)
   udt_send(sndpkt[nextseqnum])
   if (base == nextseqnum)
      start_timer
   nextseqnum++
}
else
   refuse_data(data)
```

**Invocation from above.** If window is not full, create and send packet. If full, return data to sender.

Λ

base=1
nextseqnum=1




rdt_rcv(rcvpkt) &&
corrupt(rcvpkt)

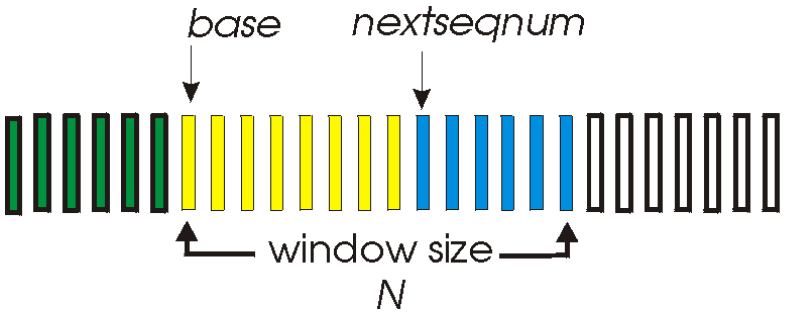
Λ

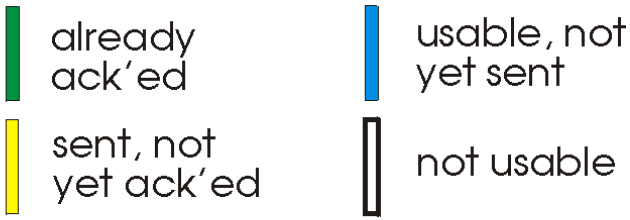
```
timeout
start_timer
udt_send(sndpkt[base])
udt_send(sndpkt[base+1])
…
udt_send(sndpkt[nextseqnum-1])
```

**Timeout.** Resend all packets that have been previously sent but not ACK'd.

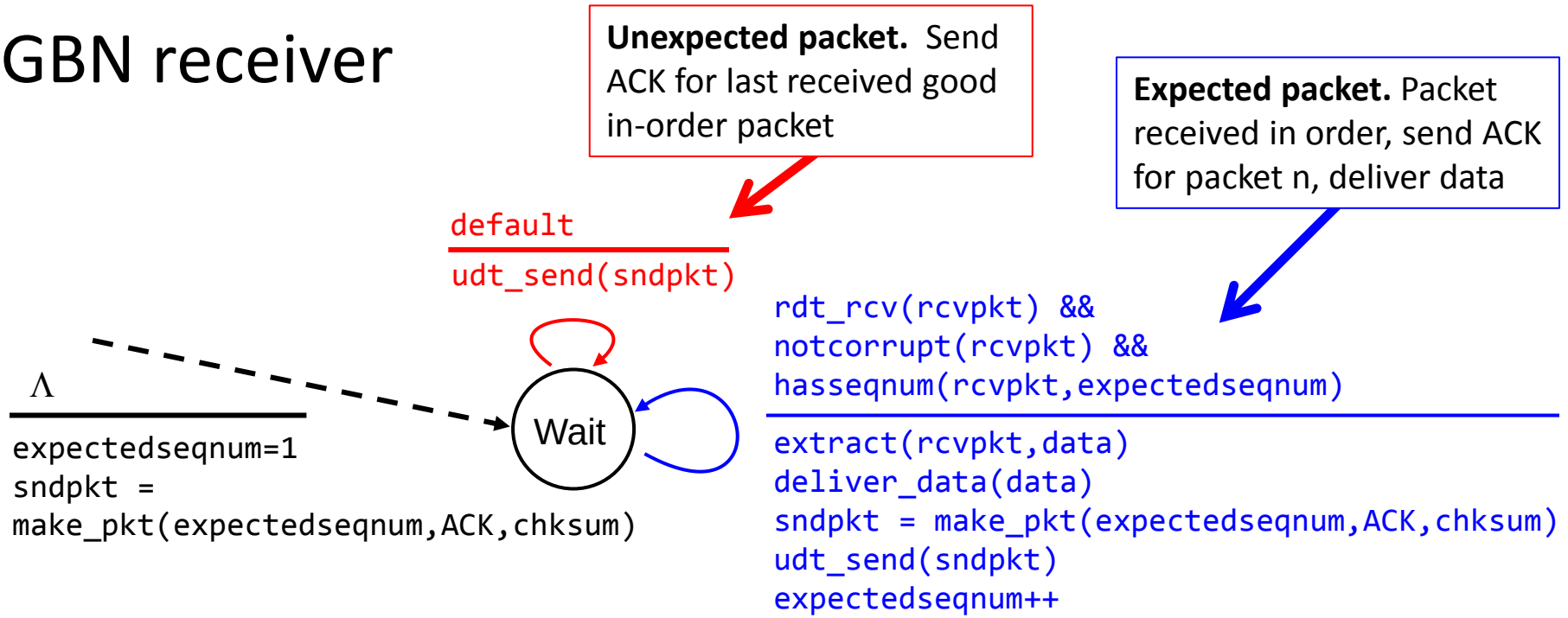
**Receipt of ACK.** Receipt of packet with seq. # n, all packets up to an including n are good.

```
rdt_rcv(rcvpkt) &&
notcorrupt(rcvpkt)
base = getacknum(rcvpkt) + 1
if (base == nextseqnum) stop_timer
else                    start_timer
```



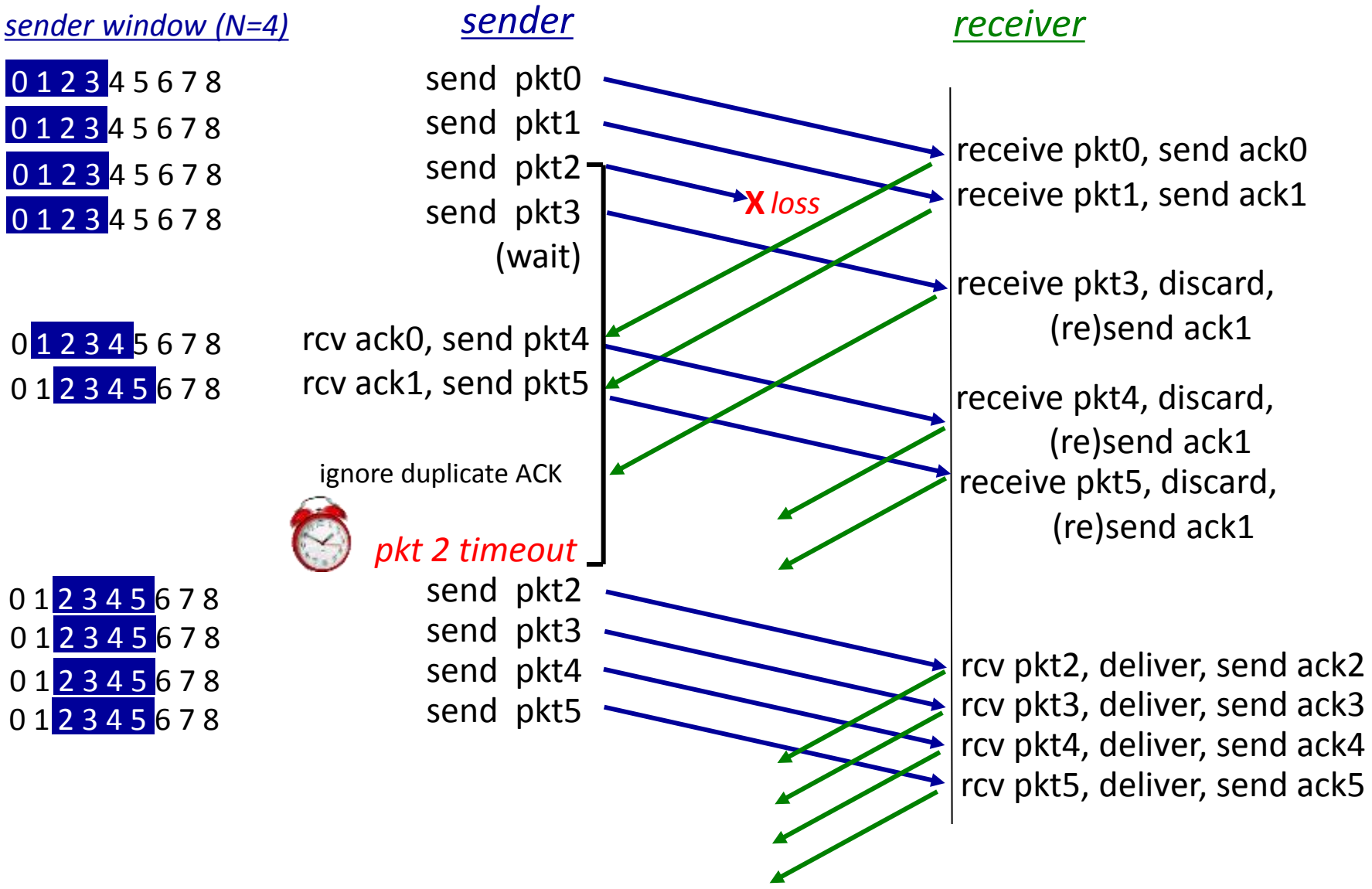



# GBN receiver




- ACK-only: always send ACK for correctly-received packet with highest *in-order* sequence #
  - May generate duplicate ACKs
  - Need only remember `expectedseqnum`
- Out-of-order packet:
  - Discard (don't buffer): *No receiver buffering!*
  - Re-ACK packet with highest in-order sequence #

# GBN in action

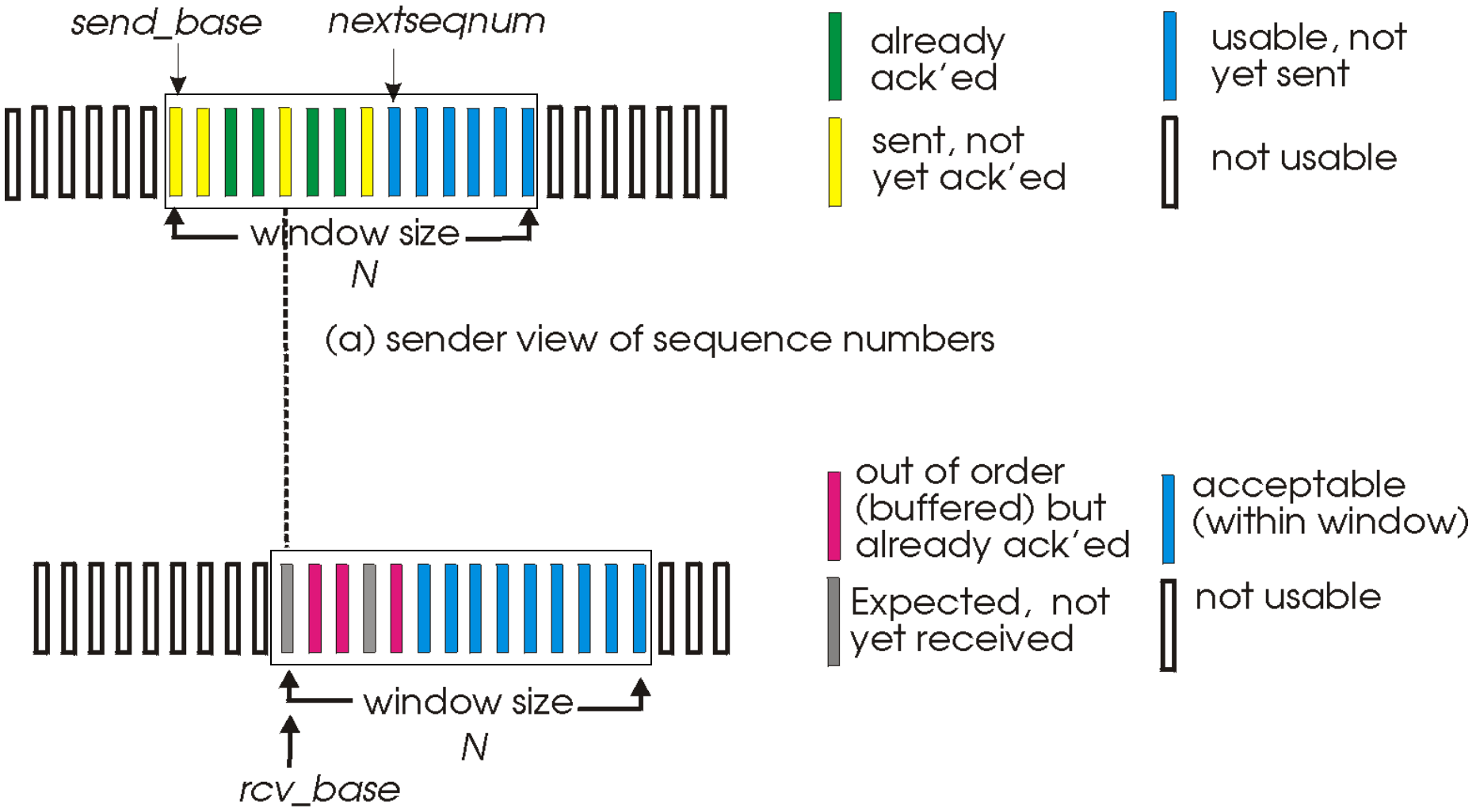



http://media.pearsoncmg.com/aw/aw_kurose_network_4/applets/go-back-n/index.html

# Selective repeat

- Receiver *individually* acknowledges all correctly received packets
  - Buffers packets, as needed, for eventual in-order delivery to upper layer
- Sender only resends packets for which ACK not received
  - Sender timer for each unACKed packet
- Sender window
  - *N* consecutive sequence #'s
  - Limits sequence #s of sent, unACKed packets

# Selective repeat: sender, receiver, windows



# Selective repeat

## Sender

**Data from above:**

- If next available sequence # in window, send packet

**Timeout(n):**

- Resend packet n, restart timer

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

- Mark packet n as received
- If n smallest unACKed packet, advance window base to next unACKed sequence #

## 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

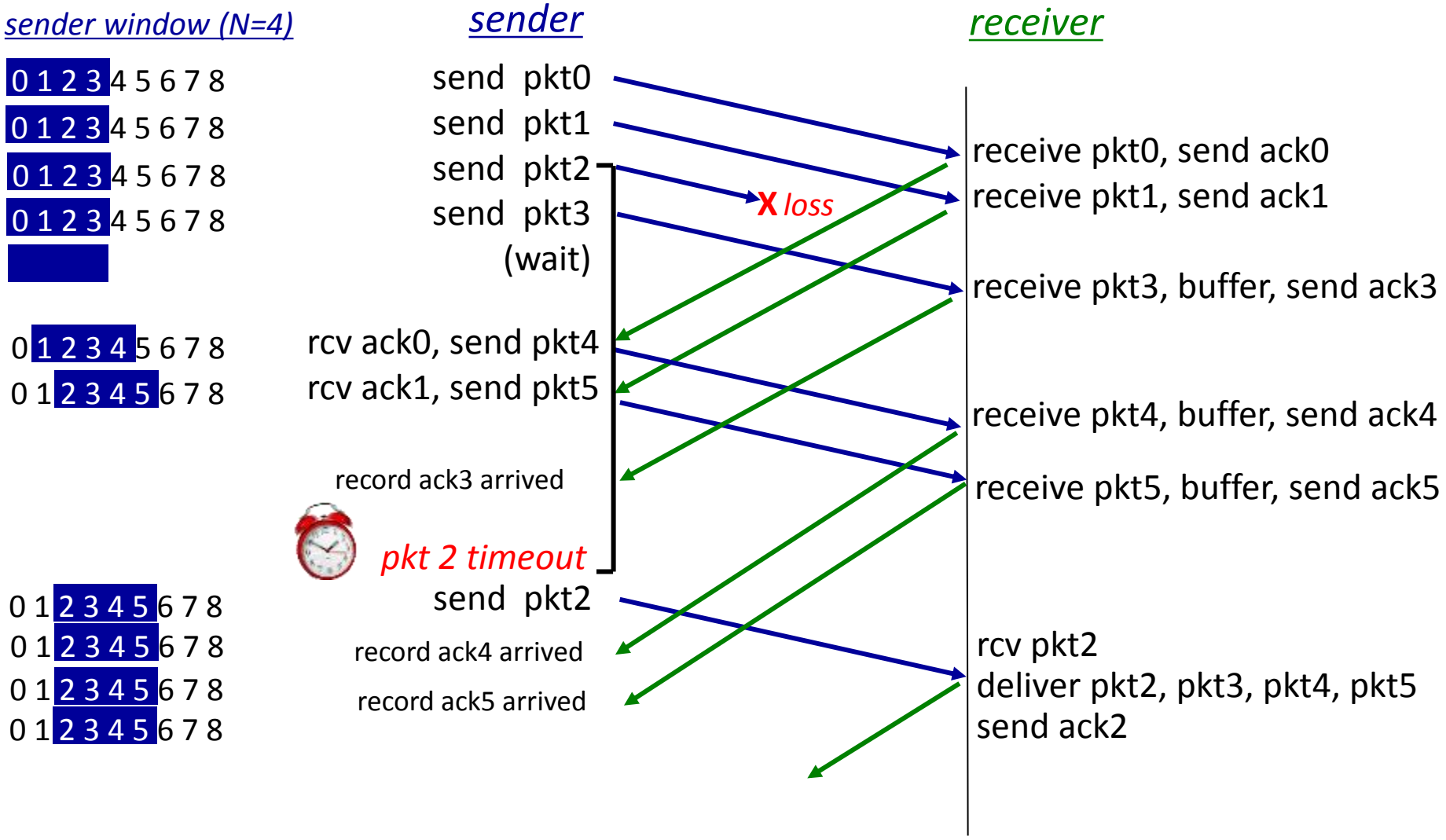
**Packet n in** [rcvbase-N,rcvbase-1]

- ACK(n)

**Otherwise:**

- Ignore

# Selective repeat in action



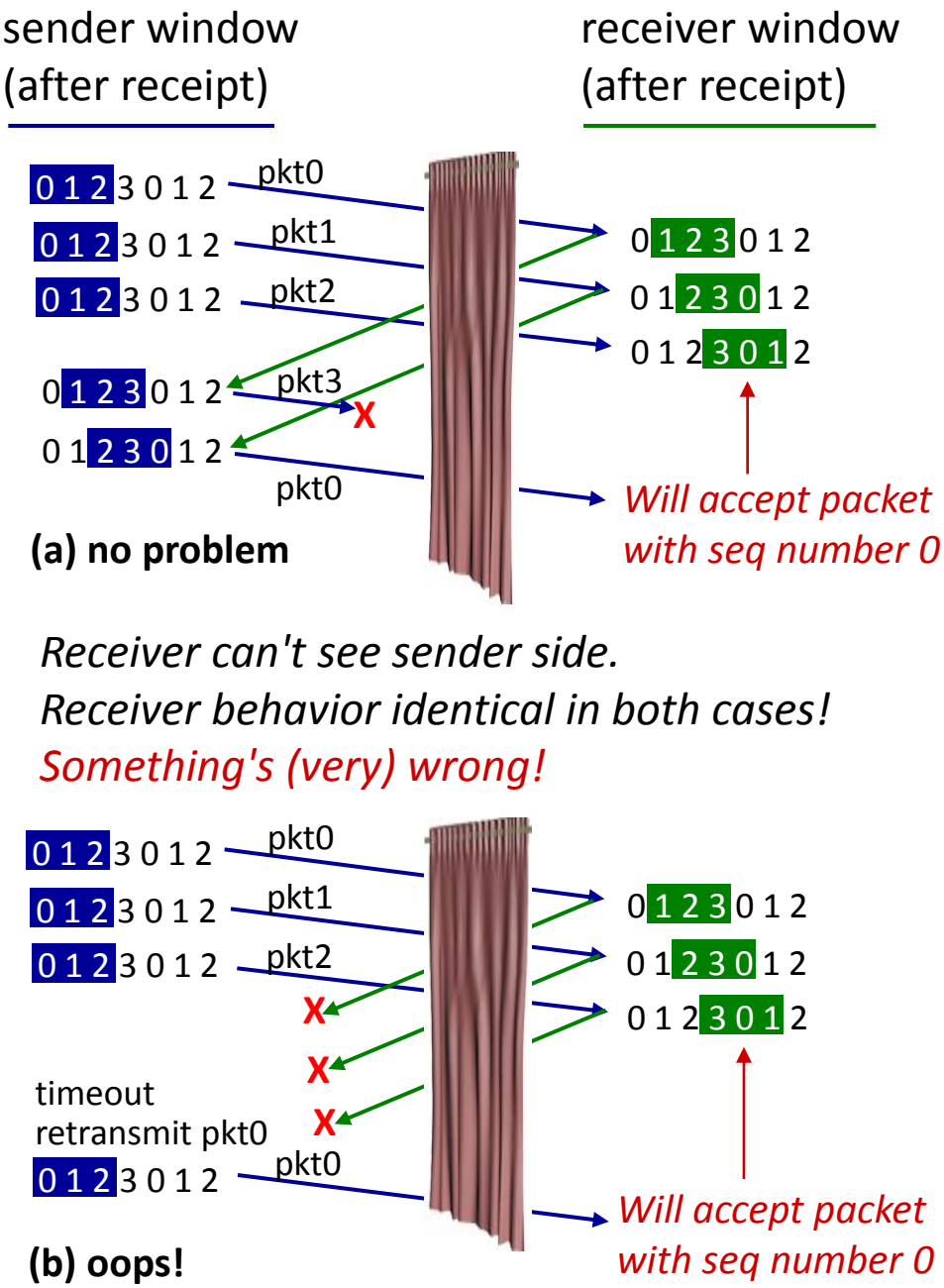

*Q: What happens when ack2 arrives?*

# Selective repeat: dilemma

Example:

- Sequence #'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 sequence # size and window size to avoid problem in (b)?




http://media.pearsoncmg.com/aw/aw_kurose_network_4/applets/SR/index.html

# Reliable data transport mechanisms

| | |
|---|---|
| **Checksum** | Detect bit errors in a packet |
| **Timer** | Used to retransmit packet should the packet or its ACK never arrive. |
| **Sequence number** | Used to resend since packets or ACK of packet may go missing |
| **Acknowledgment (ACK)** | Used to tell sender that receiver has gotten certain packet or set of packets. Typically carries the sequence number. |
| **Negative acknowledgment (NACK)** | Used to tell sender that receiver got a corrupted packet. Typically carries a sequence number. |
| **Window, pipelining** | Sender can only send packets within a certain window of sequence numbers. Increases utilization compared to stop-and-wait protocol. |

# Summary

- Reliable data transport
  - Handles packet corruption, lose, or delay
  - Tricky but can be done using ACKs, sequence numbers, and timers (e.g. rdt3.0)
- Efficient reliable data transport
  - Even more complex since stop-and-wait too slow
  - Multiple unACKed packets in flight
  - Go-Back-N
  - Selective repeat