



# COMPUTER NETWORKS

## 3-0-0 3

Amrita Vishwa Vidyapeetham  
Amritapuri Campus



# TRANSPORT LAYER



## Chapter 3: Transport Layer

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# 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

# Principles of Reliable Data Transfer

For connection-oriented service provided by TCP, it is necessary to have a reliable data transfer (RDT) protocol to ensure delivery of all packets and to enable the receiver to deliver the packets in order to its application layer.

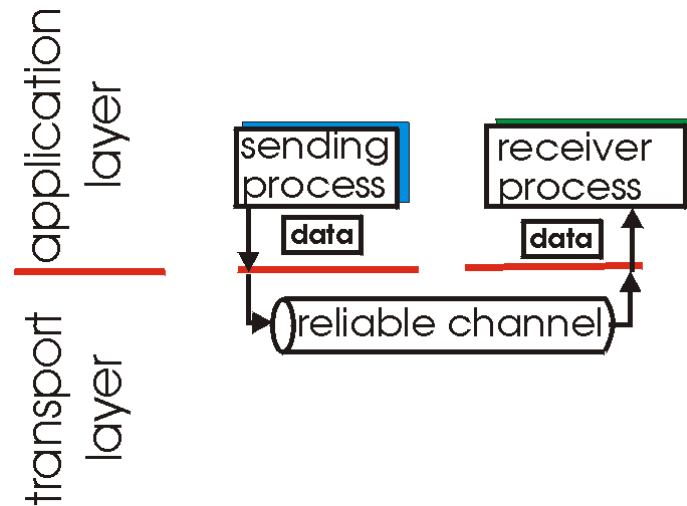
With a reliable channel, no transferred data bits are corrupted (flipped from 0 to 1, or vice versa) or lost, and all are delivered in the order in which they were sent. This is precisely the service model offered by TCP to the Internet applications that invoke it.

It is the responsibility of a reliable data transfer protocol to implement this service abstraction. This task is made difficult by the fact that the layer below the reliable data transfer protocol may be unreliable. For example, TCP is a reliable data transfer protocol that is implemented on top of an unreliable (IP) end-to-end network layer.

The internet network layer provides only best effort service with no guarantee that packets arrive at their destination. Also, since each packet is routed individually it is possible that packets are received out of order.

# Principles of reliable data transfer

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



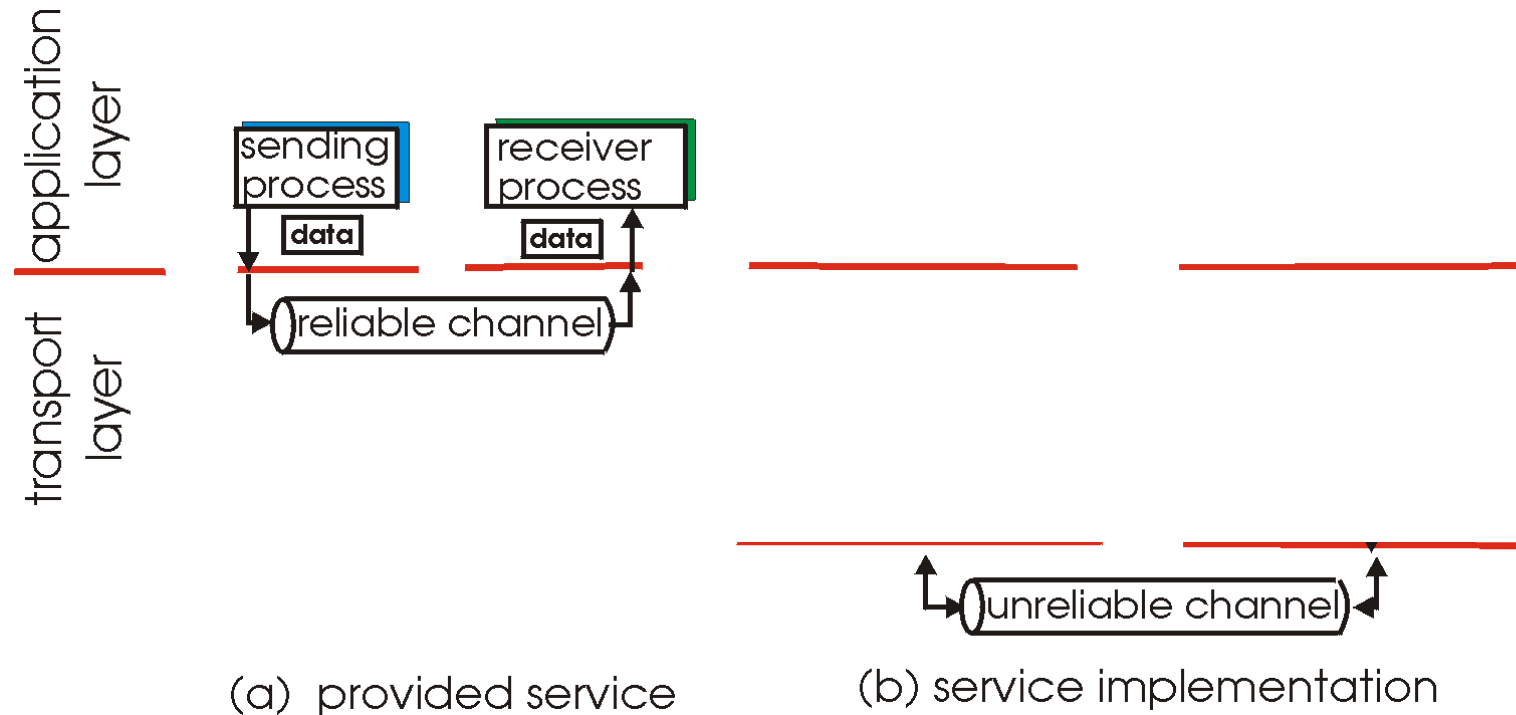
(a) provided service

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



# Principles of reliable data transfer

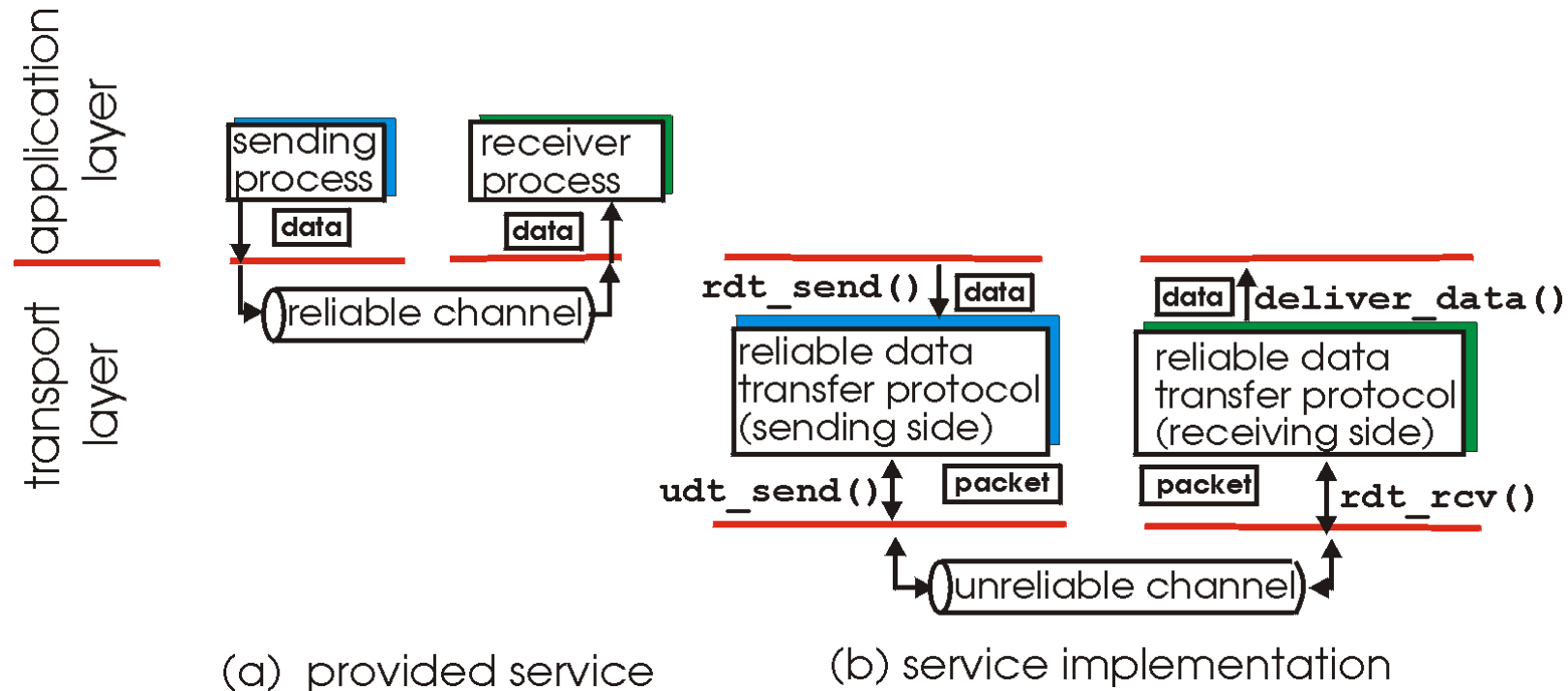
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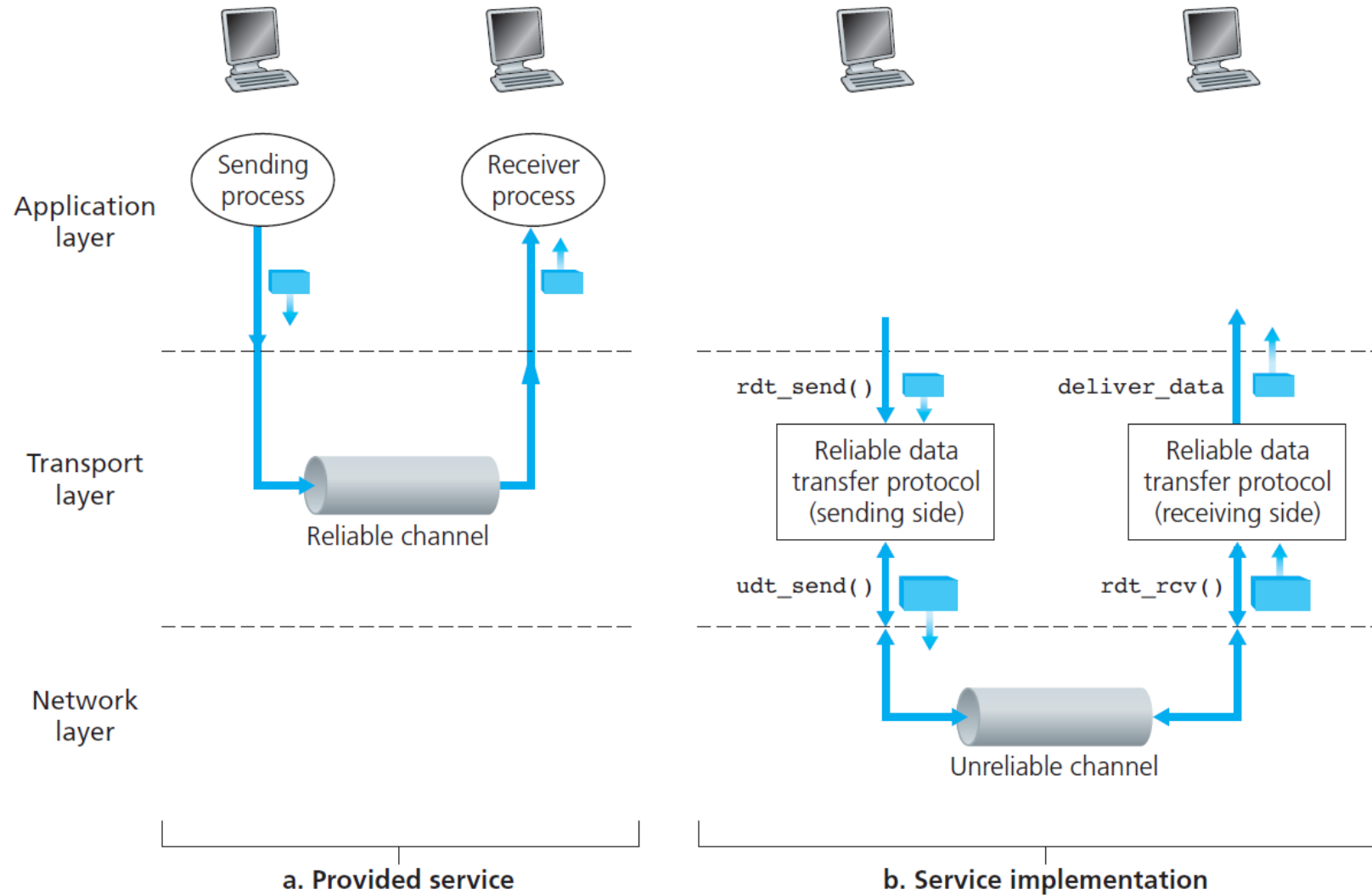
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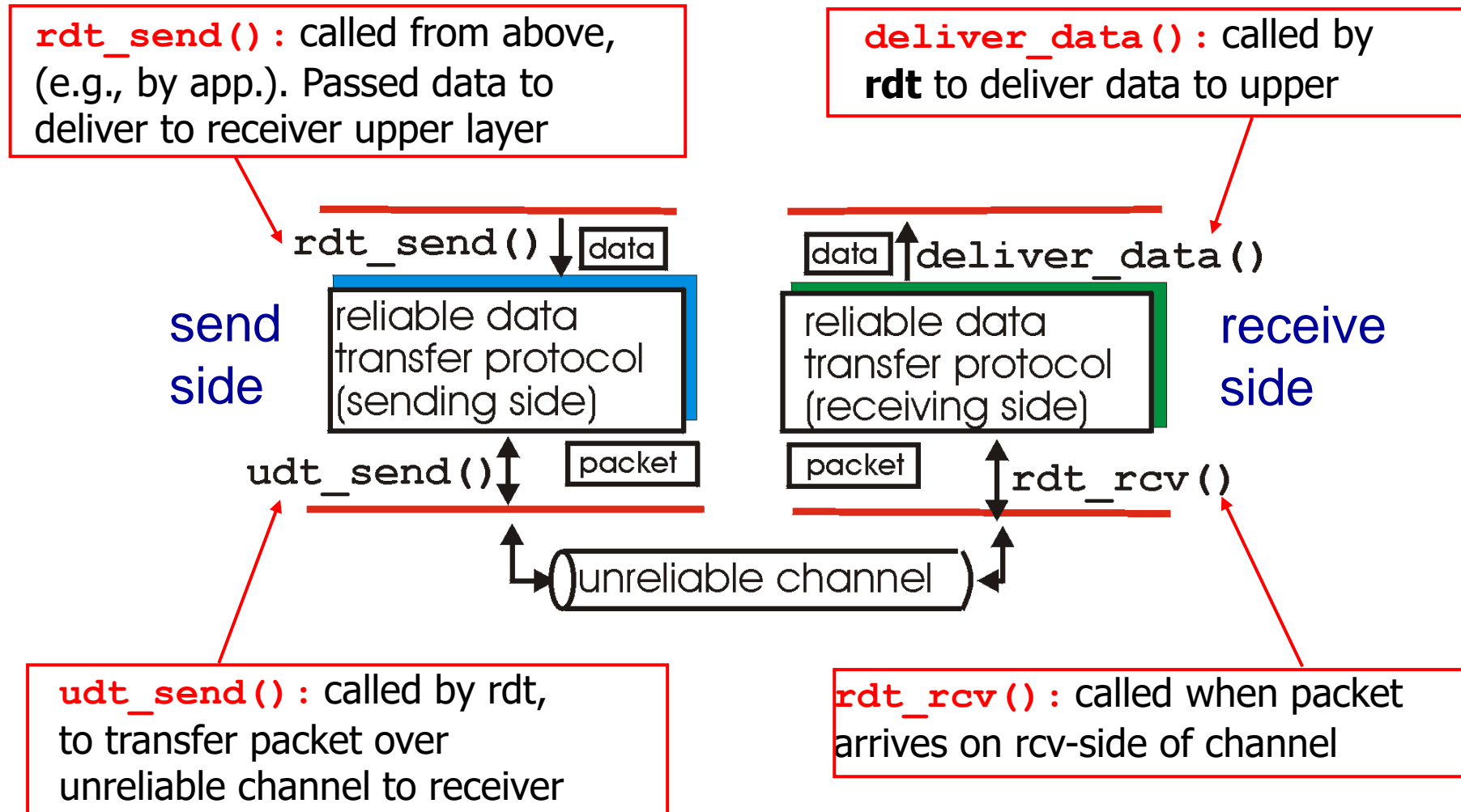
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# Principles of reliable data transfer





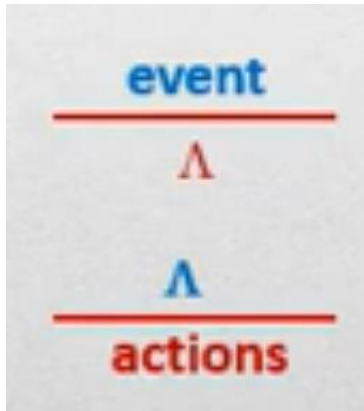
# Reliable data transfer: getting started



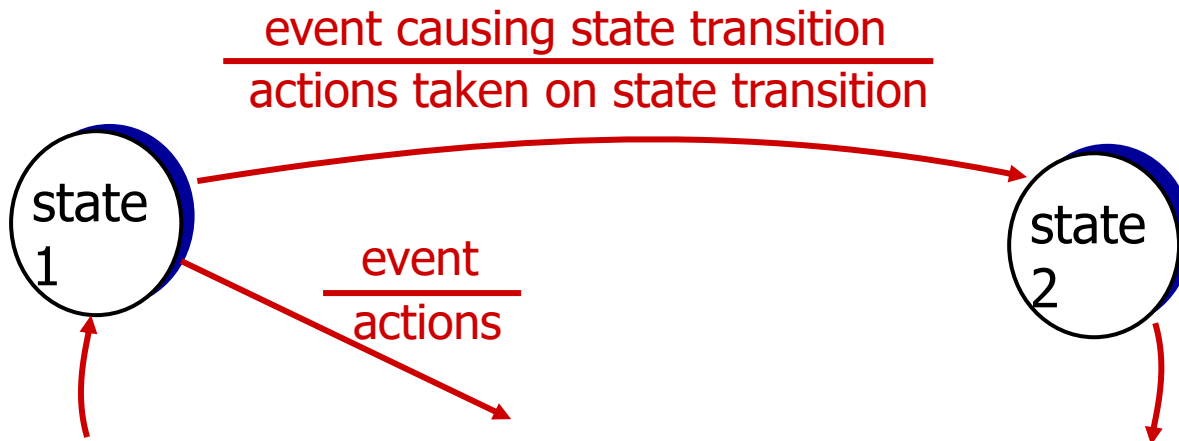
# Reliable data transfer: getting started

we'll:

- incrementally develop sender, 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 sender, receiver



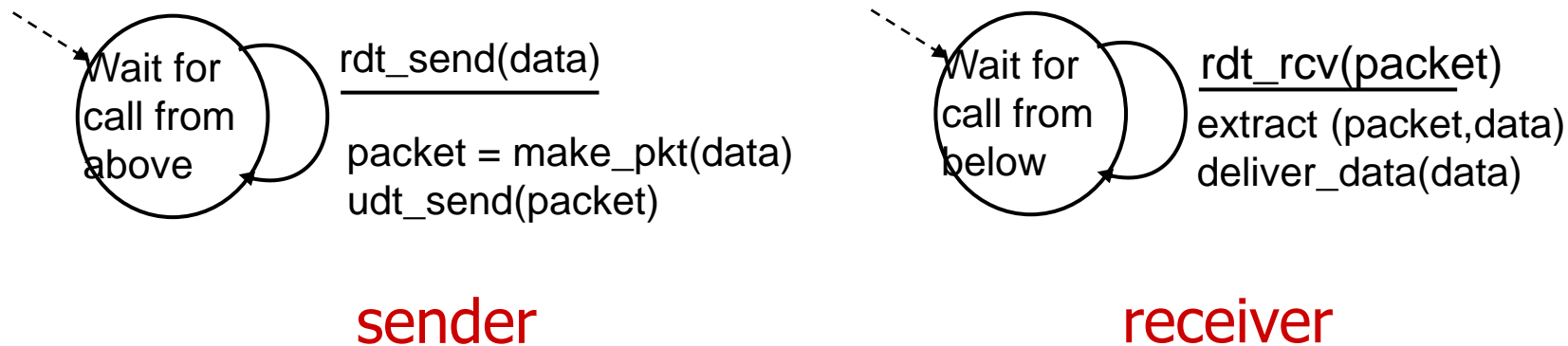
**state:** when in this "state" next state uniquely determined by next event



# rdt1.0: reliable transfer over a reliable channel

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

event  
actions

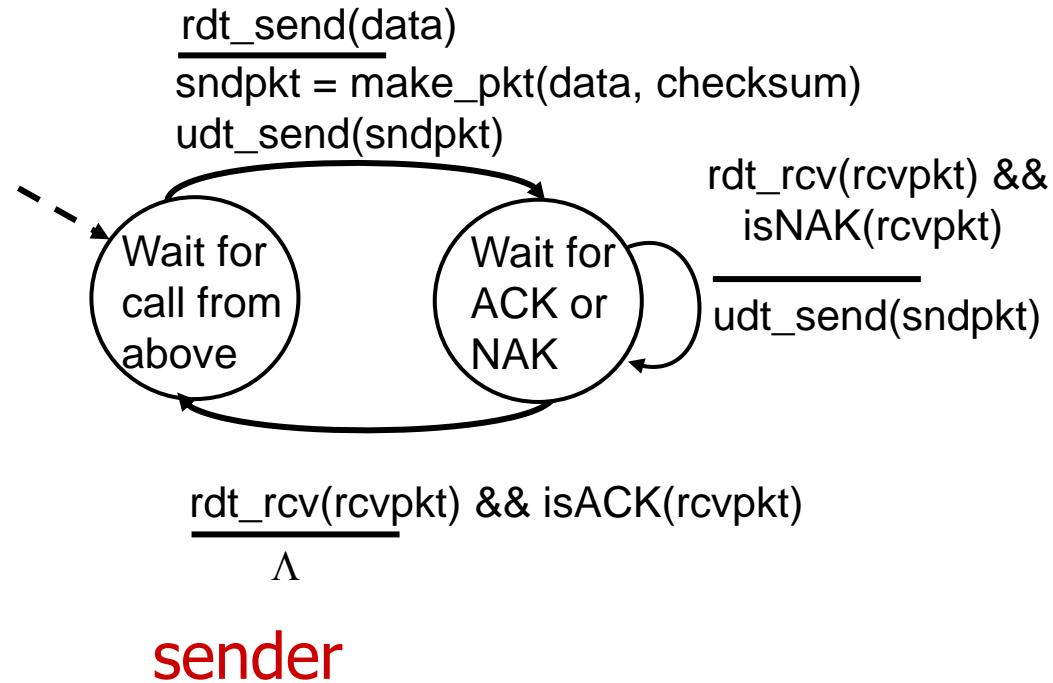


## rdt2.0: channel with bit errors

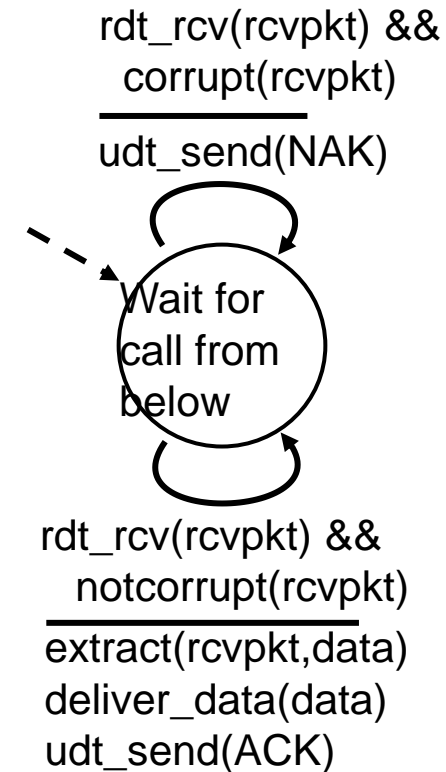
- underlying channel may flip bits in packet
  - checksum to detect bit errors
- *the* question: how to recover from errors:
  - *acknowledgements (ACKs)*: receiver explicitly tells sender that pkt received OK
  - *negative acknowledgements (NAKs)*: receiver explicitly tells sender that pkt had errors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

*How do humans recover from “errors” during conversation?*

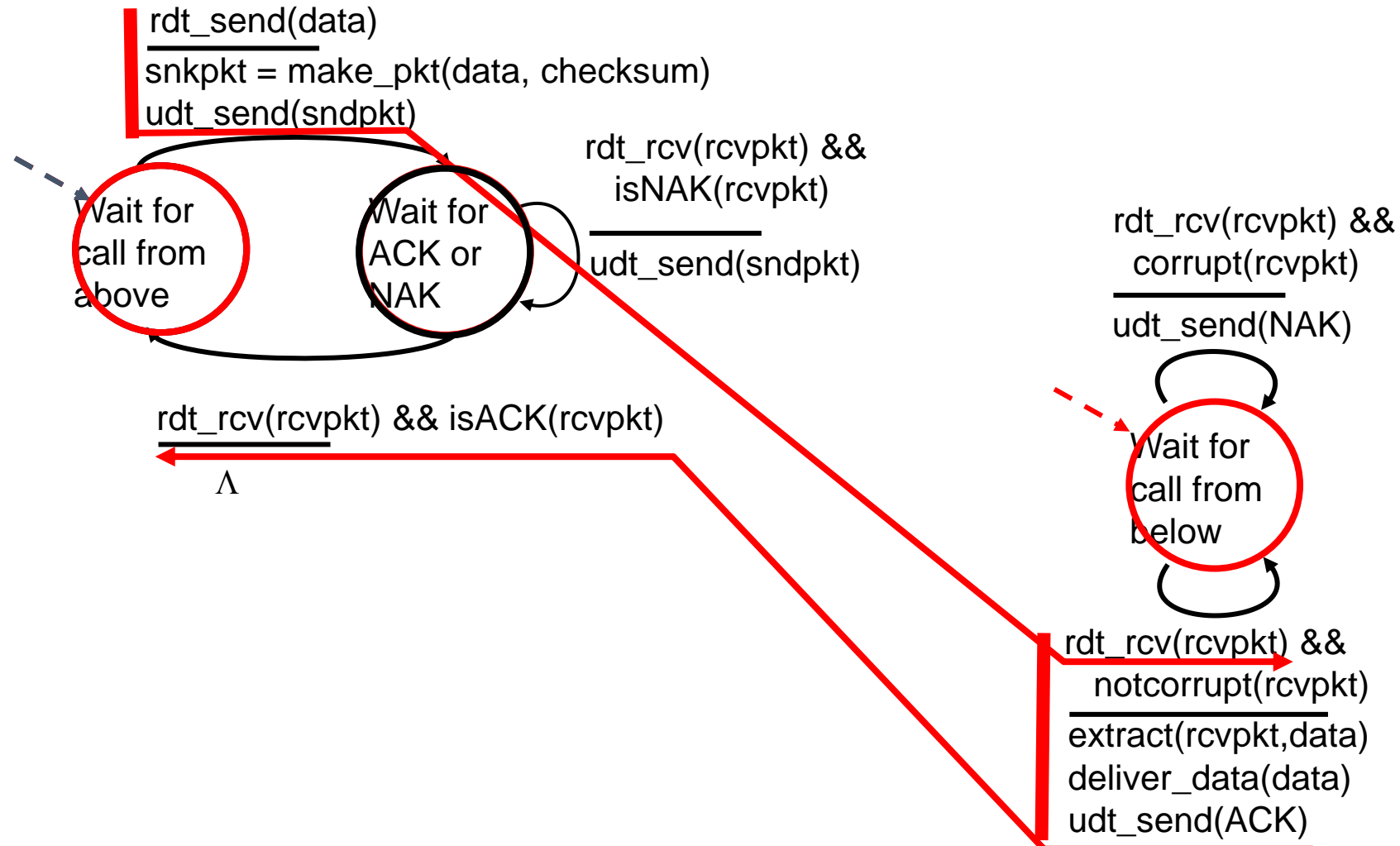
# rdt2.0: FSM specification



receiver

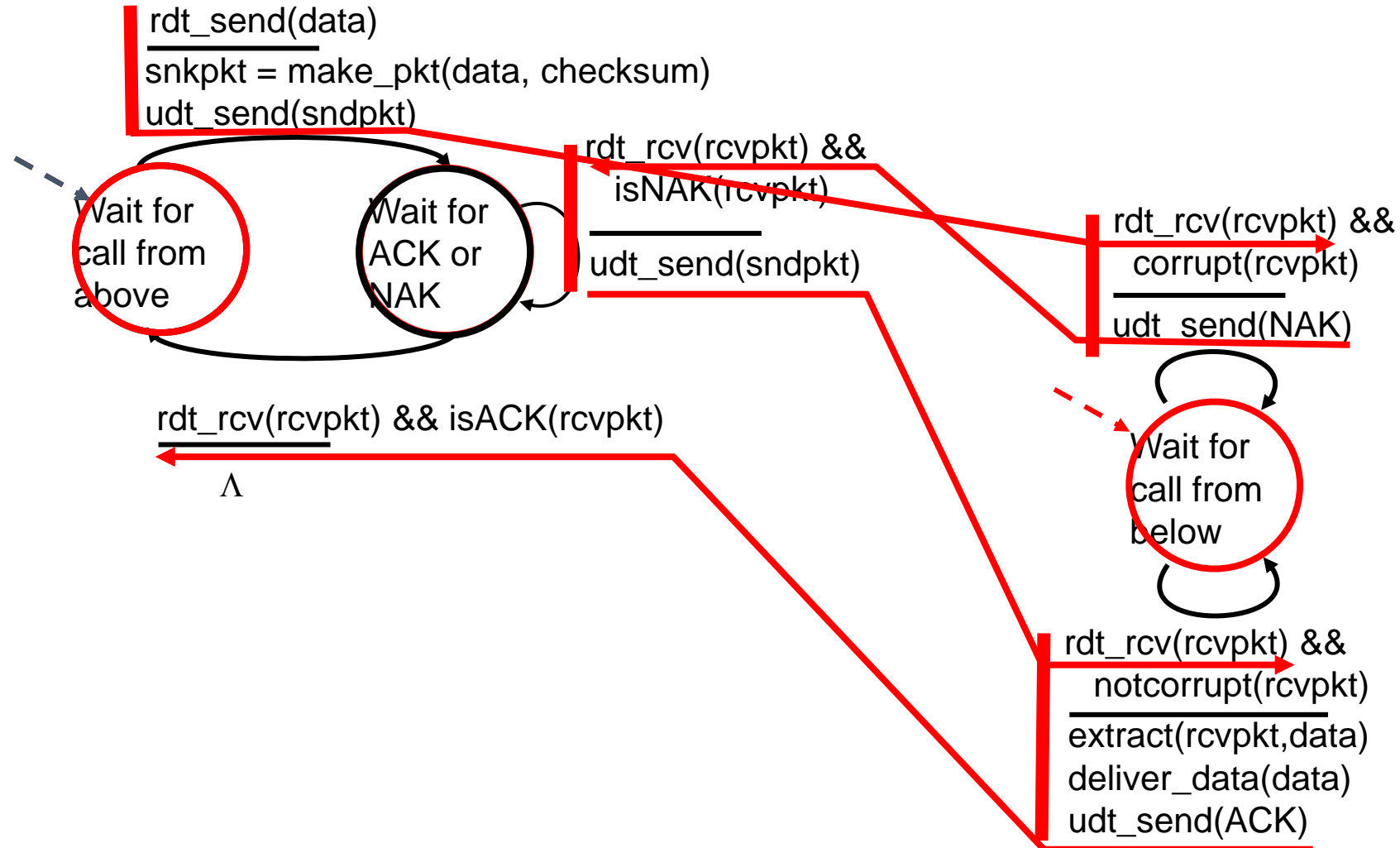


# rdt2.0: operation with no errors





# rdt2.0: error scenario



# 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

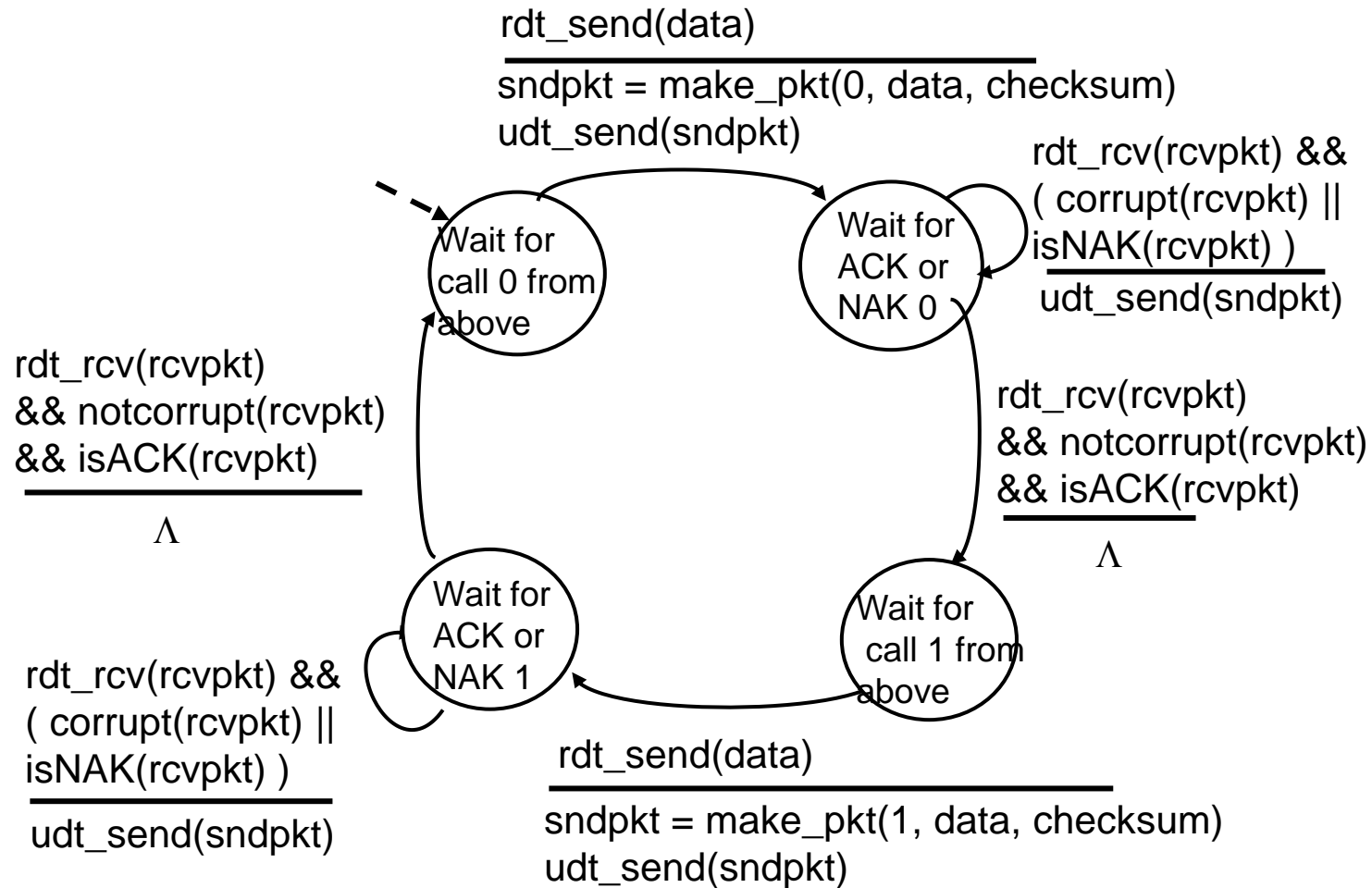
## handling duplicates:

- 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, handles garbled ACK/NAKs

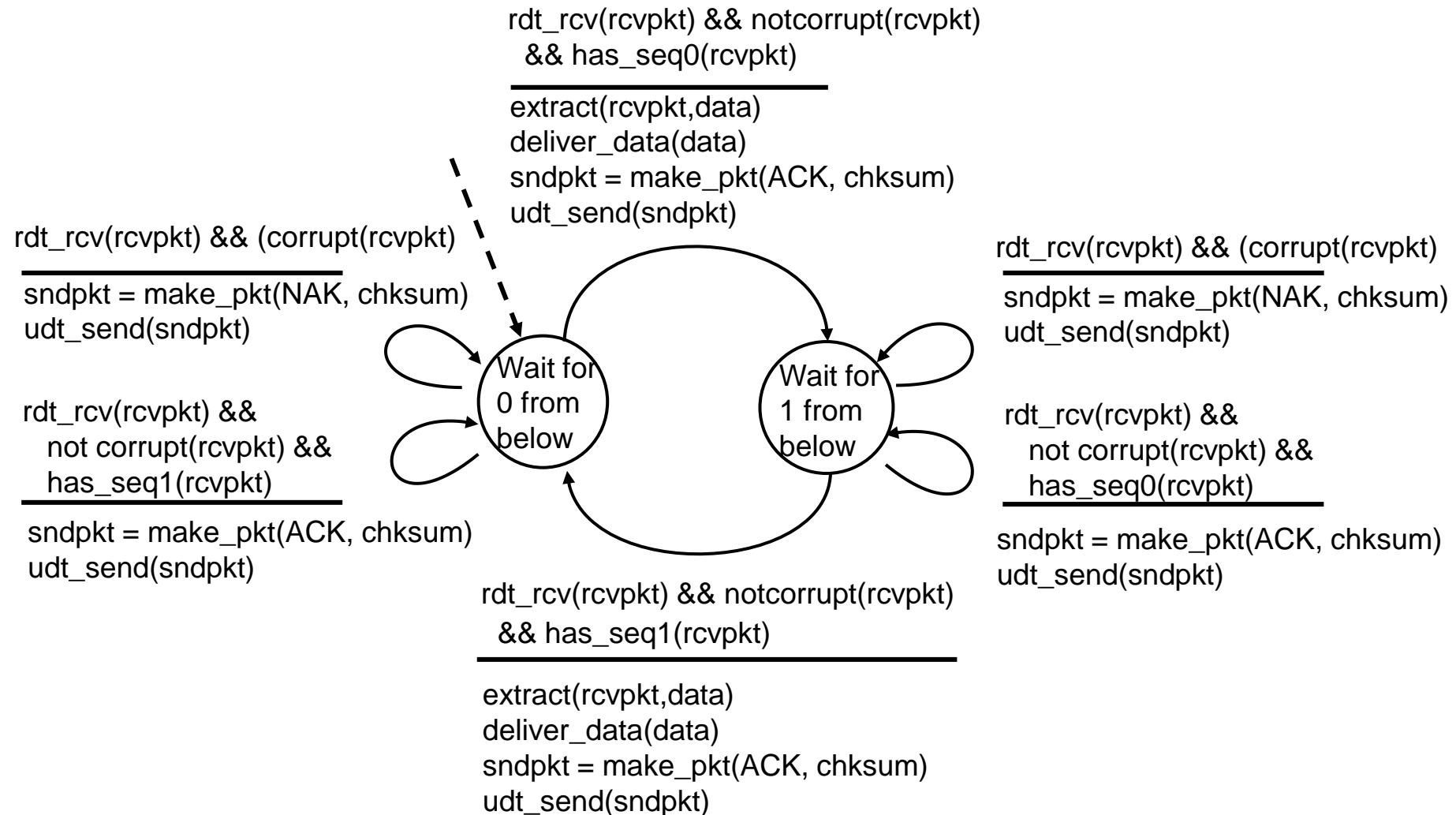


# rdt2.1: receiver, handles garbled ACK/NAKs

When an out-of-order packet is received, the receiver sends a positive acknowledgment for the packet it has received.

When a corrupted packet is received, the receiver sends a negative acknowledgment. We can accomplish the same effect as a NAK if, instead of sending a NAK, we send an ACK for the last correctly received packet.

A sender that receives two ACKs for the same packet (that is, receives **duplicate ACKs**) knows that the receiver did not correctly receive the packet following the packet that is being ACKed twice



# 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 “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

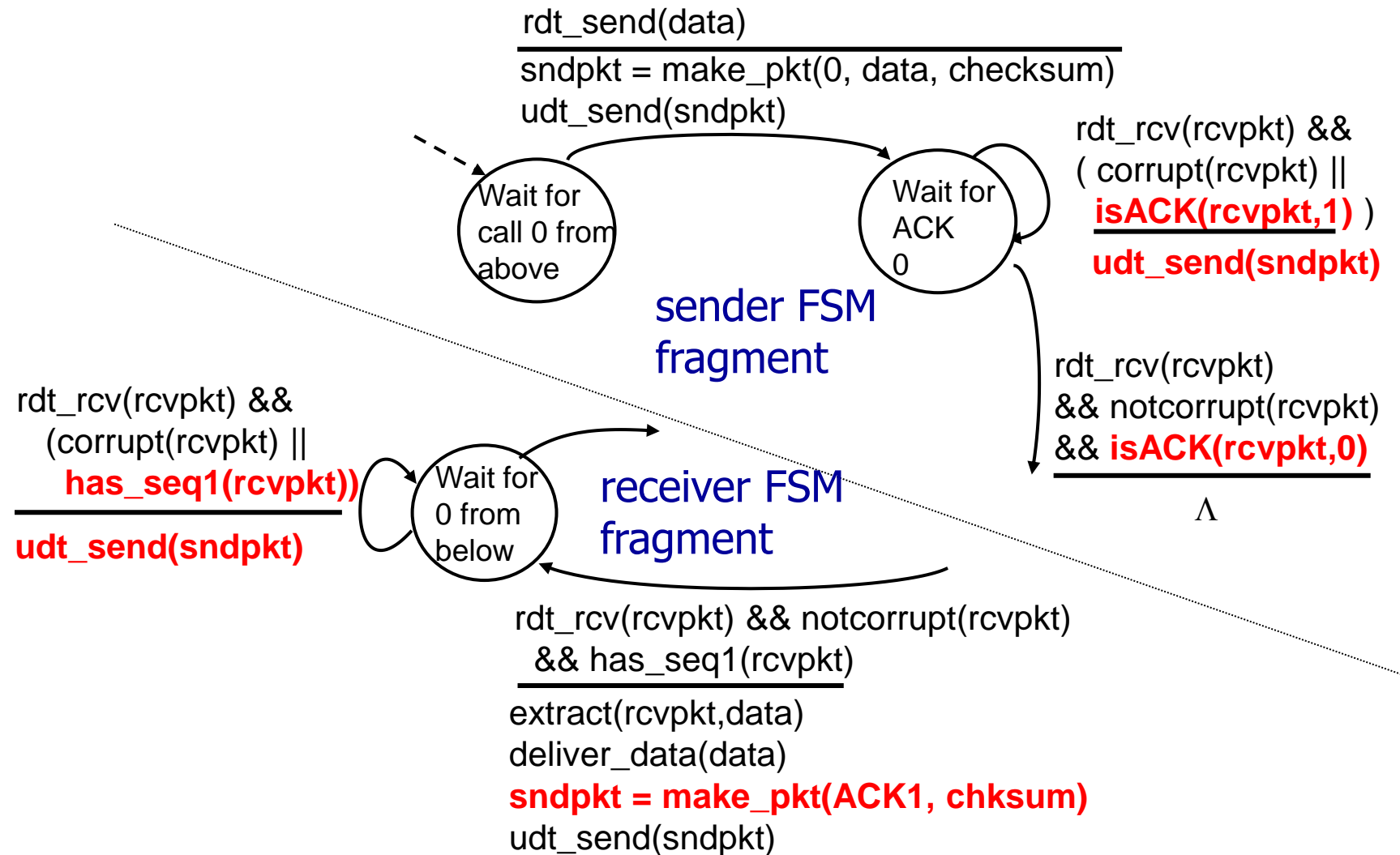
# rdt2.2: a NAK-free protocol

- 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*



# rdt2.2: sender, receiver fragments

One subtle change between rdt2.1 and rdt2.2 is that the receiver must now include the sequence number of the packet being acknowledged by an ACK message (this is done by including the ACK,0 or ACK,1 argument in make\_pkt() in the receiver FSM), and the sender must now check the sequence number of the packet being acknowledged by a received ACK message (this is done by including the 0 or 1 argument in isACK() in the sender FSM).



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

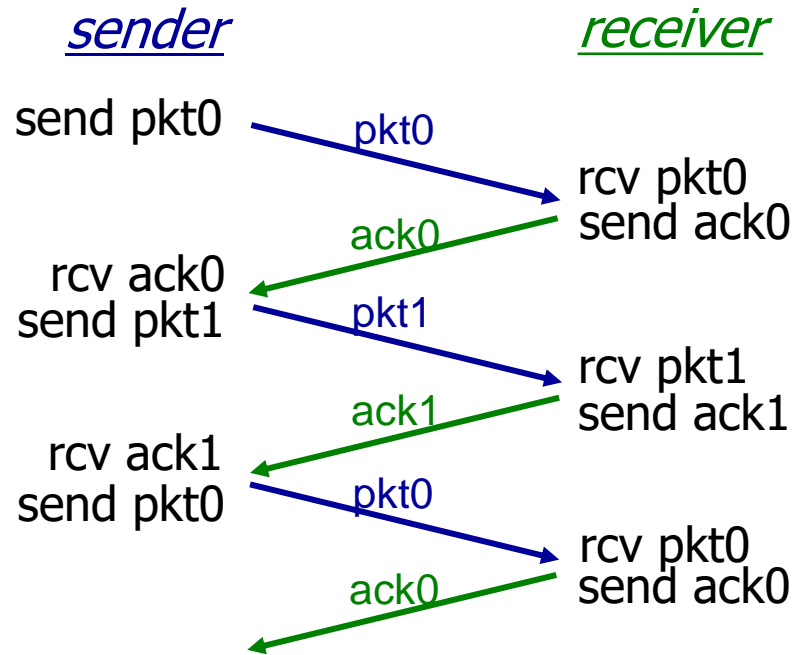
new assumption: underlying channel can also lose packets (data, ACKs)

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

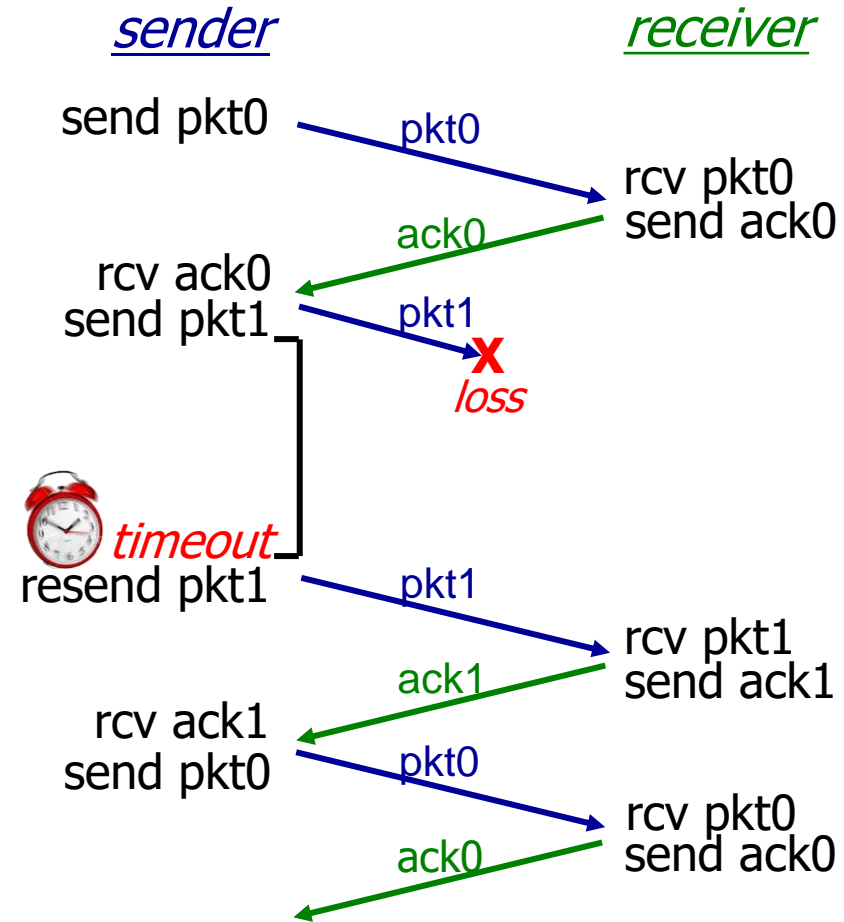
approach: sender waits “reasonable” amount of time for ACK

- 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 in action

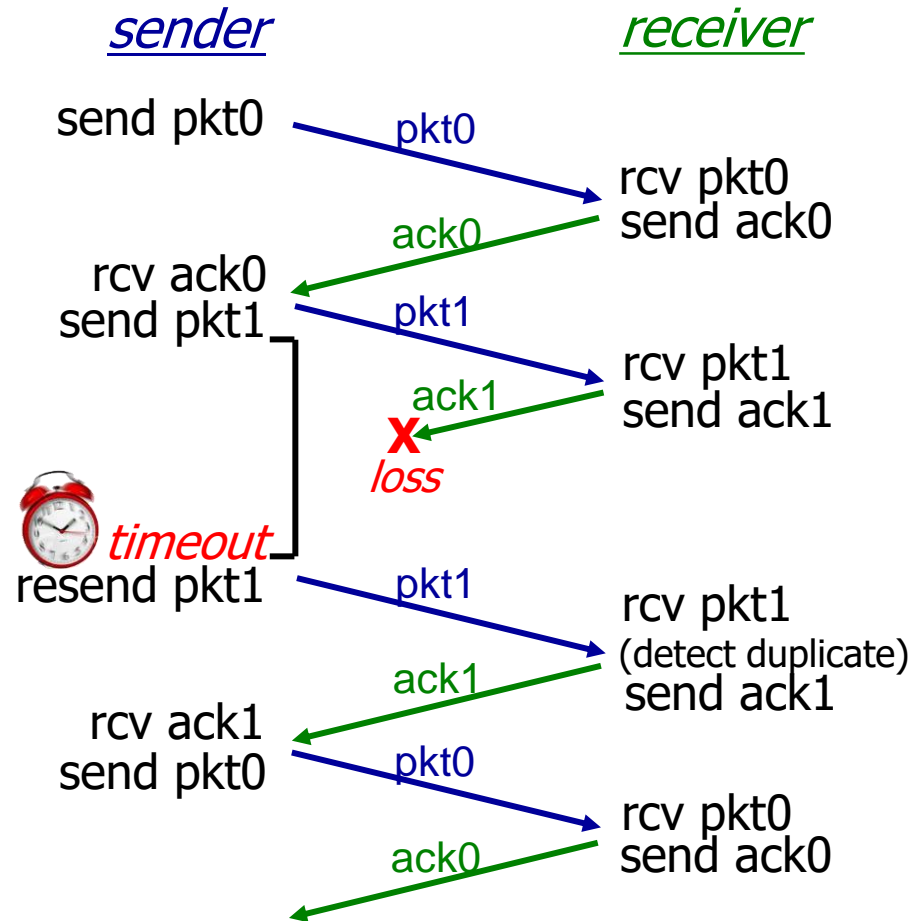


(a) no loss

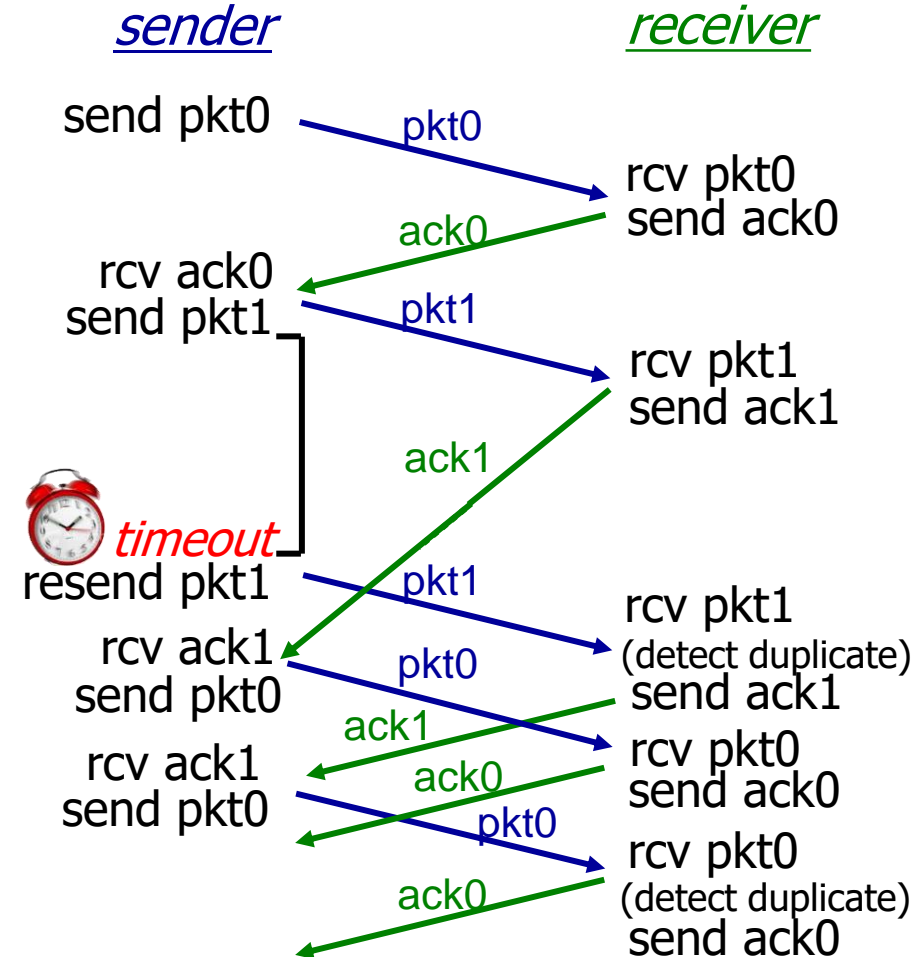


(b) packet loss

# rdt3.0 in action

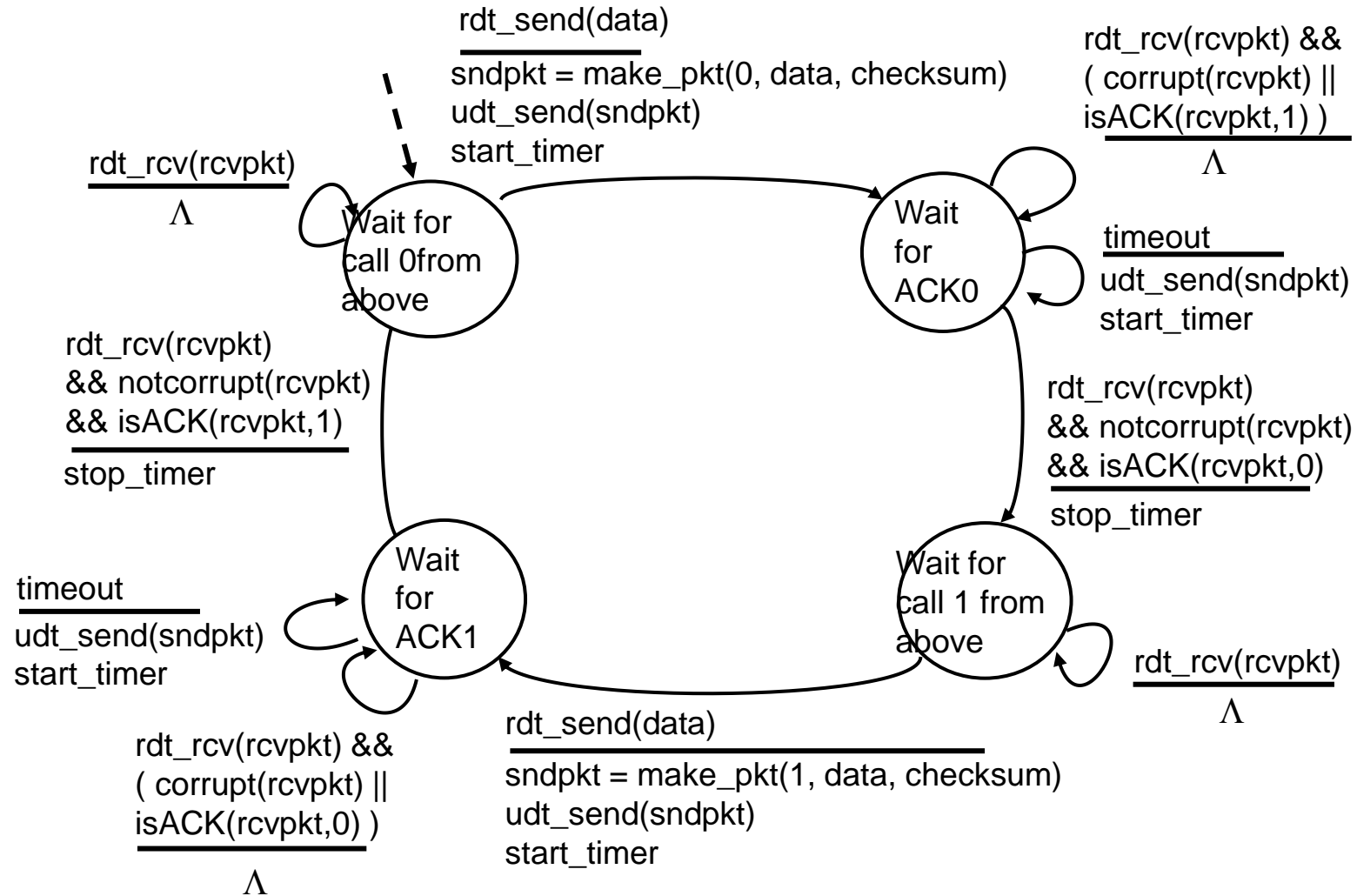


(c) ACK loss



(d) premature timeout/ delayed ACK

# rdt3.0 sender



# Performance of rdt3.0

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

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

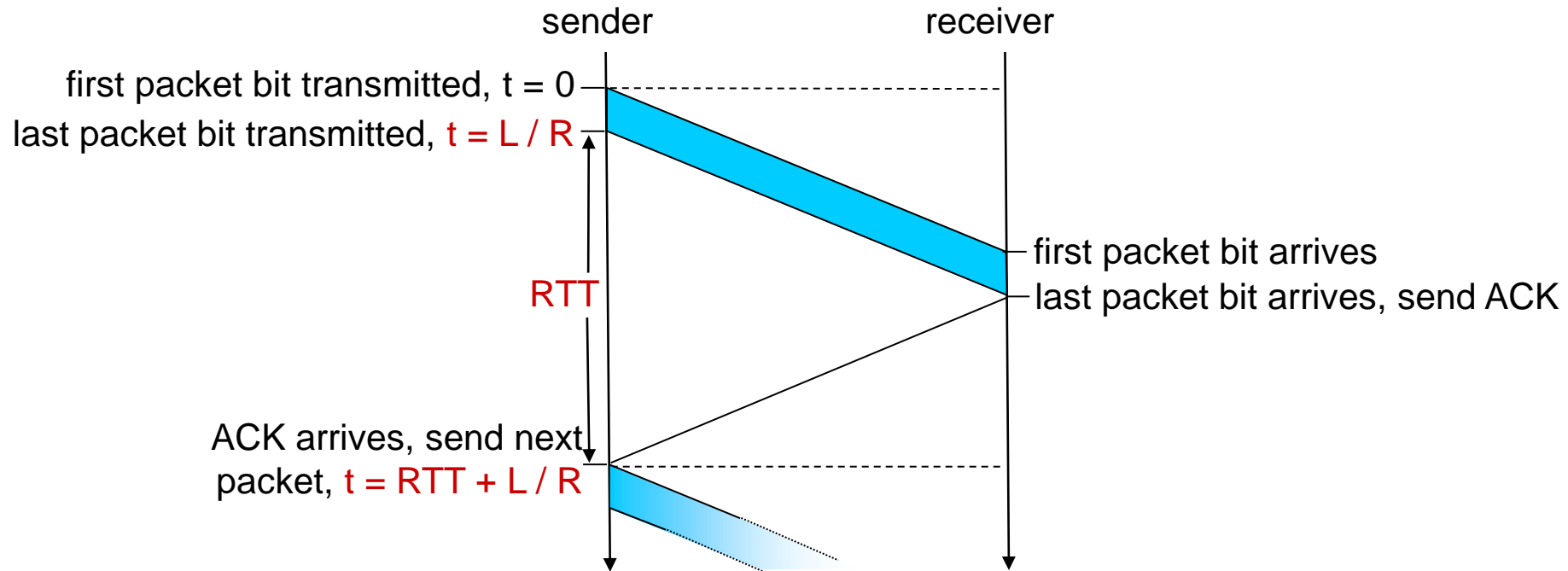
- $U_{\text{sender}}$ : *utilization* – fraction of time sender busy sending

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

- 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



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

# Namah Shivaya