National University of Computer & Emerging Sciences

CS 3001 – COMPUTER NETWORKS

Lecture 10
Chapter 3

20th February, 2025

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

A note on the use of these PowerPoint slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
- If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

For a revision history, see the slide note for this page.

Thanks and enjoy! JFK/KWR
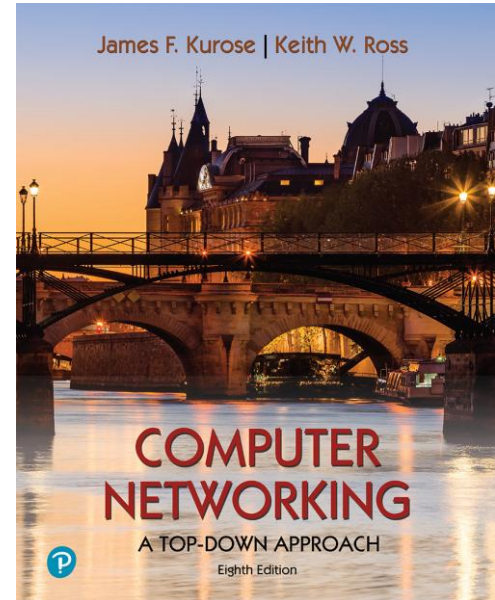
Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

rdt2.0 has a fatal flaw!

what happens if ACK/NAK corrupted?

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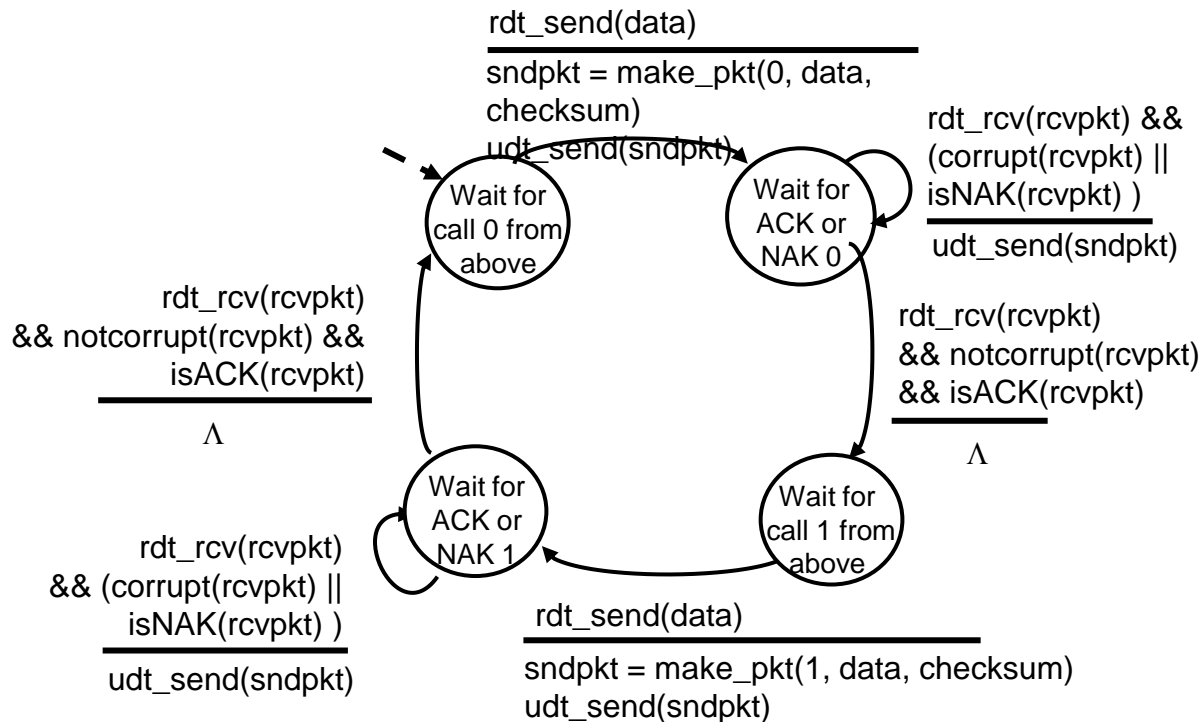- can't just retransmit: possible duplicate

handling duplicates:

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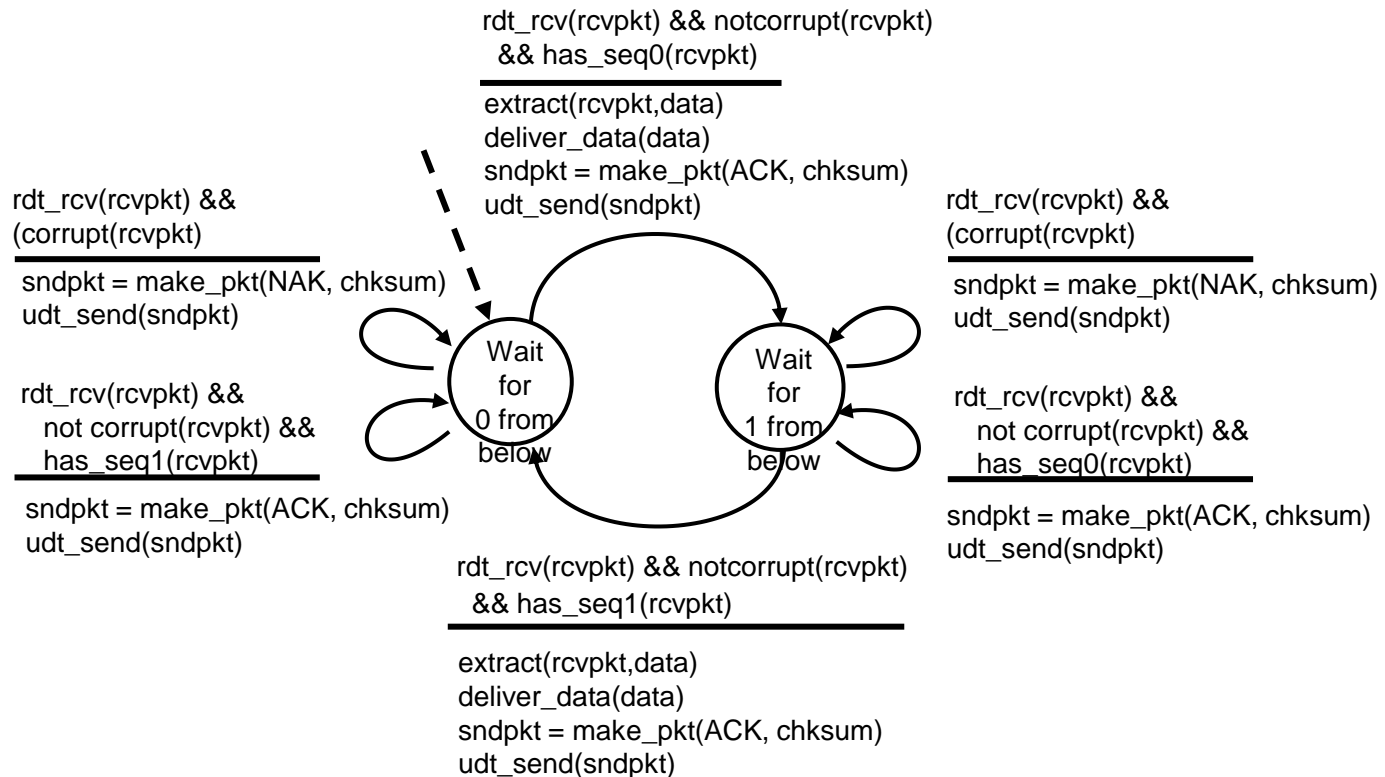- receiver discards (doesn't deliver up) duplicate pkt

stop and wait

sender sends one packet, then waits for receiver response

rdt2.1: sender, handling garbled ACK/NAKs

rdt_send(data)
_____

sndpkt = make_pkt(0, data, checksum)
udt_send(sndpkt)

(Wait for call 0 from above)

(Wait for ACK or NAK 0)

rdt_rcv(rcvpkt) &&
(corrupt(rcvpkt) ||
isNAK(rcvpkt))
_____
udt_send(sndpkt)

rdt_rcv(rcvpkt)
&& notcorrupt(rcvpkt) &&
isACK(rcvpkt)
_____
Λ

rdt_rcv(rcvpkt)
&& notcorrupt(rcvpkt)
&& isACK(rcvpkt)
_____
Λ

(Wait for ACK or NAK 1)

(Wait for call 1 from above)

rdt_rcv(rcvpkt)
&& (corrupt(rcvpkt) ||
isNAK(rcvpkt))
_____
udt_send(sndpkt)

rdt_send(data)
_____

sndpkt = make_pkt(1, data, checksum)
udt_send(sndpkt)

rdt2.1: receiver, handling garbled ACK/NAKs

rdt_rcv(rcvpkt) && notcorrupt(rcvpkt)
&& has_seq0(rcvpkt)
_____
extract(rcvpkt,data)
deliver_data(data)
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
(corrupt(rcvpkt)
_____
sndpkt = make_pkt(NAK, chksum)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
   not corrupt(rcvpkt) &&
   has_seq1(rcvpkt)
_____
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
(corrupt(rcvpkt)
_____
sndpkt = make_pkt(NAK, chksum)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
   not corrupt(rcvpkt) &&
   has_seq0(rcvpkt)
_____
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)

Wait for 0 from below

Wait for 1 from below

rdt_rcv(rcvpkt) && notcorrupt(rcvpkt)
&& has_seq1(rcvpkt)
_____
extract(rcvpkt,data)
deliver_data(data)
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)

rdt2.1: discussion

sender:

- seq # added to pkt
- two seq. #s (0,1) will suffice. Why? [since it is a simple stop and wait protocol, if receiver receives the same sequence number twice (i.e. consecutively), it knows it is duplicate.]
- must check if received ACK/NAK corrupted
- twice as many states
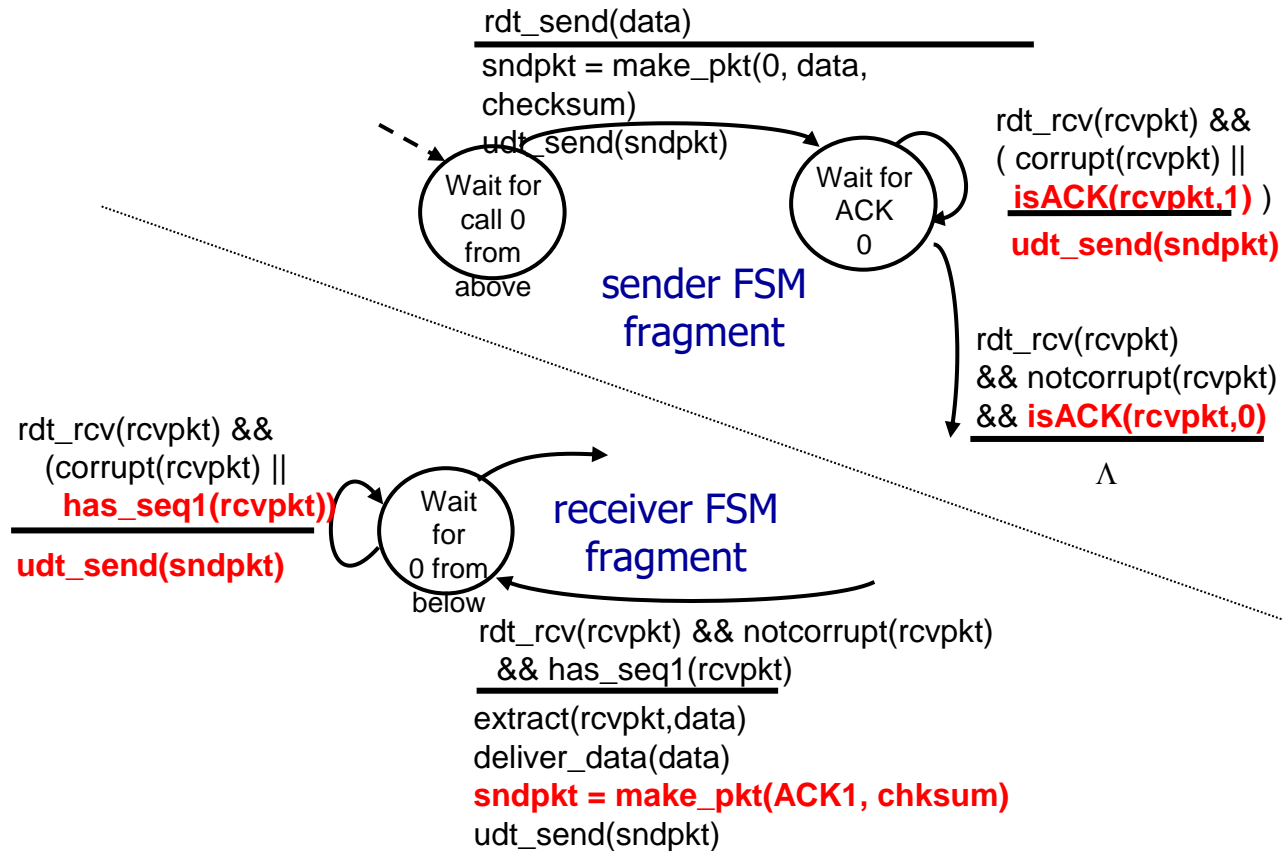 - state must "remember" whether "expected" pkt should have seq # of 0 or 1

receiver:

- must check if received packet is duplicate
  - state indicates whether 0 or 1 is expected pkt seq #
- note: receiver can *not* know if its last ACK/NAK received OK at sender

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*

As we will see, TCP uses this approach to be NAK-free

rdt2.2: sender, receiver fragments

rdt_send(data)

sndpkt = make_pkt(0, data, checksum)
udt_send(sndpkt)

Wait for call 0 from above

Wait for ACK 0

rdt_rcv(rcvpkt) &&
(corrupt(rcvpkt) ||
isACK(rcvpkt,1))
udt_send(sndpkt)

sender FSM fragment

rdt_rcv(rcvpkt)
&& notcorrupt(rcvpkt)
&& **isACK(rcvpkt,0)**

Λ

rdt_rcv(rcvpkt) &&
(corrupt(rcvpkt) ||
has_seq1(rcvpkt))

udt_send(sndpkt)

Wait for 0 from below

receiver FSM fragment

rdt_rcv(rcvpkt) && notcorrupt(rcvpkt)
&& has_seq1(rcvpkt)

extract(rcvpkt,data)
deliver_data(data)
sndpkt = make_pkt(ACK1, chksum)
udt_send(sndpkt)

rdt3.0: channels with errors *and* loss

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

- checksum, sequence #s, ACKs, retransmissions will be of help … but not quite enough

Q: How do *humans* handle lost sender-to-receiver words in conversation?

rdt3.0: channels with errors *and* 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 packet being ACKed
- use countdown timer to interrupt after "reasonable" amount of time
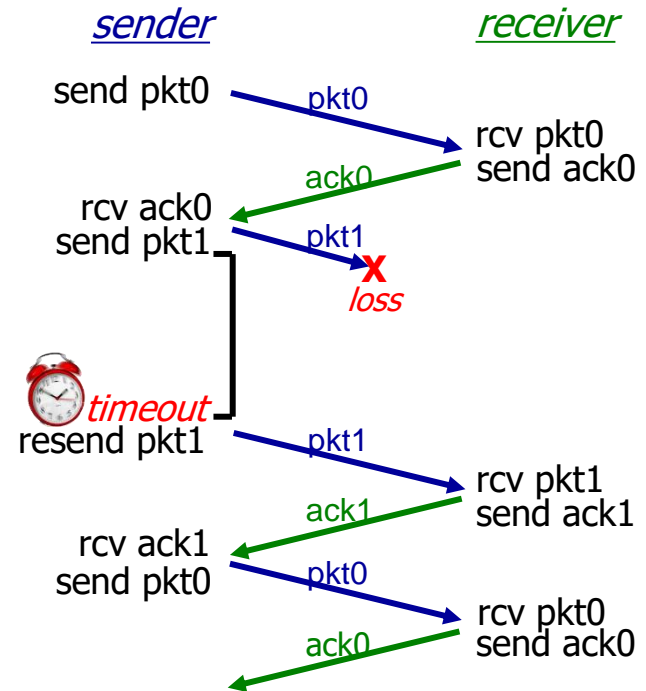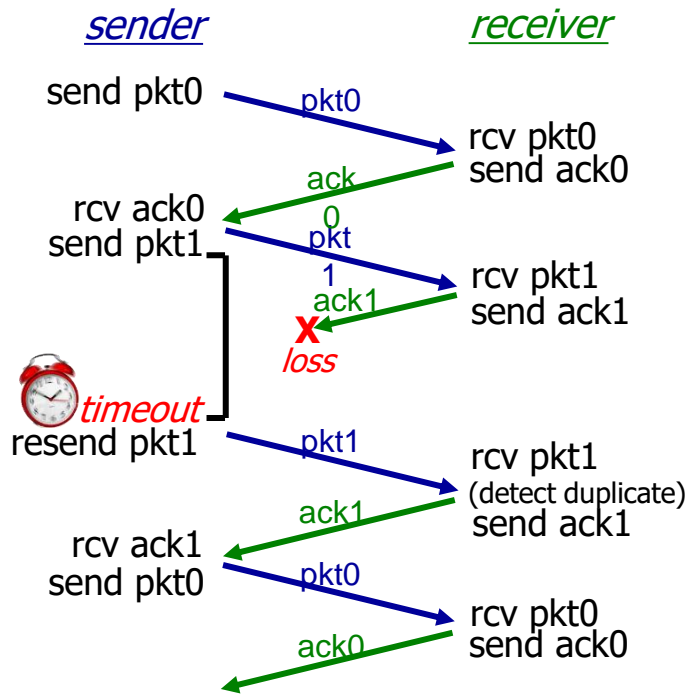
timeout

rdt3.0 sender
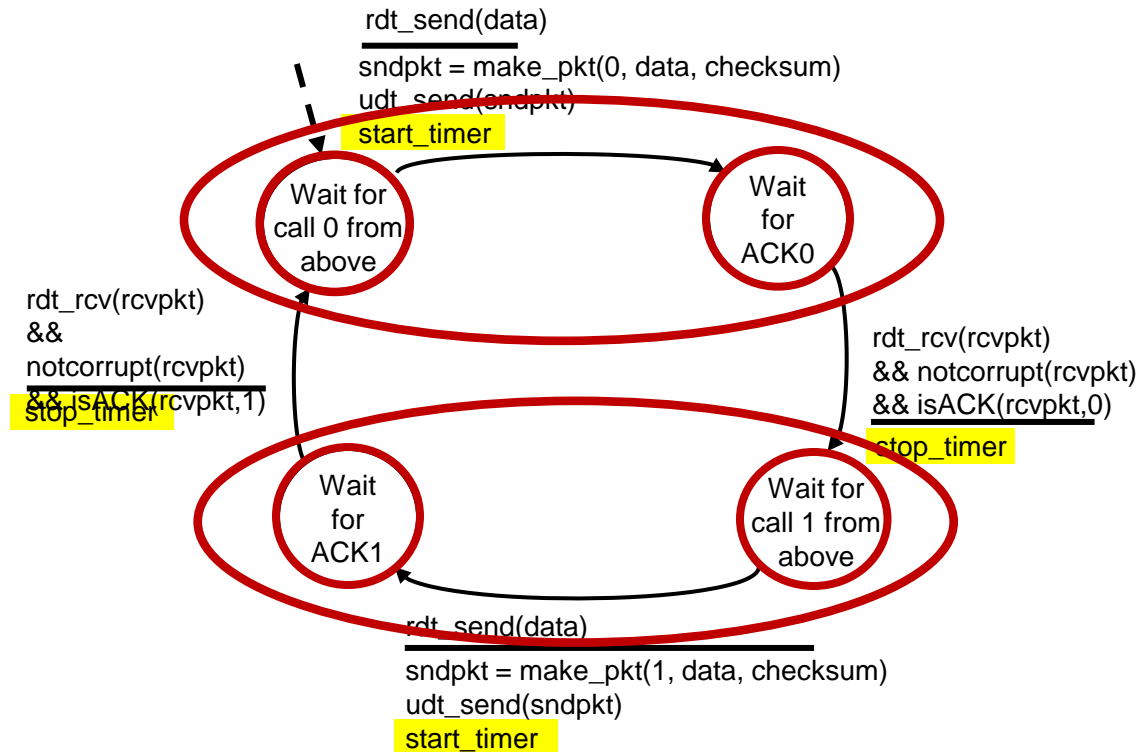
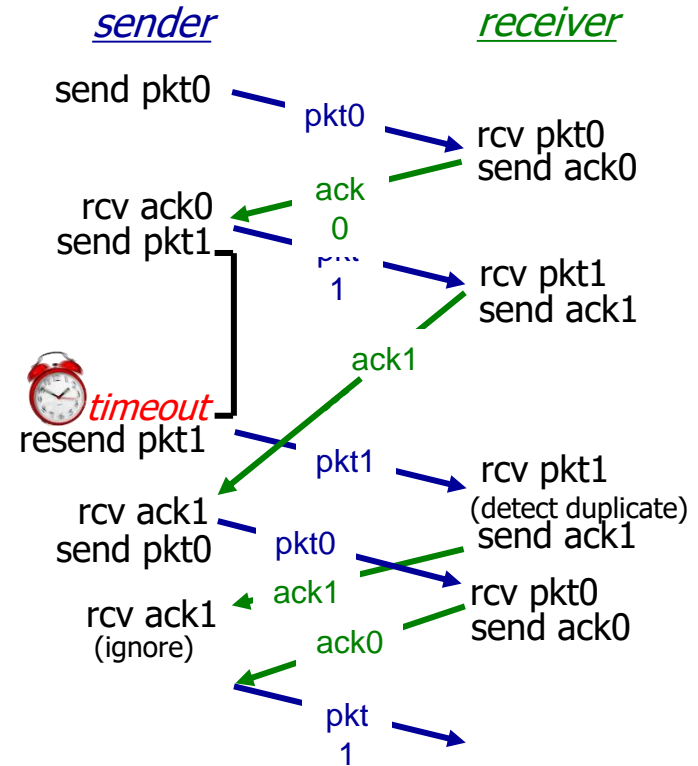# rdt3.0 sender
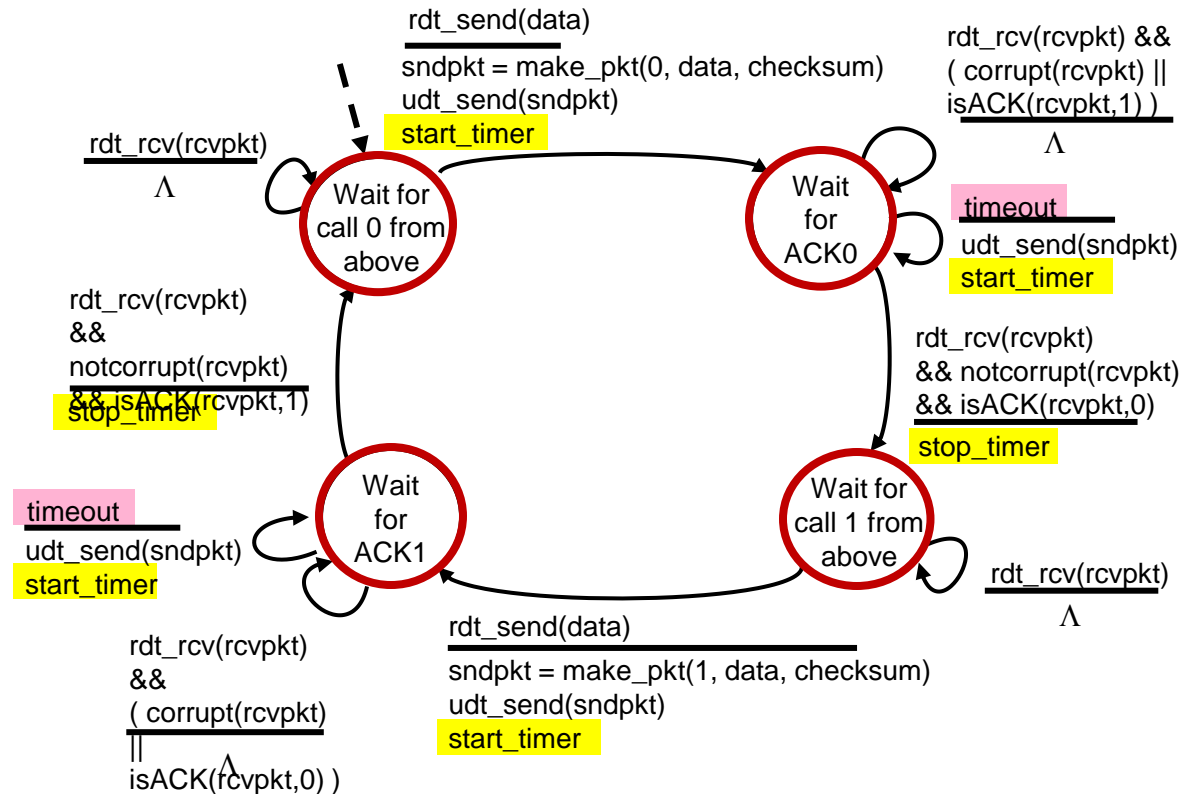
rdt3.0 in action
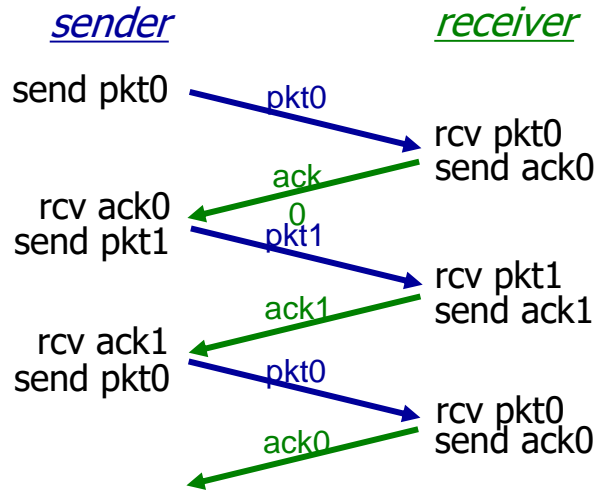
(a) no loss

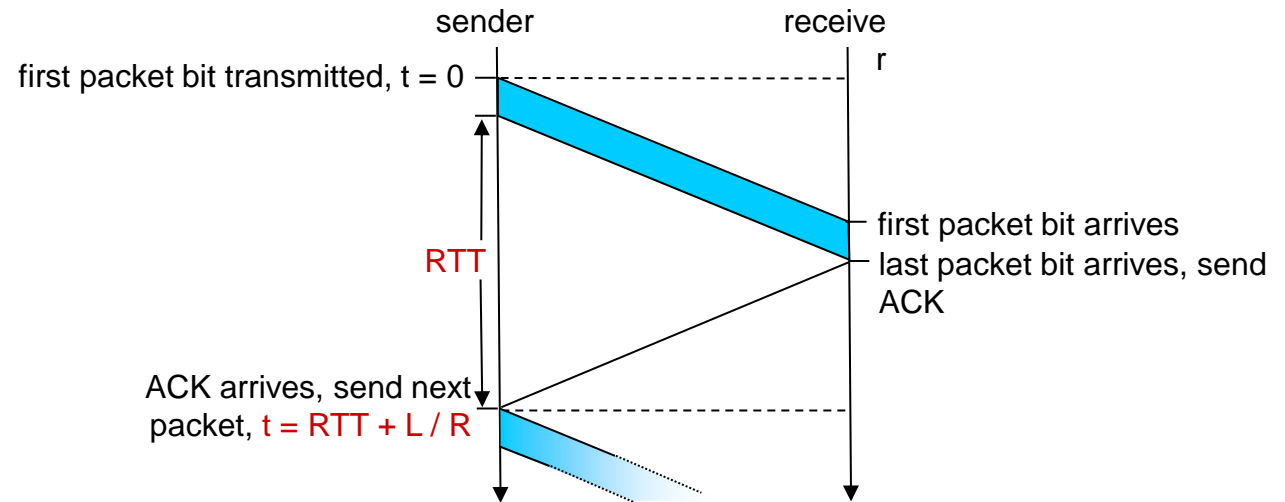(b) packet loss

rdt3.0 in action

(c) ACK loss

(d) premature timeout/ delayed ACK

Performance of rdt3.0 (stop-and-wait)

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

- example: 1 Gbps link, 15 ms prop. delay, 8000 bit packet

  - time to transmit packet into channel:

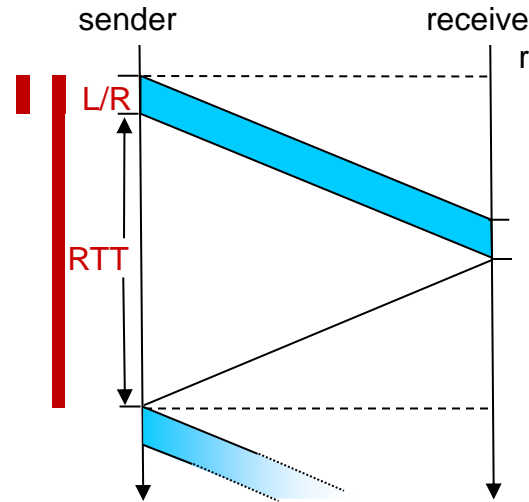 $$D_{trans} = \frac{L}{R} = \frac{8000 \text{ bits}}{10^9 \text{ bits/sec}} = 8 \text{ microsecs}$$

rdt3.0: stop-and-wait operation

sender   receiver

first packet bit transmitted, t = 0

RTT

first packet bit arrives

last packet bit arrives, send ACK

ACK arrives, send next packet, t = RTT + L / R

rdt3.0: stop-and-wait operation

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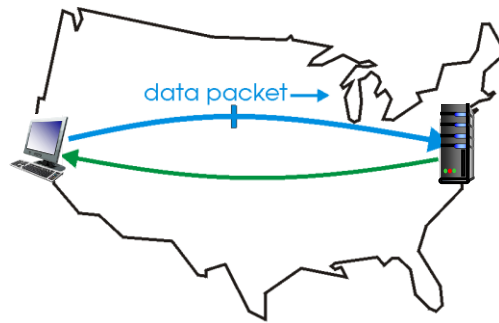
$$= \frac{.008}{30.008}$$

$$= 0.00027$$

- rdt 3.0 protocol performance stinks!
- Protocol limits performance of underlying infrastructure (channel)
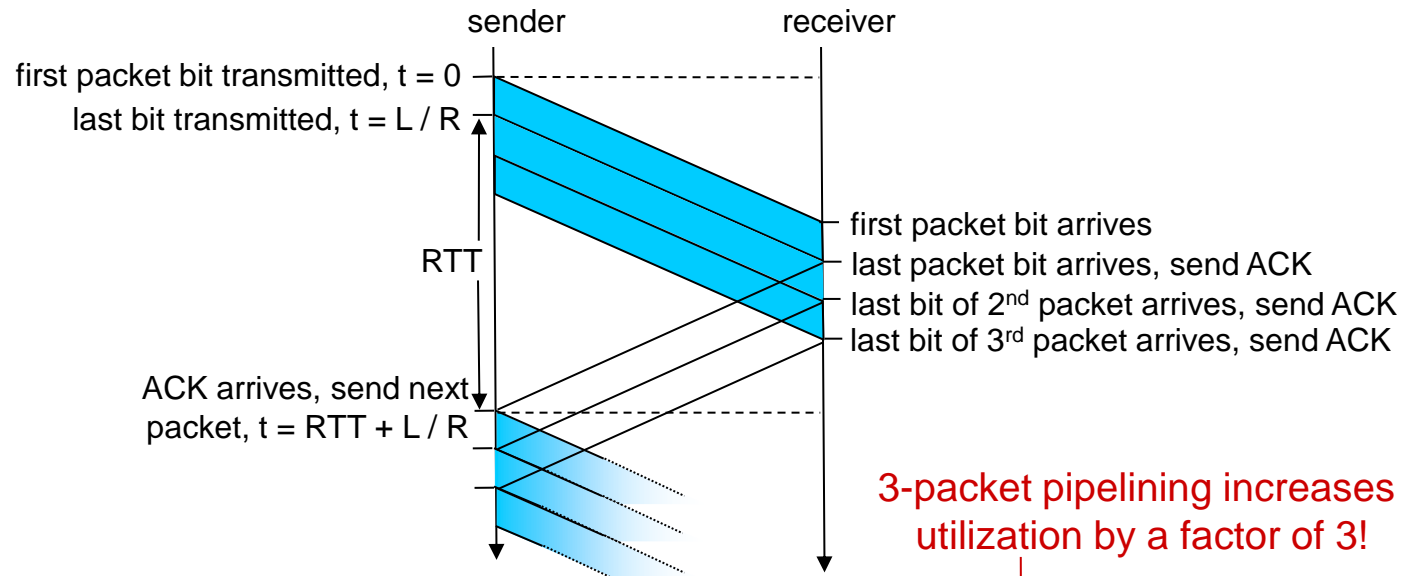
rdt3.0: pipelined protocols operation

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

sender

receiver

first packet bit transmitted, t = 0

last bit transmitted, t = L / R

RTT

first packet bit arrives

last packet bit arrives, send ACK

last bit of 2nd packet arrives, send ACK

last bit of 3rd packet arrives, send ACK

ACK arrives, send next
packet, t = RTT + L / R

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

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

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
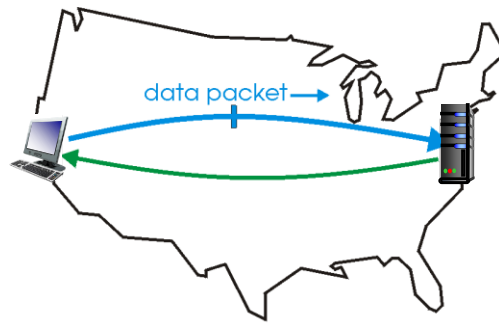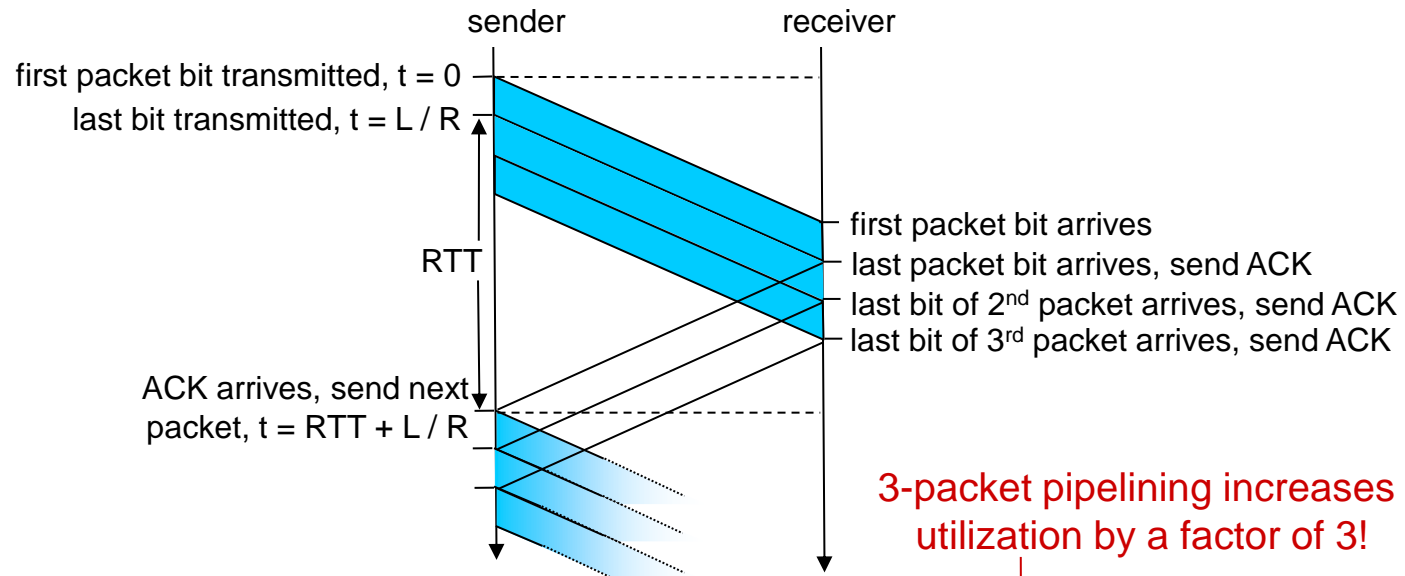
Pipelining: increased utilization

sender   receiver

first packet bit transmitted, t = 0 - - - - - - - - - - - - - - - - -

last bit transmitted, t = L / R

first packet bit arrives

RTT   last packet bit arrives, send ACK

last bit of 2nd packet arrives, send ACK
last bit of 3rd packet arrives, send ACK

ACK arrives, send next
packet, t = RTT + L / R

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

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

Midterm I

You R Bright

Good Luck on your exam!!

Quiz 2 – Chapter 2