

Transport Layer



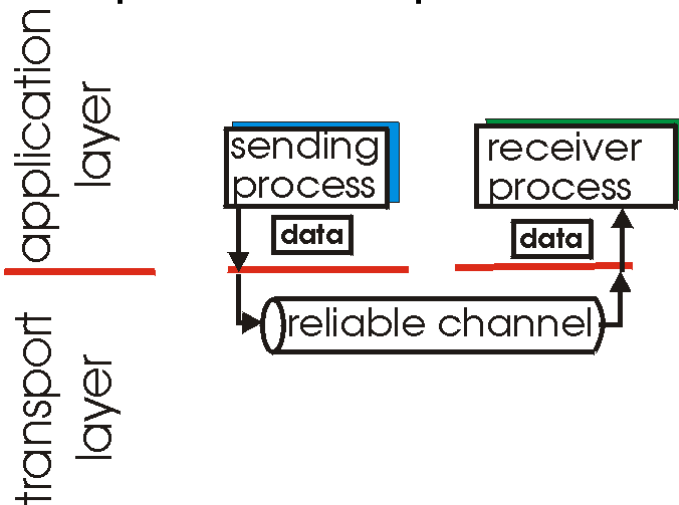
Instructor: C. Pu (Ph.D., Assistant Professor)

Lecture 09

puc@marshall.edu

Principles of Reliable Data Transfer

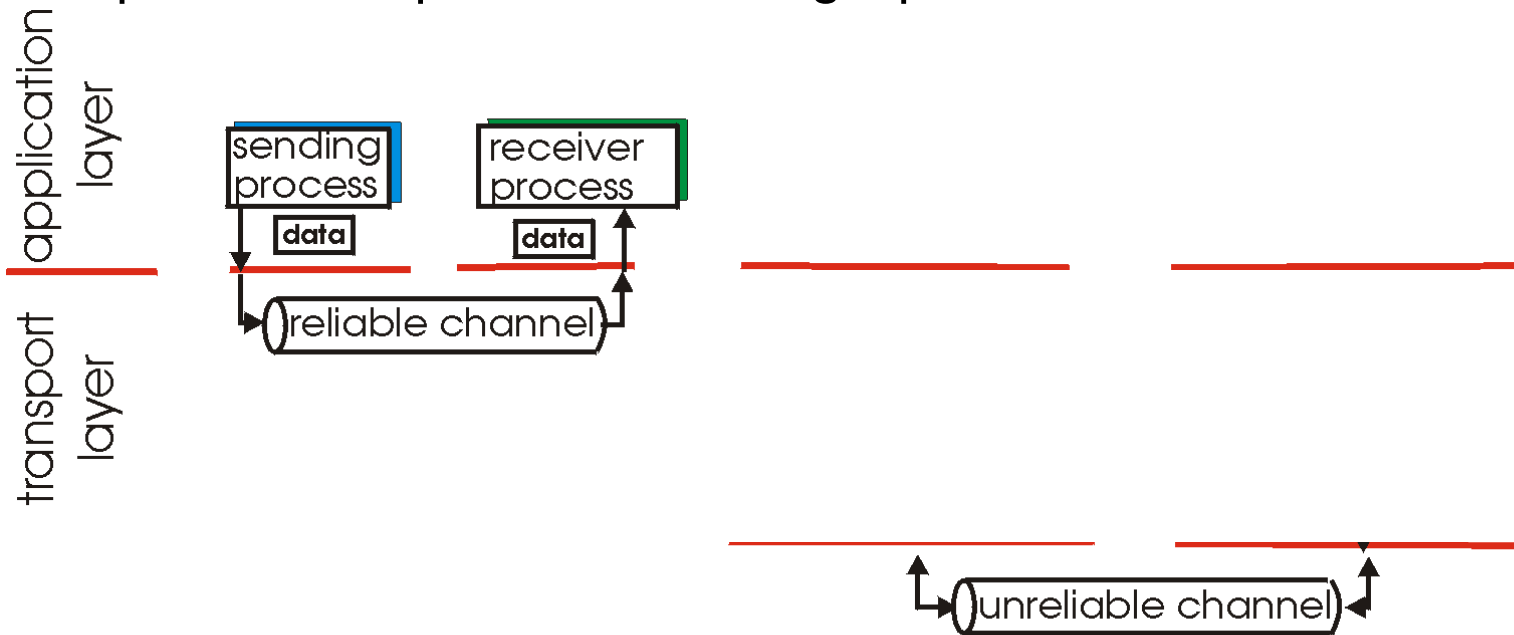
- important in app., transport, link layers
- top-10 list of important networking topics!



(a) provided service

Principles of Reliable Data Transfer (cont.)

- important in app., transport, link layers
- top-10 list of important networking topics!



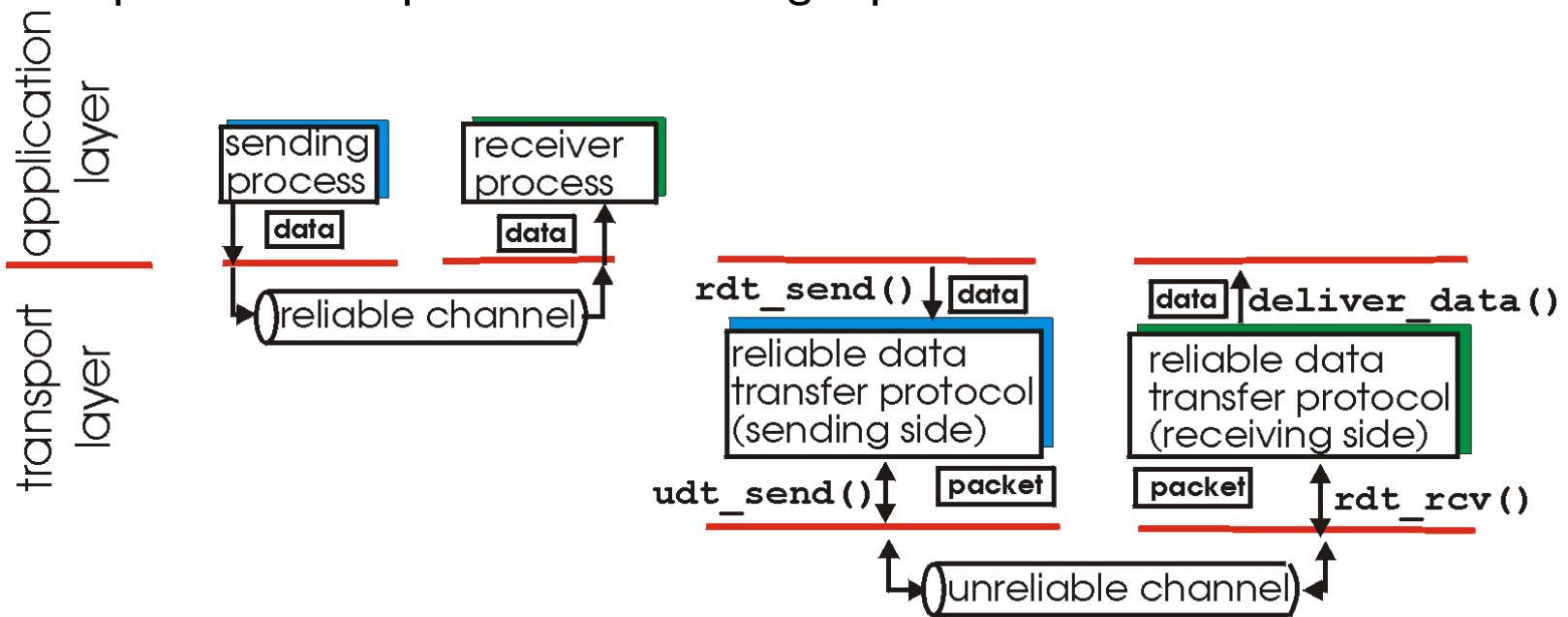
(a) provided service

(b) service implementation

- characteristics of unreliable channel will determine complexity of reliable data transfer (rdt) protocol

Principles of Reliable Data Transfer (cont.)

- important in app., transport, link layers
- top-10 list of important networking topics!



(a) provided service

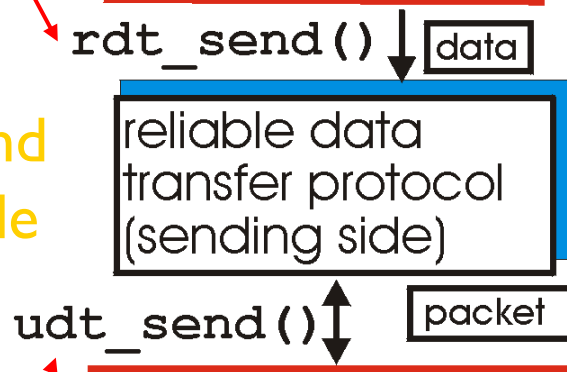
(b) service implementation

- characteristics of **unreliable channel** will determine complexity of reliable data transfer (rdt) protocol

Reliable Data Transfer: Getting Started

rdt_send(): called from **above**, (e.g., by app.). Pass data to be delivered to receiver upper layer

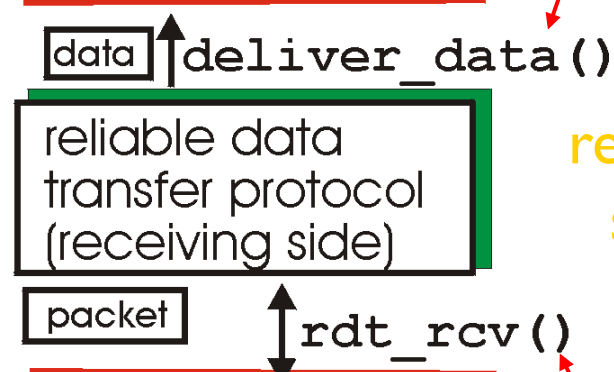
send
side



udt_send(): called by **rdt**, to transfer packet over unreliable channel to receiver

deliver_data(): called by **rdt** to deliver data to upper layer

receive
side

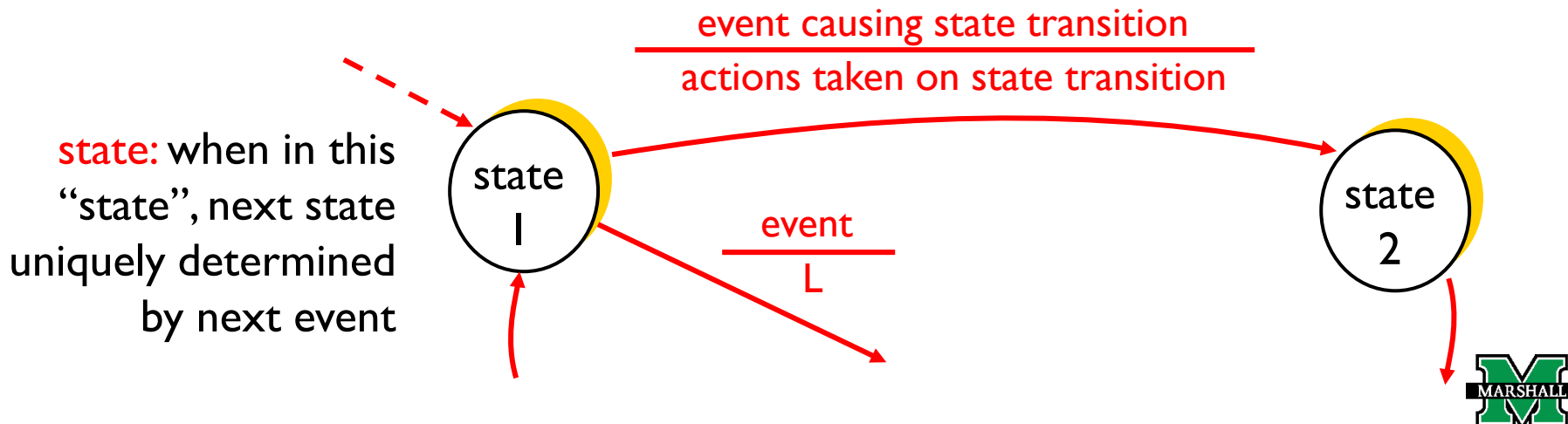


rdt_rcv(): called **when packet arrives** on receiver side of channel



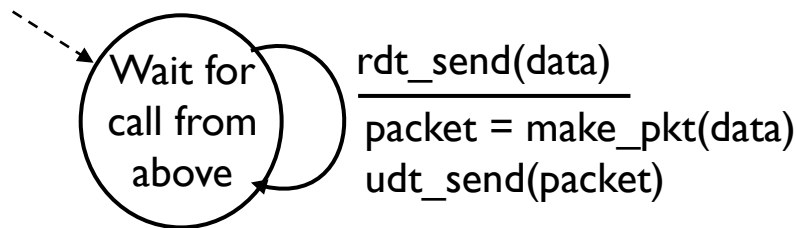
Reliable Data Transfer: Getting Started (cont.)

- We'll:
 - incrementally develop sender and receiver sides of **reliable data transfer protocol (rdt)**
 - consider only **unidirectional data transfer**
 - but control info will flow on both directions!
 - use **finite state machines** (FSM) to specify the behaviors of sender and receiver

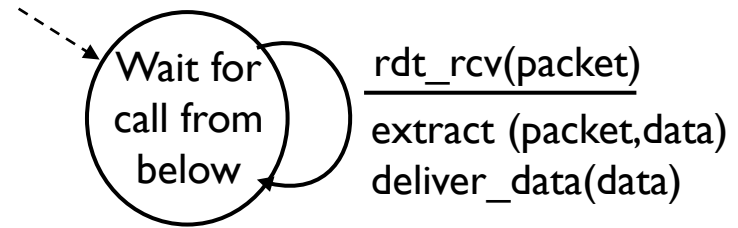


rdt1.0: Reliable Transfer over a Reliable Channel

- underlying channel perfectly reliable
 - no bit errors
 - no loss of packets
- separate FSMs for sender and receiver:
 - sender sends data into underlying channel
 - receiver reads data from underlying channel



sender



receiver

with a perfectly reliable channel, there is no need for the receiver side to provide any feedback to the sender since nothing can go wrong!



rdt2.0: Channel with Bit Errors

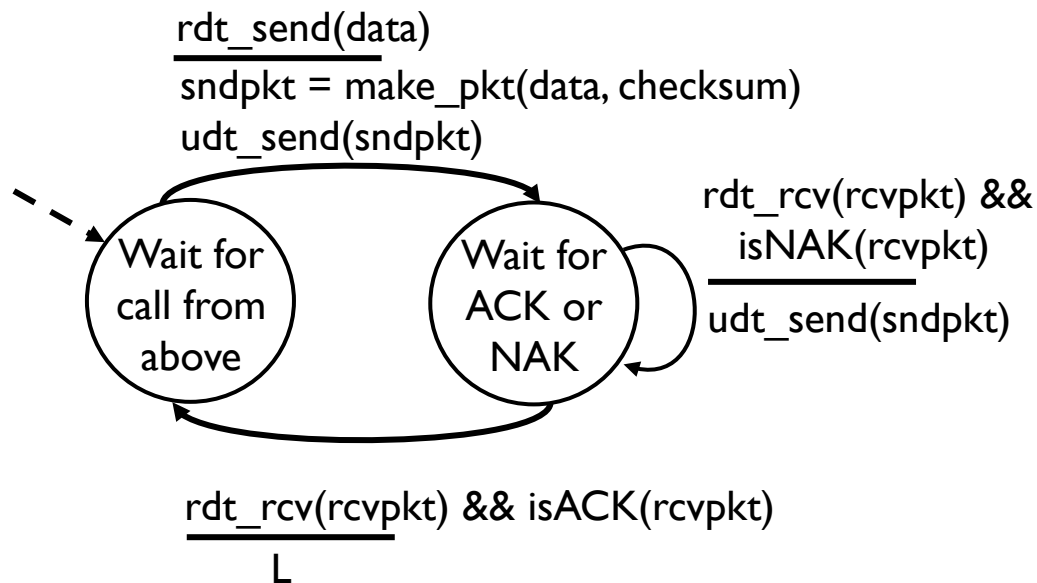
- consider a more realistic model
 - underlying channel may flip bits in packet
 - bit errors occur in the physical components of a network as a packet is transmitted, propagates, or is buffered
 - checksum to detect bit errors
- how people might deal with such a situation?
 - conversation over a phone
 - the message taker might say “OK” after each sentence has been heard, understood, and recorded
 - if the message taker hears garbled sentence, the message sender is asked to repeat



rdt2.0: Channel with Bit Errors

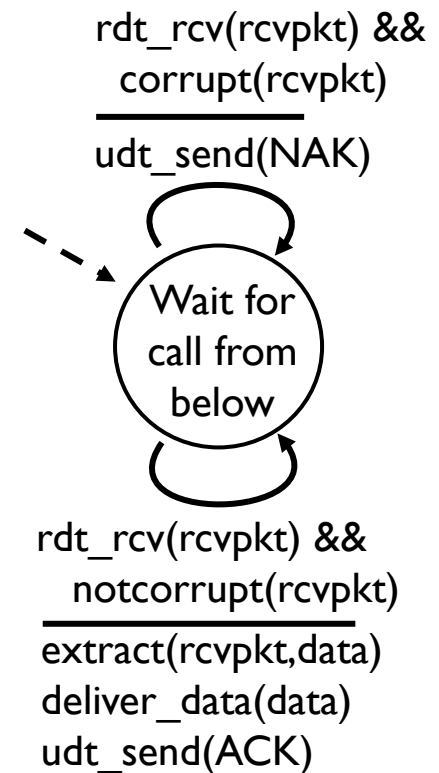
- the question: how to recover from errors?
 - *positive acknowledgements (ACKs)*:
 - receiver explicitly tells sender that pkt received OK with *ACKs*
 - *negative acknowledgements (NAKs)*:
 - receiver explicitly tells sender that pkt had errors with *NAK*
 - sender retransmits pkt on receipt of *NAK*
- new mechanisms in **rdt2.0** (beyond **rdt1.0**):
 - error detection
 - *receiver feedback*: control msgs (*ACKs* and *NAKs*) from receiver to sender
 - positive acknowledgement (*ACKs*)
 - negative acknowledgement (*NAKs*)

rdt2.0: FSM specification

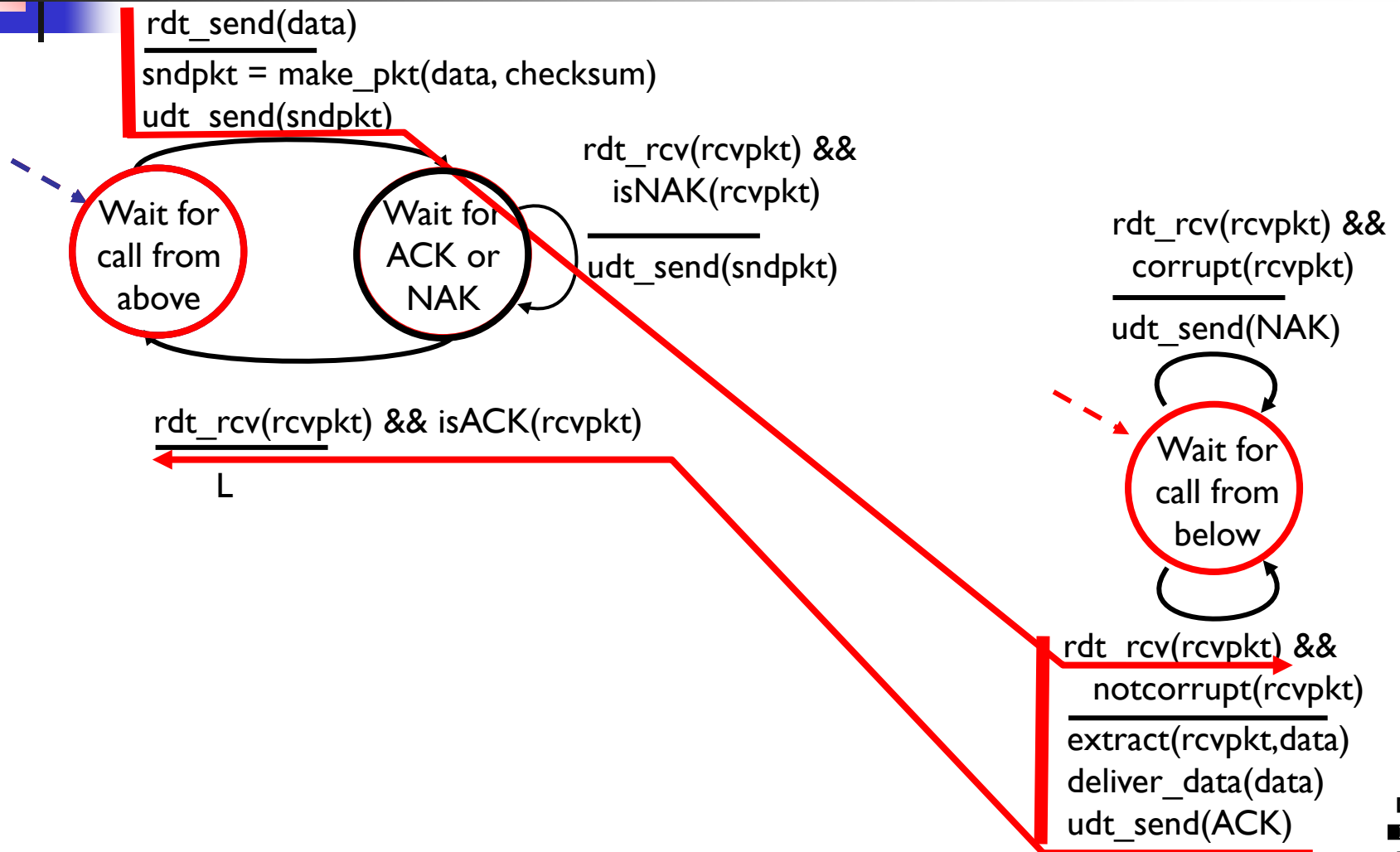


sender

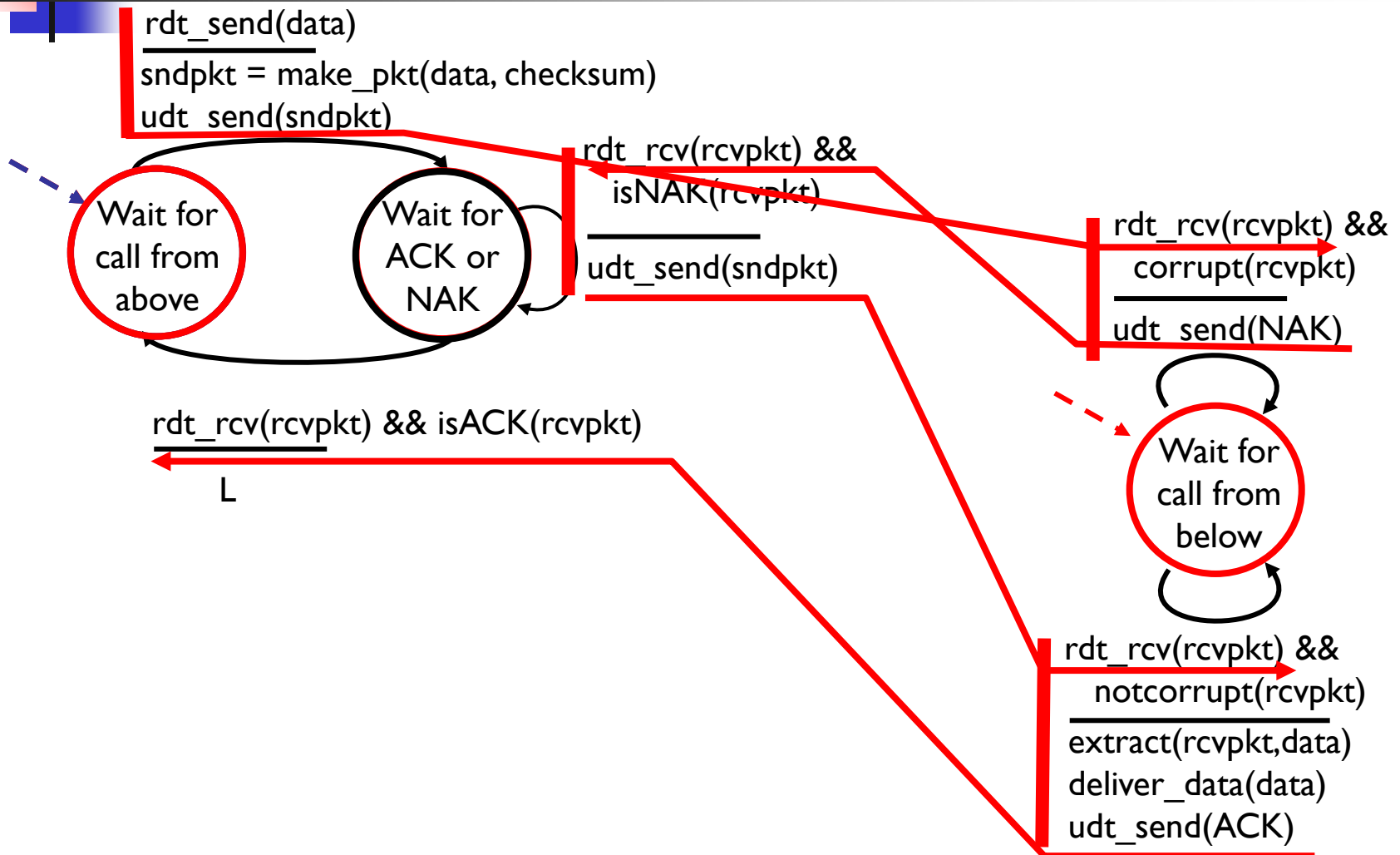
receiver



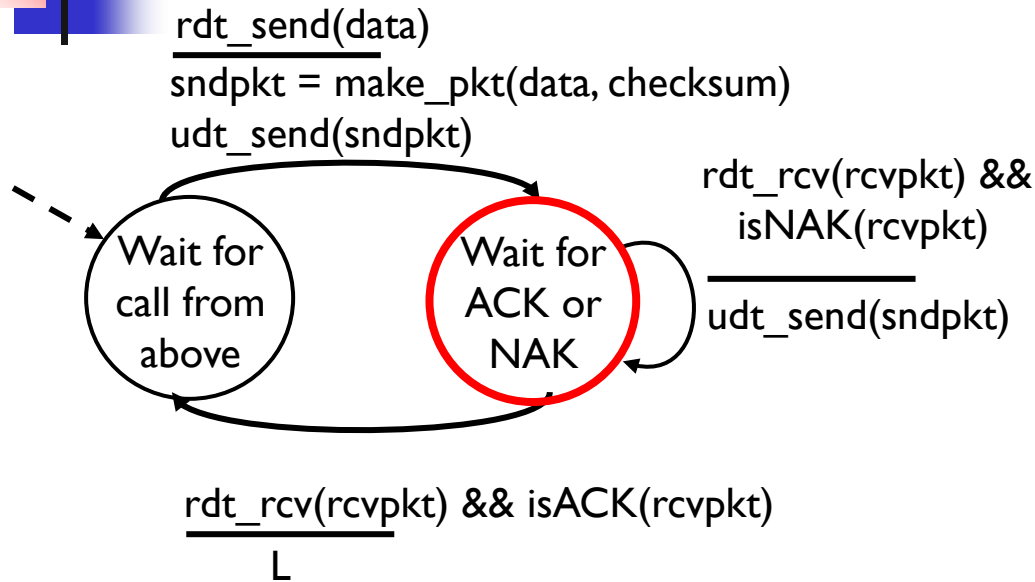
rdt2.0: Operation with No Errors



rdt2.0: Error Scenario



rdt2.0: FSM specification



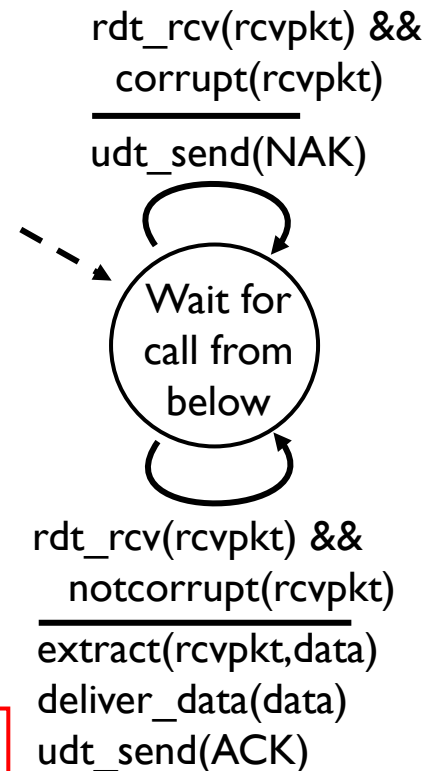
sender

stop and wait

sender sends one packet, then waits for receiver response.

sender will not send a new data until it is sure that the receiver has correctly received the current packet.

receiver



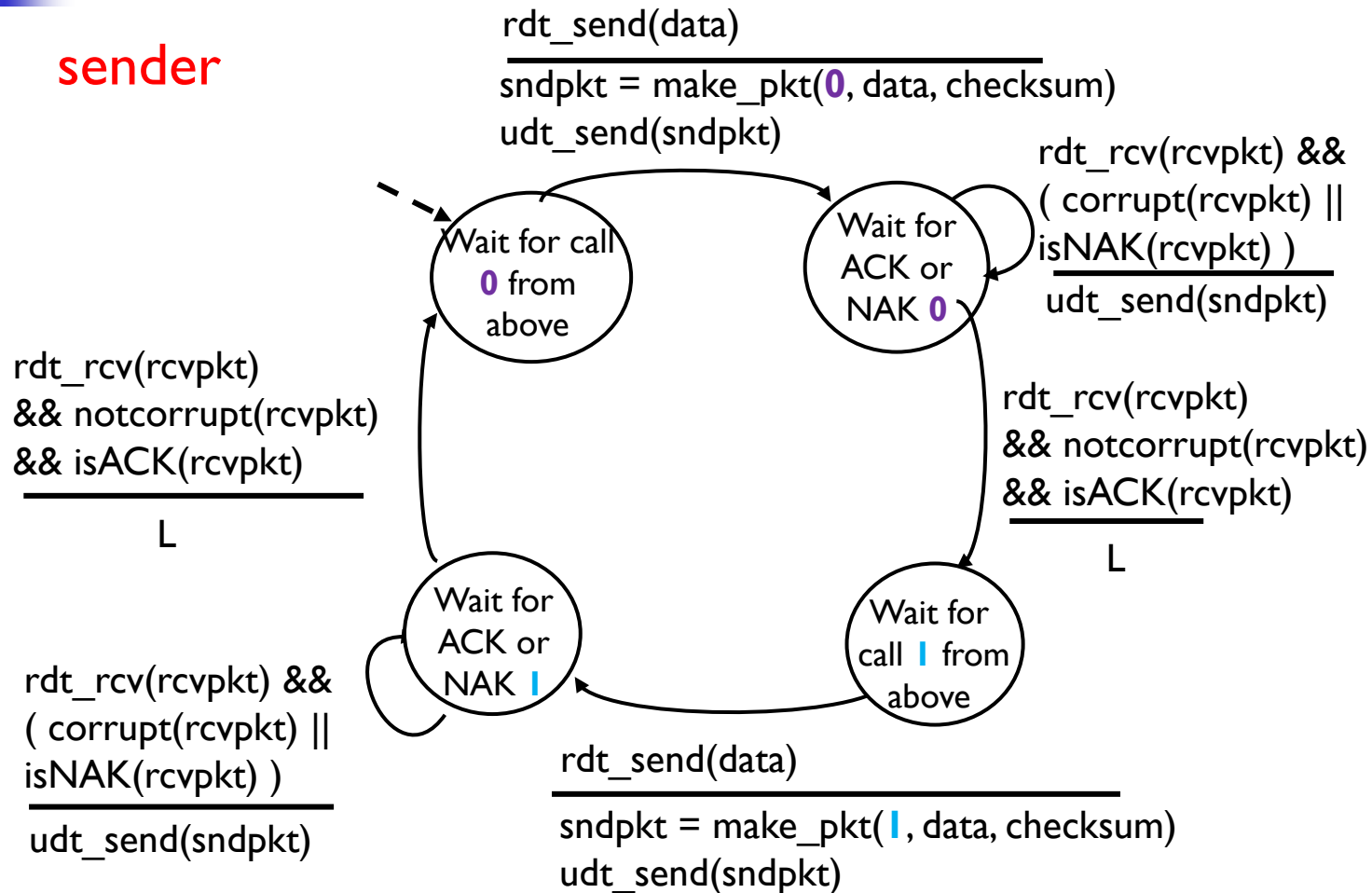


rdt2.0 has a Fatal Flaw!

- What happens if ACK/NAK corrupted?
 - add checksum to ACK/NAK to detect errors
 - more difficult question: how to *recover* from errors in ACK/NAK
 - sender doesn't know what happened at receiver!
 - sender does not know whether or not the receiver has correctly received the last piece of transmitted data
 - can't just retransmit: possible duplicate
- **Handling duplicates:**
 - sender retransmits current pkt if ACK/NAK garbled
 - sender adds *sequence number*, *1-bit*, to each pkt
 - receiver discards (doesn't deliver up) duplicate pkt

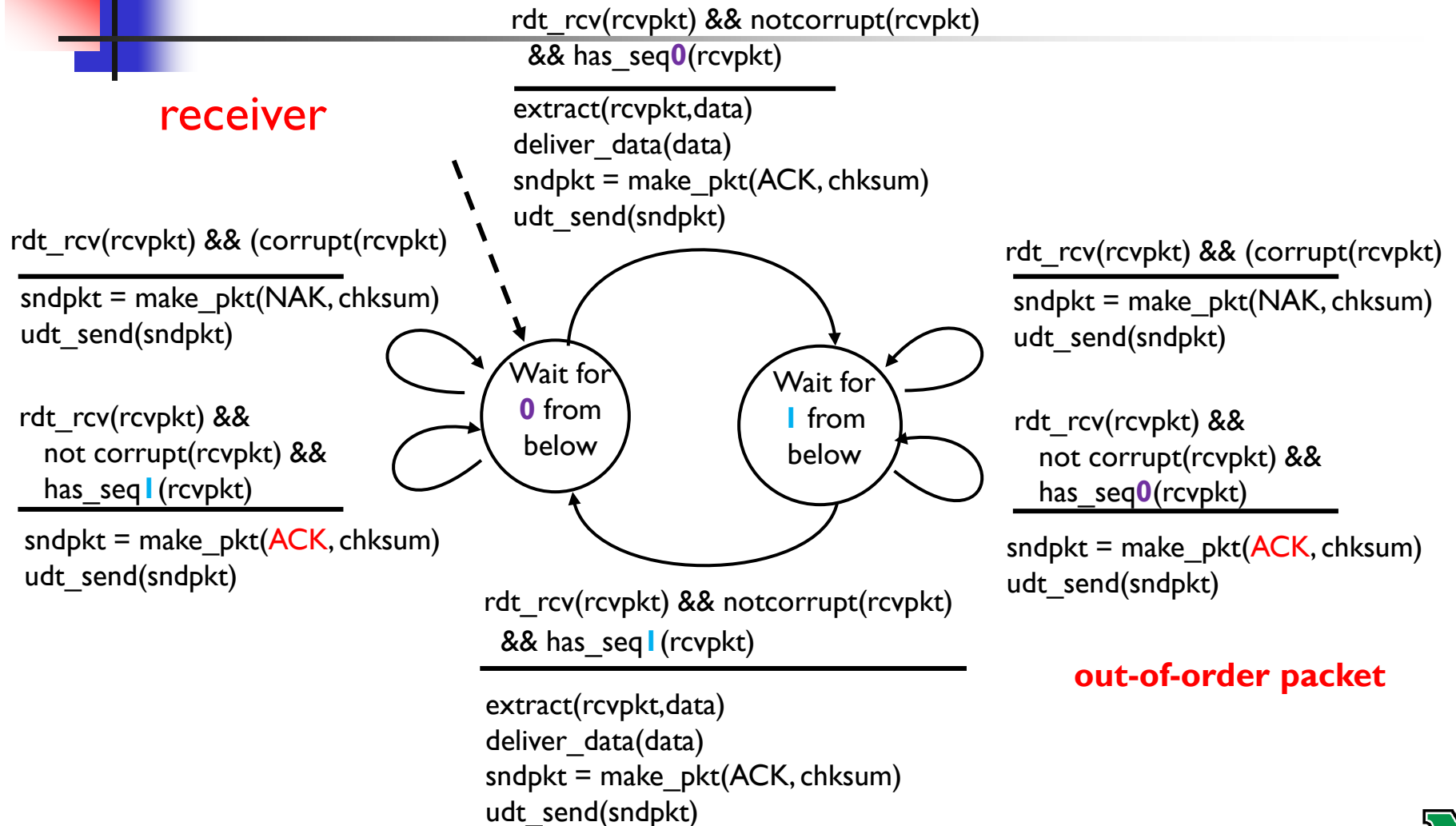
rdt2.1: Sender, handles garbled ACK/NAKs

sender



rdt2.1: Receiver, handles garbled ACK/NAKs

receiver





rdt2.1: Discussion

- Sender:

- seq # added to pkt
- two seq. #'s (0,1) will suffice. Why?
- must check if received ACK/NAK corrupted
- twice as many states
 - state must “remember” whether “current” pkt has 0 or 1 seq. #

- 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



rdt3.0: Channels with Errors and Loss

- **new assumption:** underlying channel can also *lose packets* (data or ACKs)
 - two additional concerns:
 - how to detect packet loss?
 - what to do when packet loss occurs?
 - checksum, seq. #, ACKs, retransmissions will be of help
- **approach:** sender *waits* “reasonable” amount of *time* for ACK
 - detecting & recovering from lost packets from the sender side
 - how long must the sender wait?
 - at least as long as a *round trip time (RTT)* between sender and receiver



rdt3.0: Channels with Errors and Loss (cont.)

- **approach:** sender waits “reasonable” amount of time for ACK (cont.)
 - retransmits if no ACK received in this time
 - if pkt (or ACK) just delayed (not lost):
 - retransmission will be duplicate, but use of **seq. #'s** already handles this
 - receiver must specify **seq #** of pkt being ACKed
 - requires **countdown timer** (the sender):
 - (1) start the timer each time when a packet is sent
 - (2) respond to a timer interrupt
 - (3) stop the timer

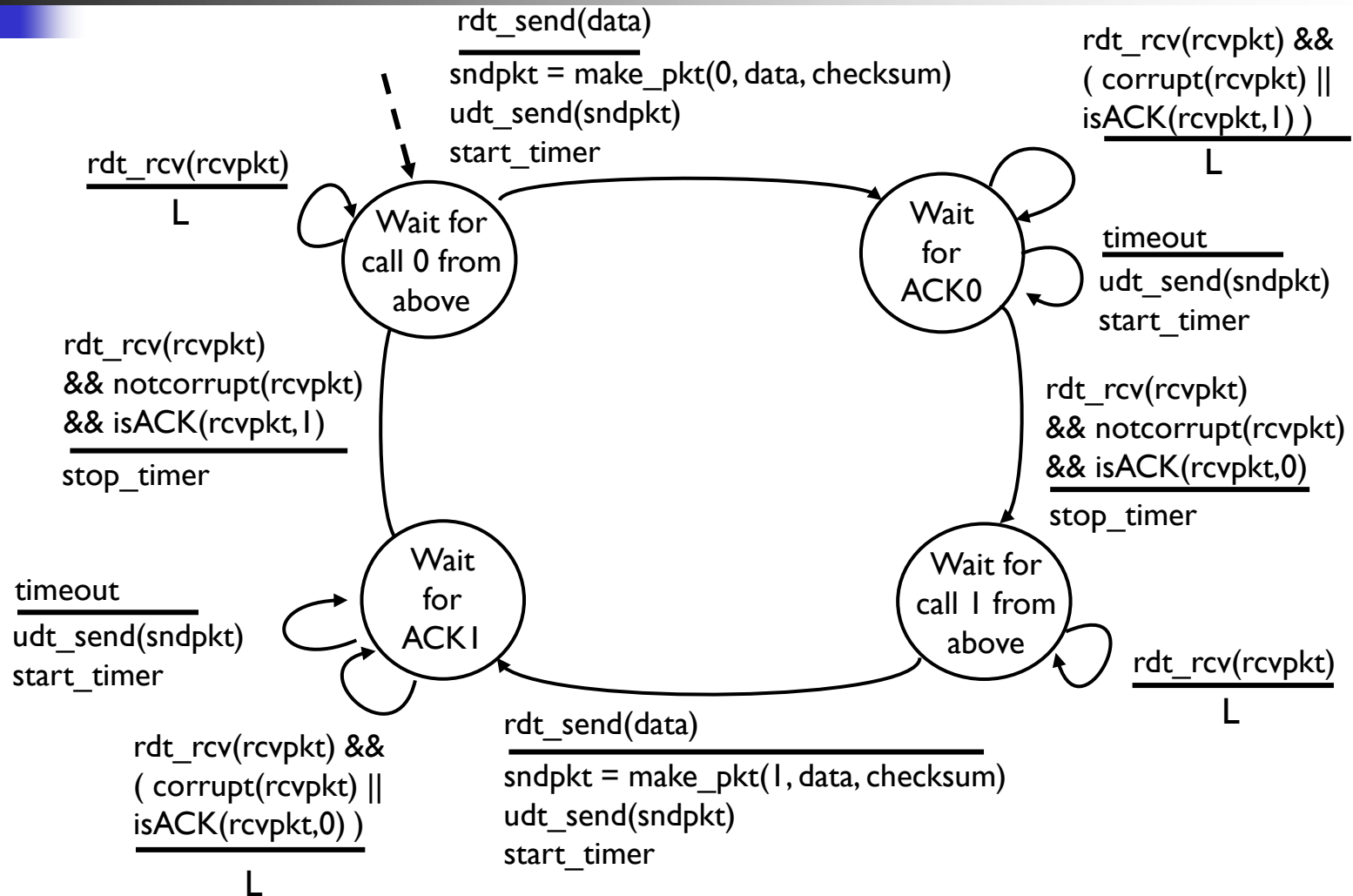


rdt3.0: Channels with Errors and Loss (cont.)

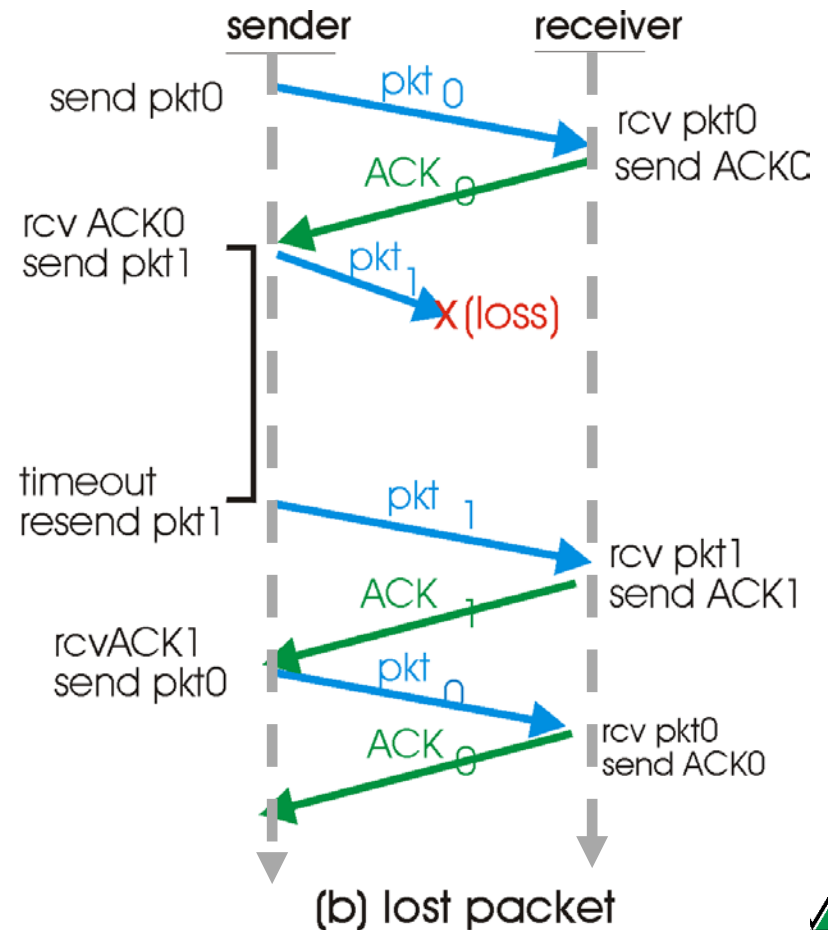
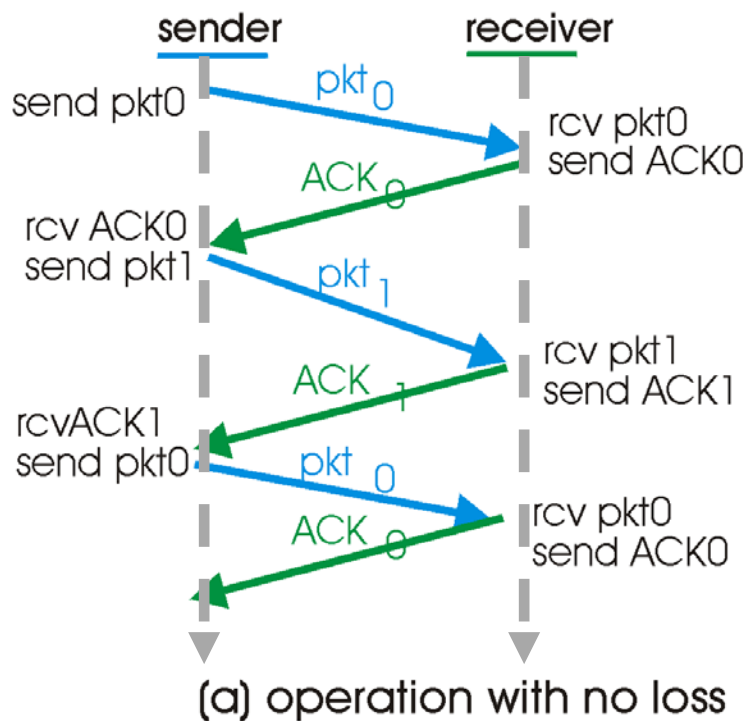
- from the sender's point of view, the sender does NOT know whether
 - a data packet was lost
 - an ACK was lost
 - if the packet or ACK was simply overly delayed
 - → in all case, the sender just retransmits!!

rdt3.0: Sender

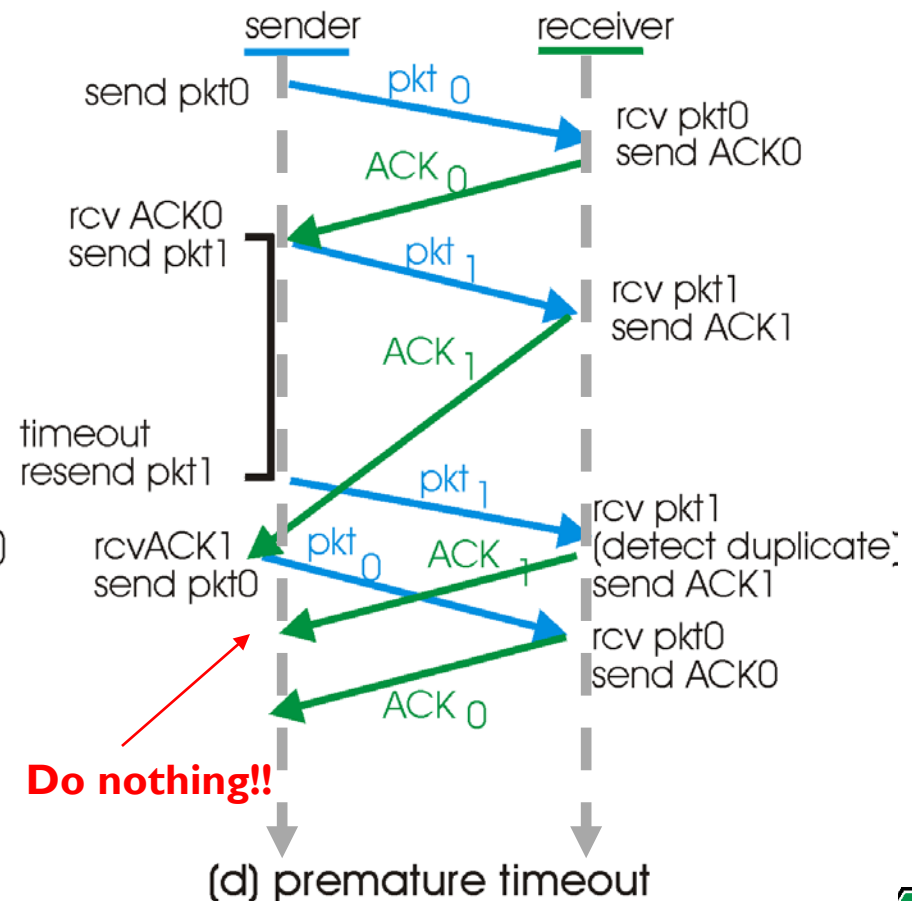
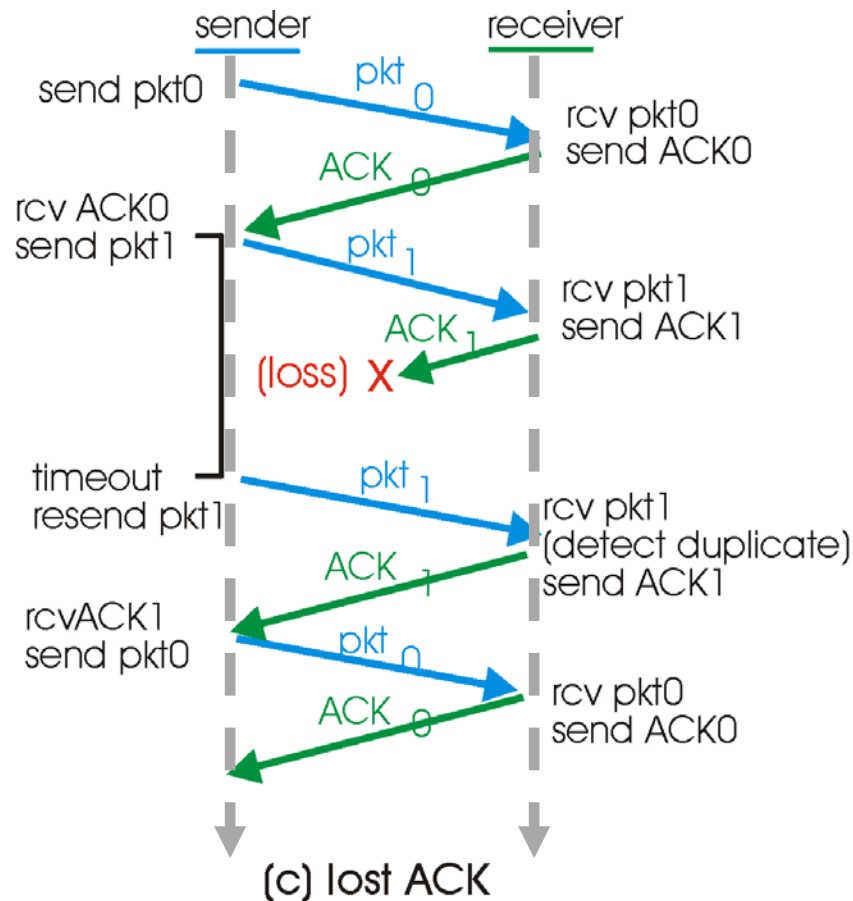
What about a receiver side?



rdt3.0 in Action



rdt3.0 in Action (cont.)





Performance of rdt3.0

- rdt3.0 works, but **performance stinks**
 - For example: 1 Gbps link, 15 ms end-to-end delay, 1KB packet:

$$T_{\text{transmit}} = \frac{L \text{ (packet length in bits)}}{R \text{ (transmission rate, bps)}} = \frac{8000 \text{ bit/pkt}}{10^{**}9 \text{ bit/sec}} = 8 \text{ microsec}$$

- RTT: the speed-of-light propagation delay, approximately 30 msec
 - the time t when the last bit of the packet emerging at the receiver

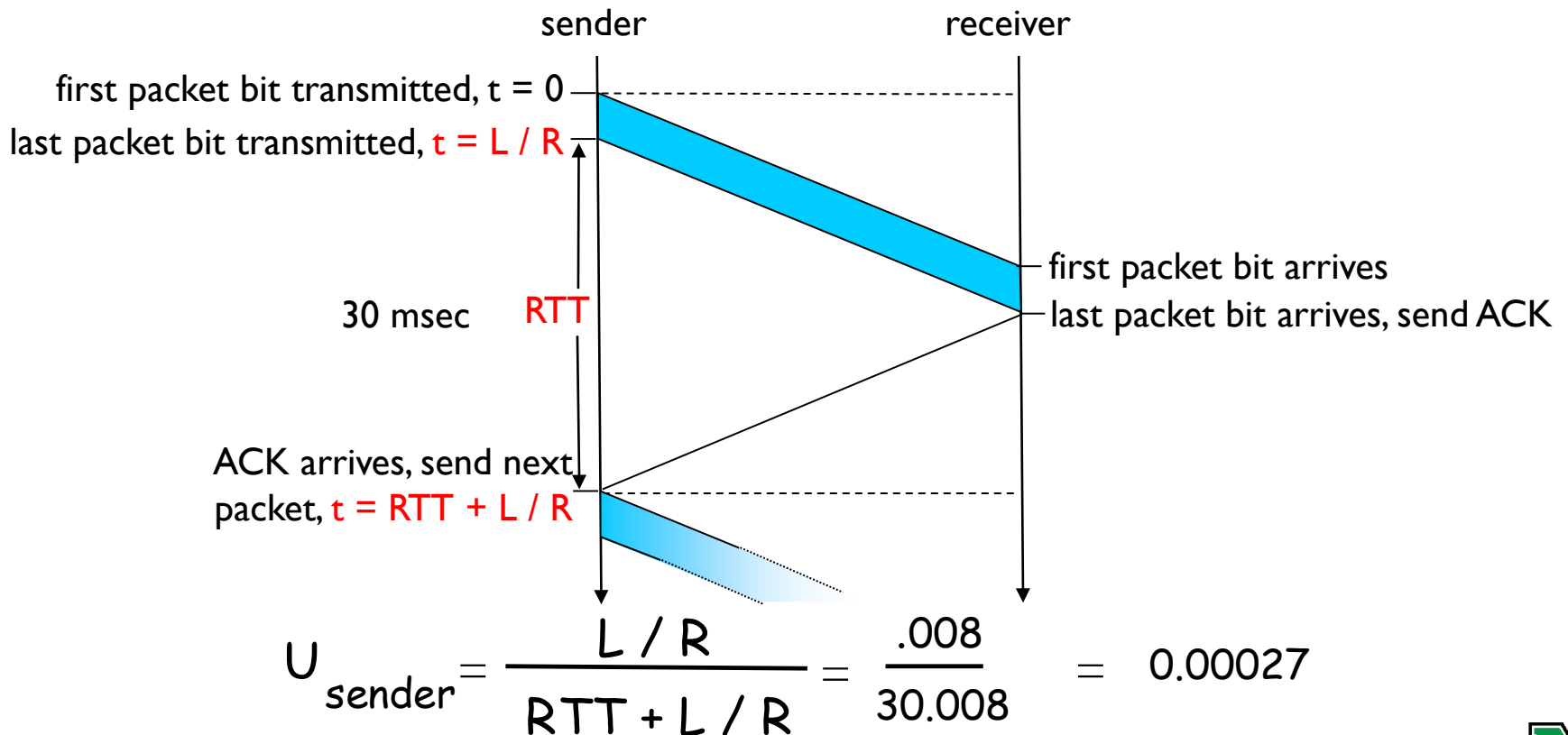
$$t = \text{RTT}/2 + L/R = 15.008 \text{ msec}$$

- When the ACK will come back?

$$t = \text{RTT} + L/R = 30.008 \text{ msec}$$

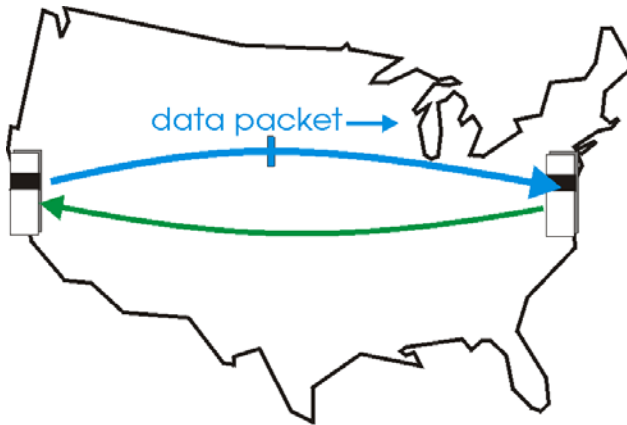
rdt3.0: stop-and-wait Operation

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

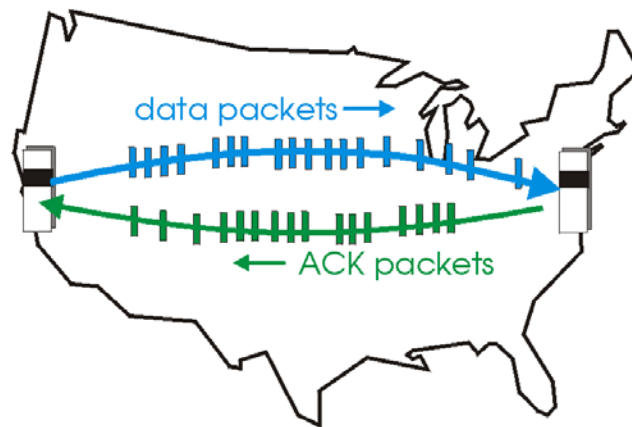


Pipelined Protocols

- **pipelining**: sender allows multiple, “in-flight”, yet-to-be-acknowledged pkts. **sending multiple pkts without waiting for acknowledgments**
 - range of sequence numbers must be increased
 - buffering at sender and/or receiver
 - two generic forms of pipelined protocols: *Go-Back-N*, *selective repeat*

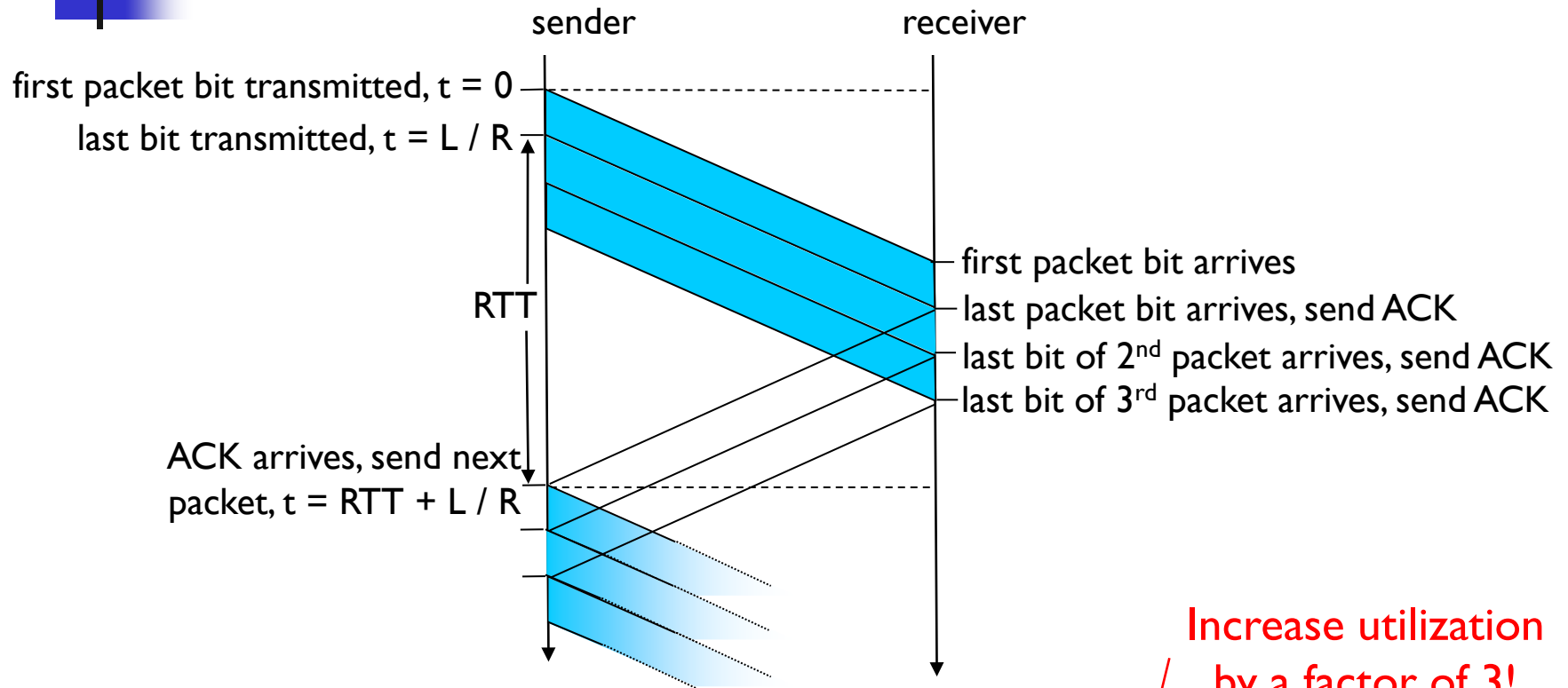


(a) a stop-and-wait protocol in operation



(b) a pipelined protocol in operation

Pipelining: Increased Utilization



$$U_{\text{sender}} = \frac{3 * L / R}{RTT + L / R} = \frac{.024}{30.008} = 0.0008$$

Increase utilization
by a factor of 3!