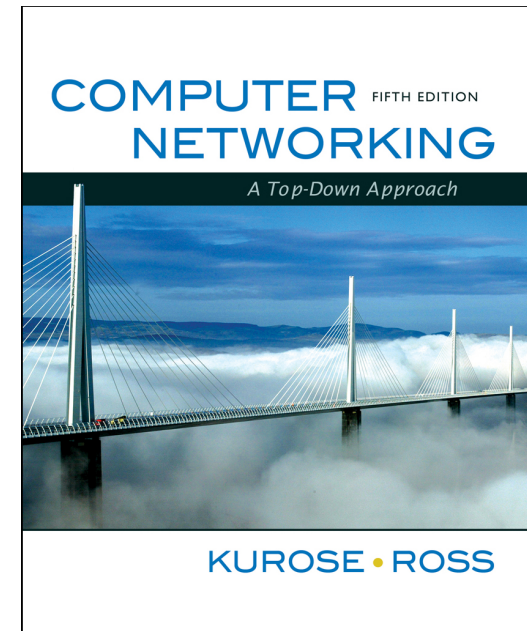


Chapter 3

Transport Layer



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*Computer Networking:
A Top Down Approach
5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April
2009.*

Chapter 3: Transport Layer

Our goals:

- ❖ understand principles behind transport layer services:
 - multiplexing/demultiplexing
 - reliable data transfer
 - flow control
 - congestion control
- ❖ learn about transport layer protocols in the Internet:
 - UDP: connectionless transport
 - TCP: connection-oriented transport
 - TCP congestion control

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

UDP: User Datagram Protocol [RFC 768]

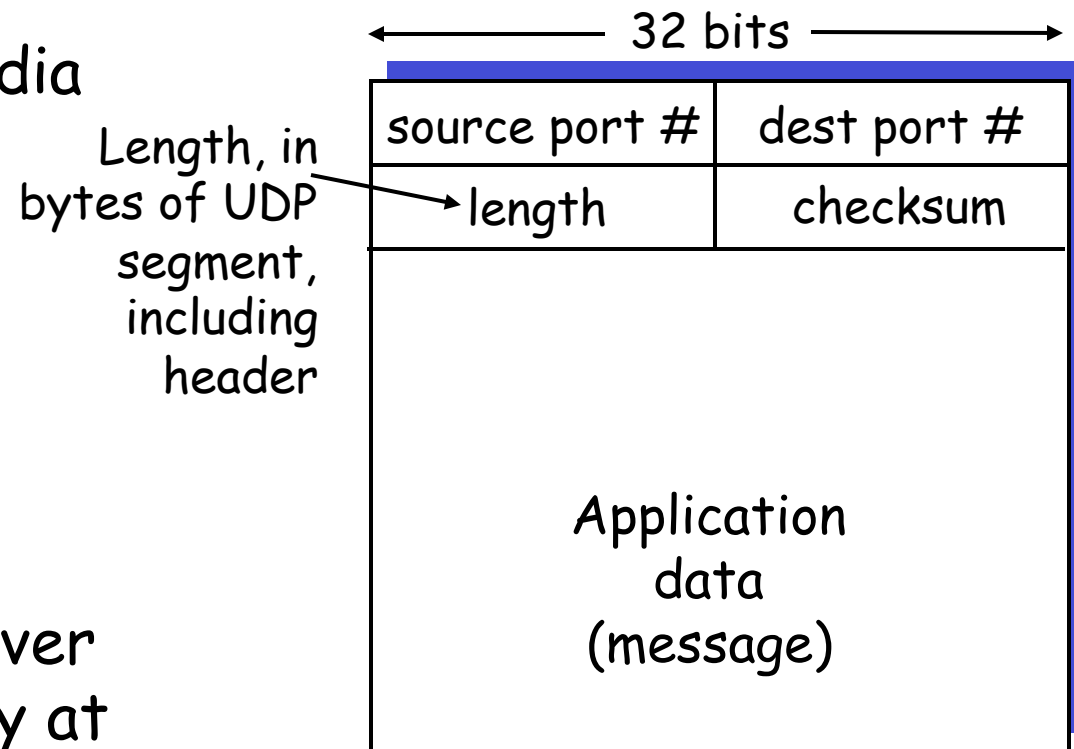
- ❖ “no frills,” “bare bones” Internet transport protocol
- ❖ “best effort” service, UDP segments may be:
 - lost
 - delivered out of order to app
- ❖ *connectionless*:
 - no handshaking between UDP sender, receiver
 - each UDP segment handled independently of others

Why is there a UDP?

- ❖ no connection establishment (which can add delay)
- ❖ simple: no connection state at sender, receiver
- ❖ small segment header
- ❖ no congestion control: UDP can blast away as fast as desired

UDP: more

- ❖ often used for streaming multimedia apps
 - loss tolerant
 - rate sensitive
- ❖ other UDP uses
 - DNS
 - SNMP
- ❖ reliable transfer over UDP: add reliability at application layer
 - application-specific error recovery!



UDP segment format

UDP checksum

Goal: detect “errors” (e.g., flipped bits) in transmitted segment

Sender:

- ❖ treat segment contents as sequence of 16-bit integers
- ❖ checksum: addition (1's complement sum) of segment contents
- ❖ sender puts checksum value into UDP checksum field

Receiver:

- ❖ compute checksum of received segment
 - ❖ check if computed checksum equals checksum field value:
 - NO - error detected
 - YES - no error detected.
But maybe errors nonetheless? More later
-

Internet Checksum Example

- ❖ Note: when adding numbers, a carryout from the most significant bit needs to be added to the result
- ❖ Example: add two 16-bit integers

	1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	
	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	
<hr/>																	
wraparound	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
<hr/>																	
sum	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0	
checksum	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1

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- Bit error: Ack, seq.#
- Loss: Time out
- Pipelining
- Selective Repeat

3.5 Connection-oriented transport: TCP

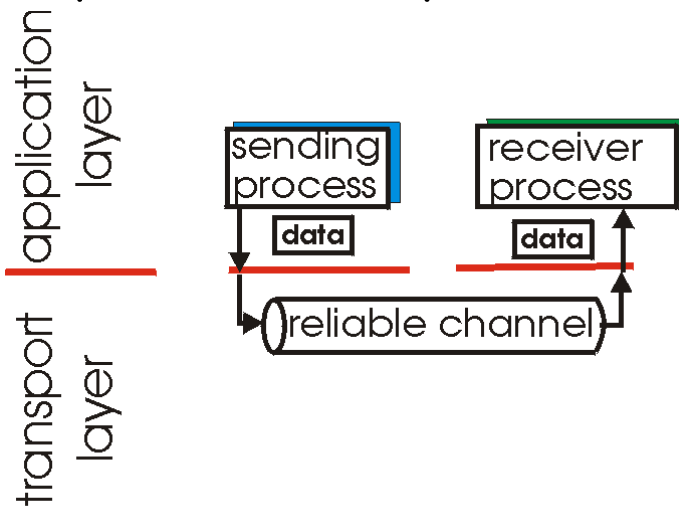
- segment structure
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Principles of Reliable data transfer

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

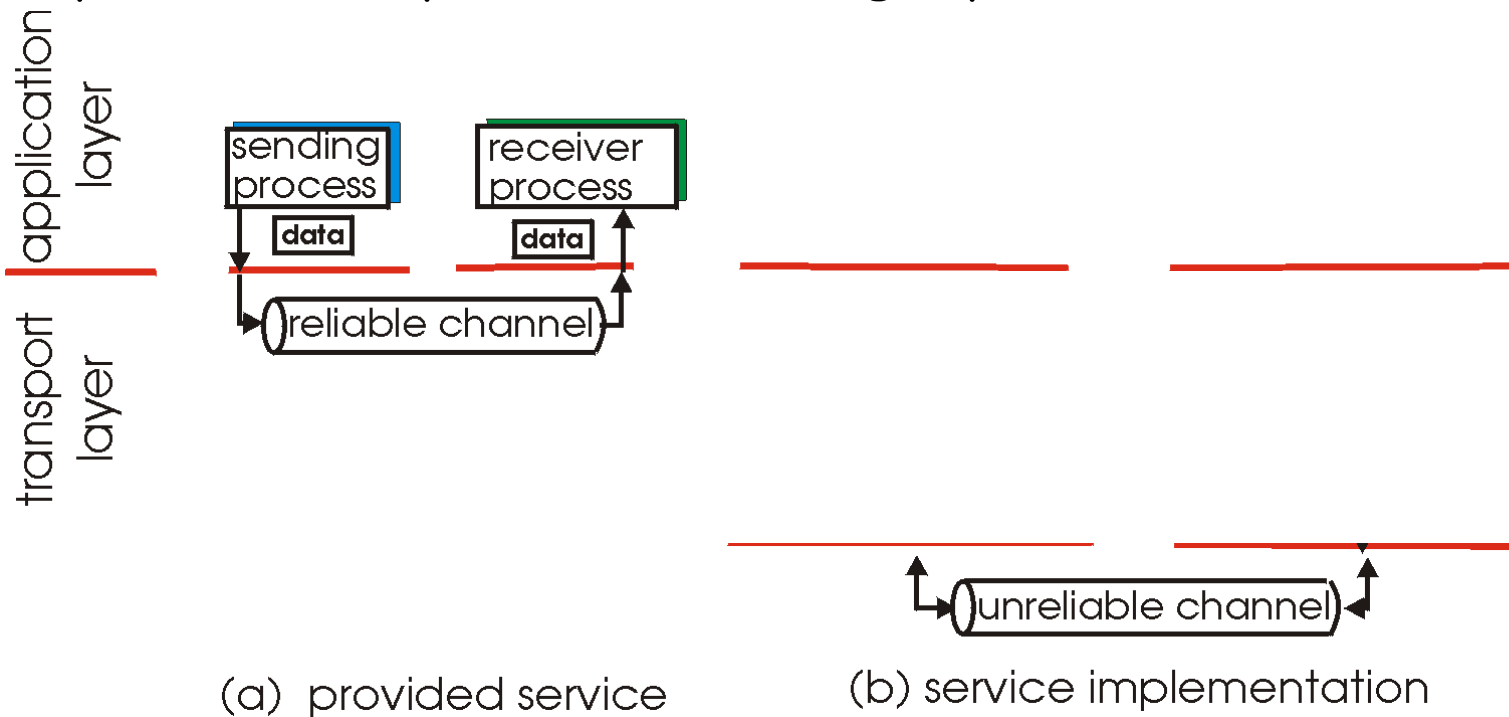


(a) provided service

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

Principles of Reliable data transfer

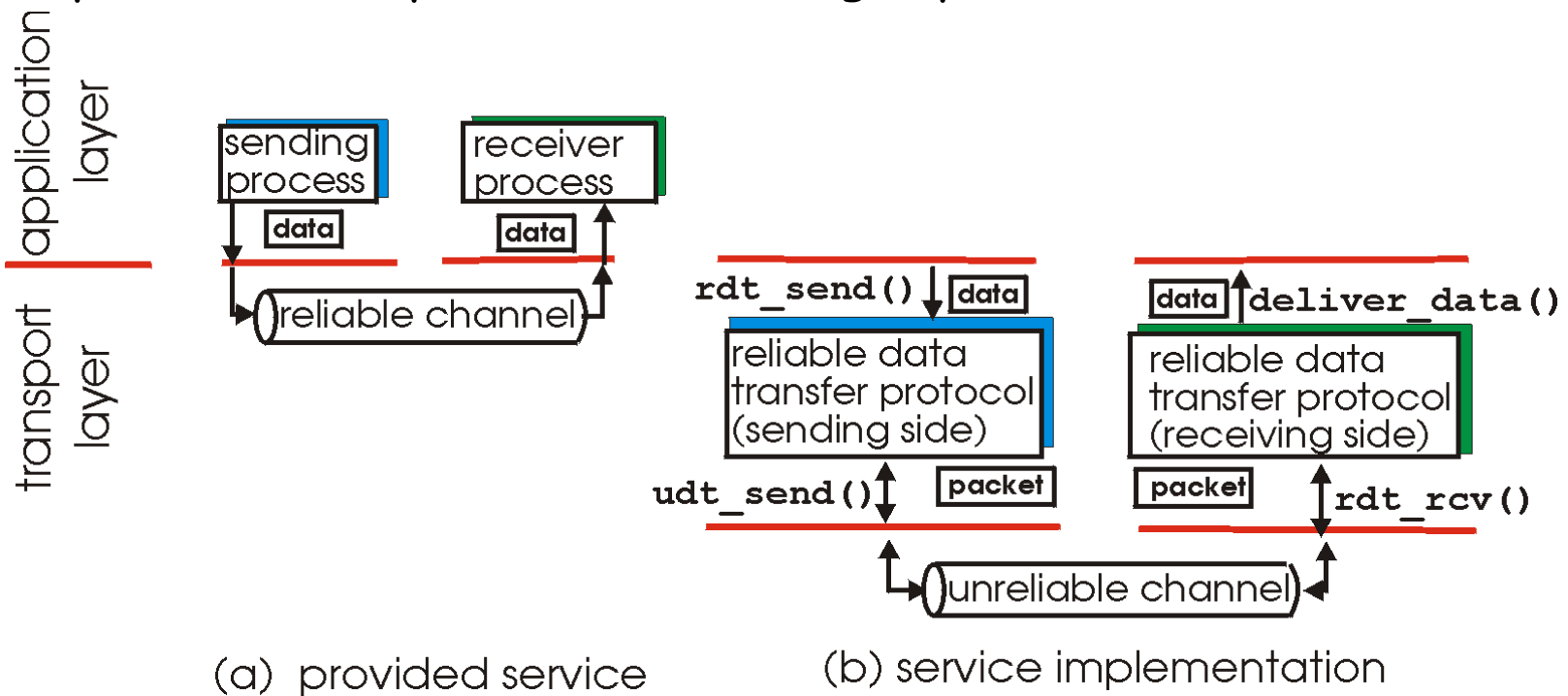
- ❖ important in app., transport, link layers
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- ❖ characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

Principles of Reliable data transfer

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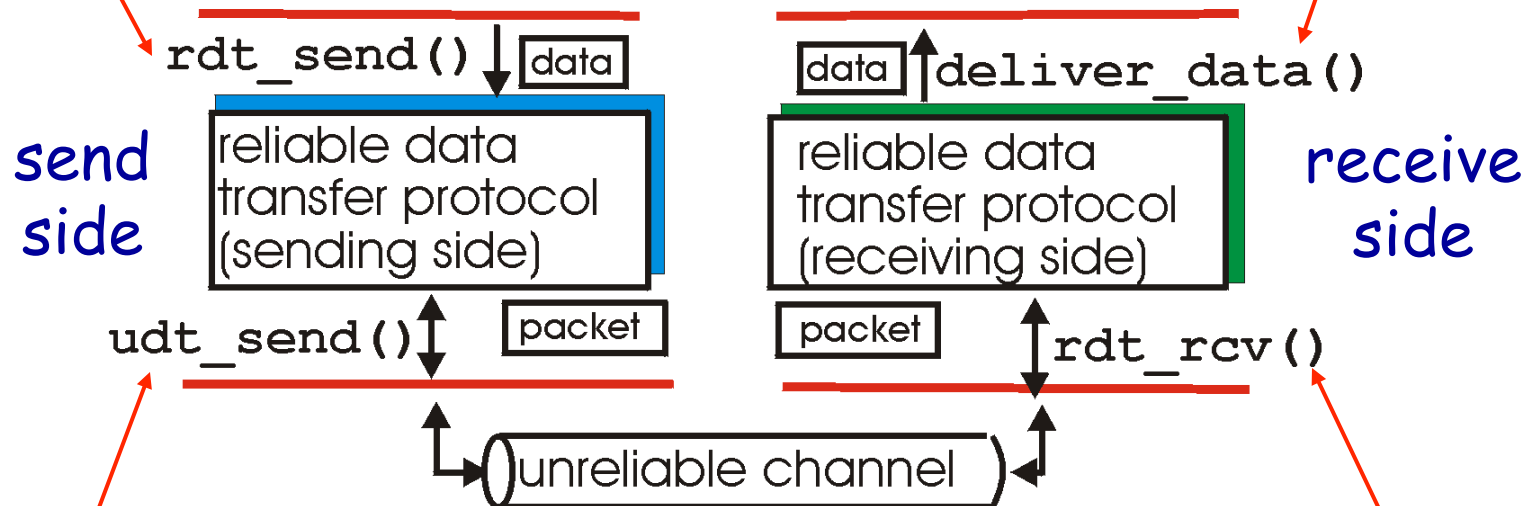


- ❖ characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

Reliable data transfer: getting started

rdt_send() : called from above, (e.g., by app.). Passed data to deliver to receiver upper layer

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



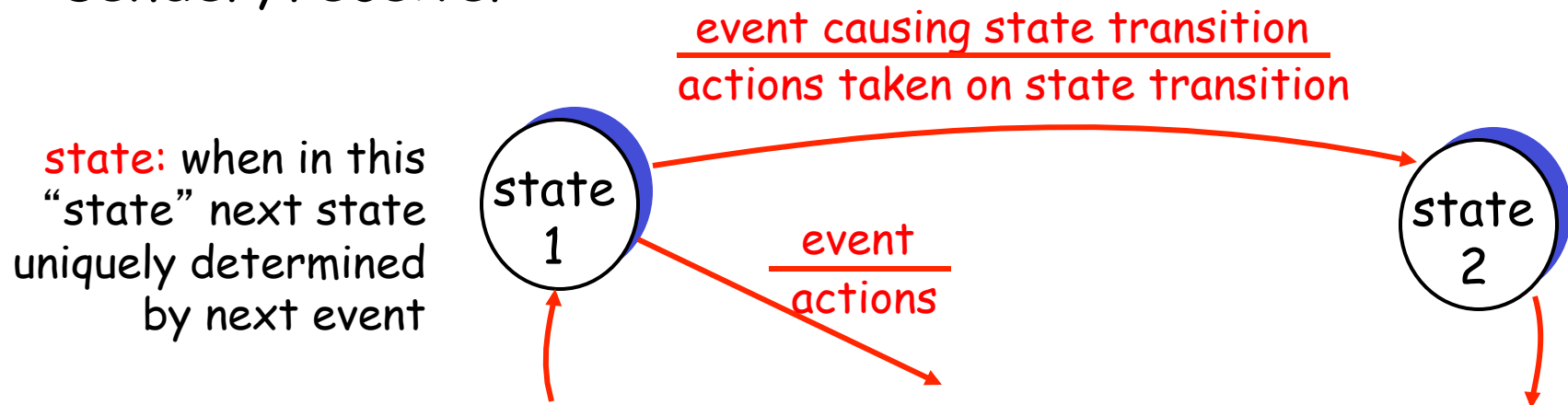
udt_send() : called by rdt, to transfer packet over unreliable channel to receiver

rdt_rcv() : called when packet arrives on rcv-side of channel

Reliable data transfer: getting started

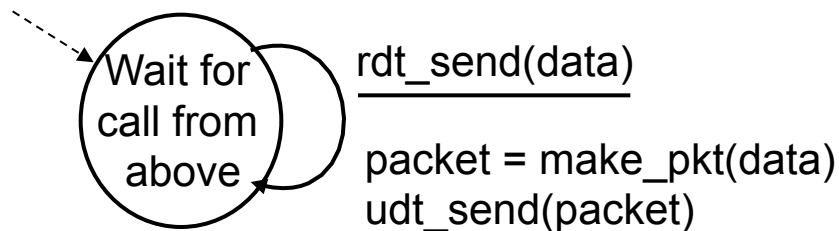
We'll:

- ❖ 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

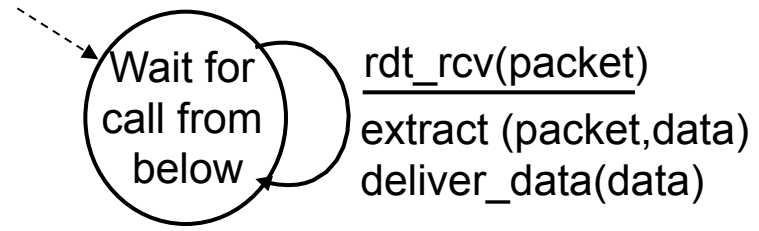


Rdt1.0: reliable transfer over a reliable channel

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



sender



receiver

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Rdt2.0: channel with bit errors

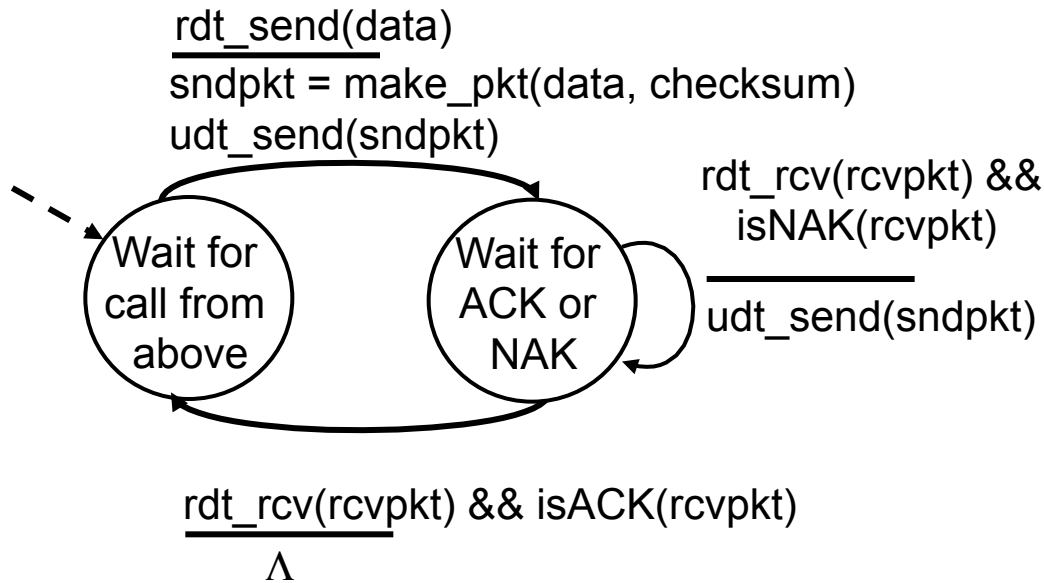
- ❖ underlying channel may flip bits in packet
 - checksum to detect bit errors
- ❖ *the question: how to recover from errors:*

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

Rdt2.0: channel with bit errors

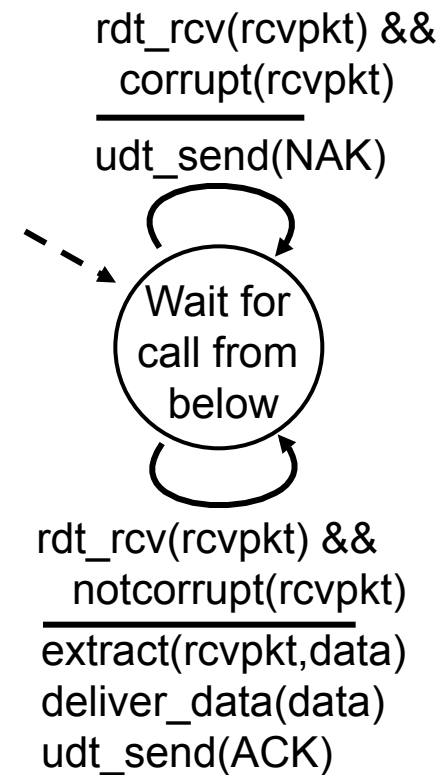
- ❖ underlying channel may flip bits in packet
 - checksum to detect bit errors
- ❖ *the question: how to recover from errors:*
 - *acknowledgements (ACKs):* receiver explicitly tells sender that pkt received OK
 - *negative acknowledgements (NAKs):* receiver explicitly tells sender that pkt had errors
 - 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

rdt2.0: FSM specification

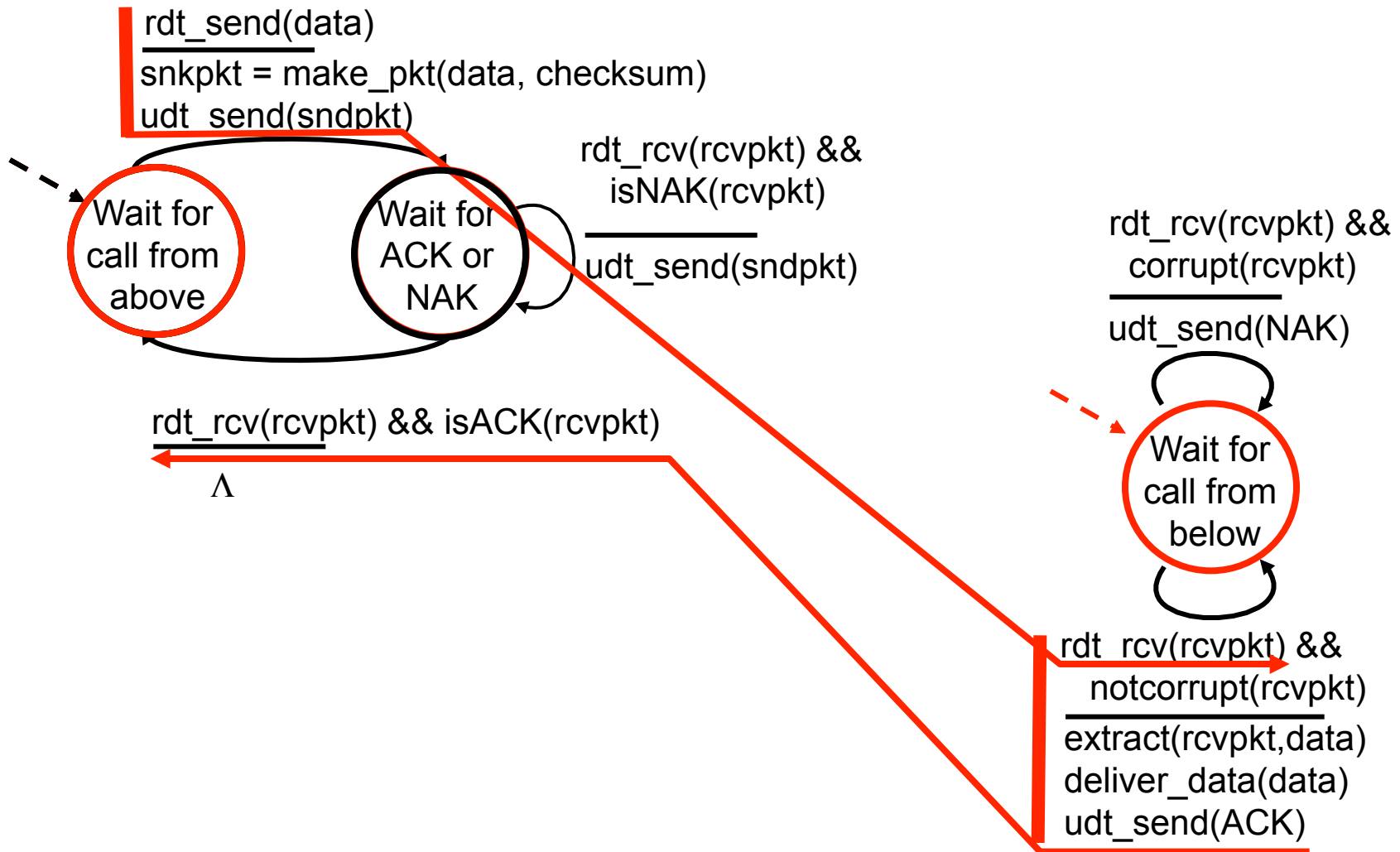


sender

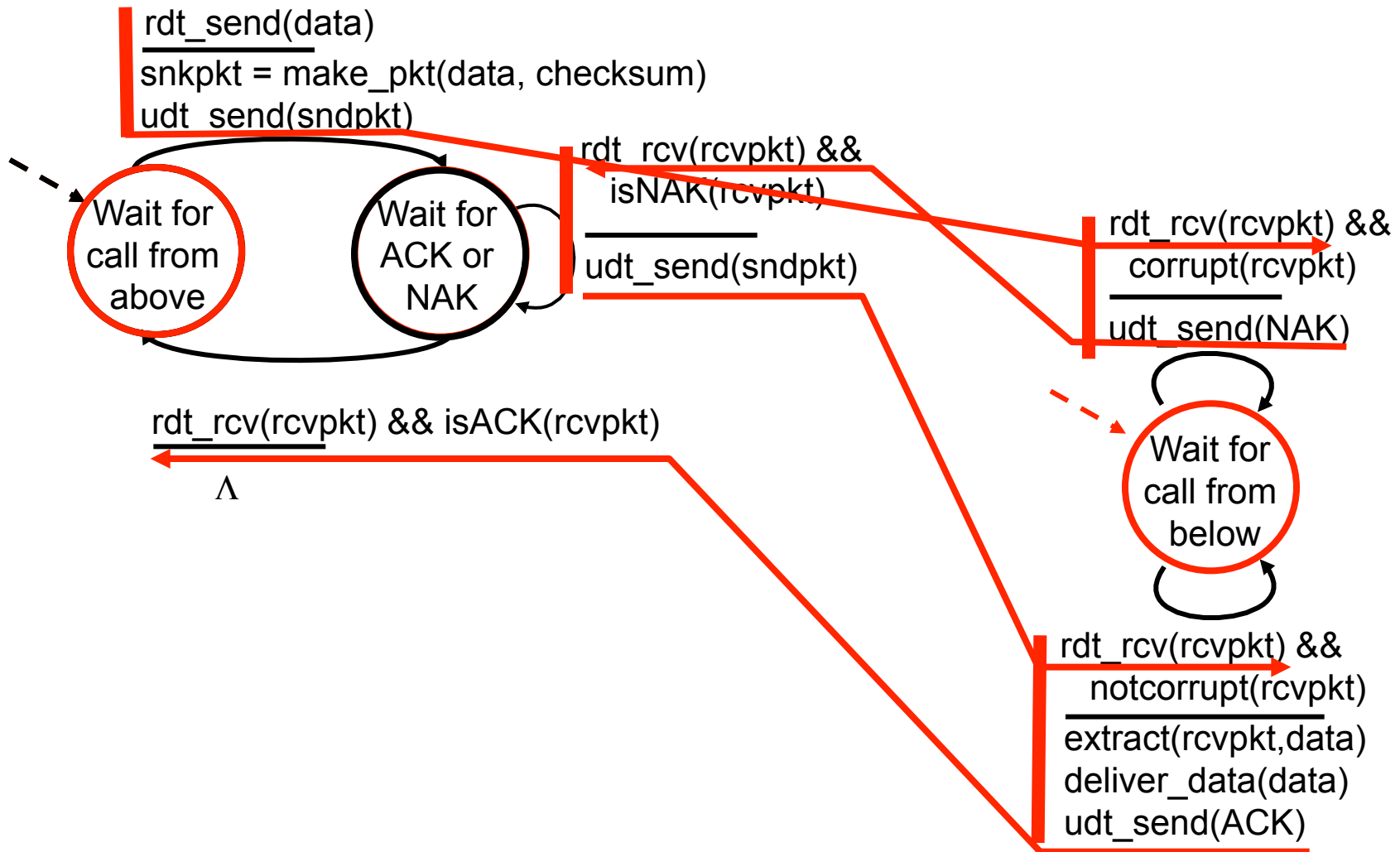
receiver



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

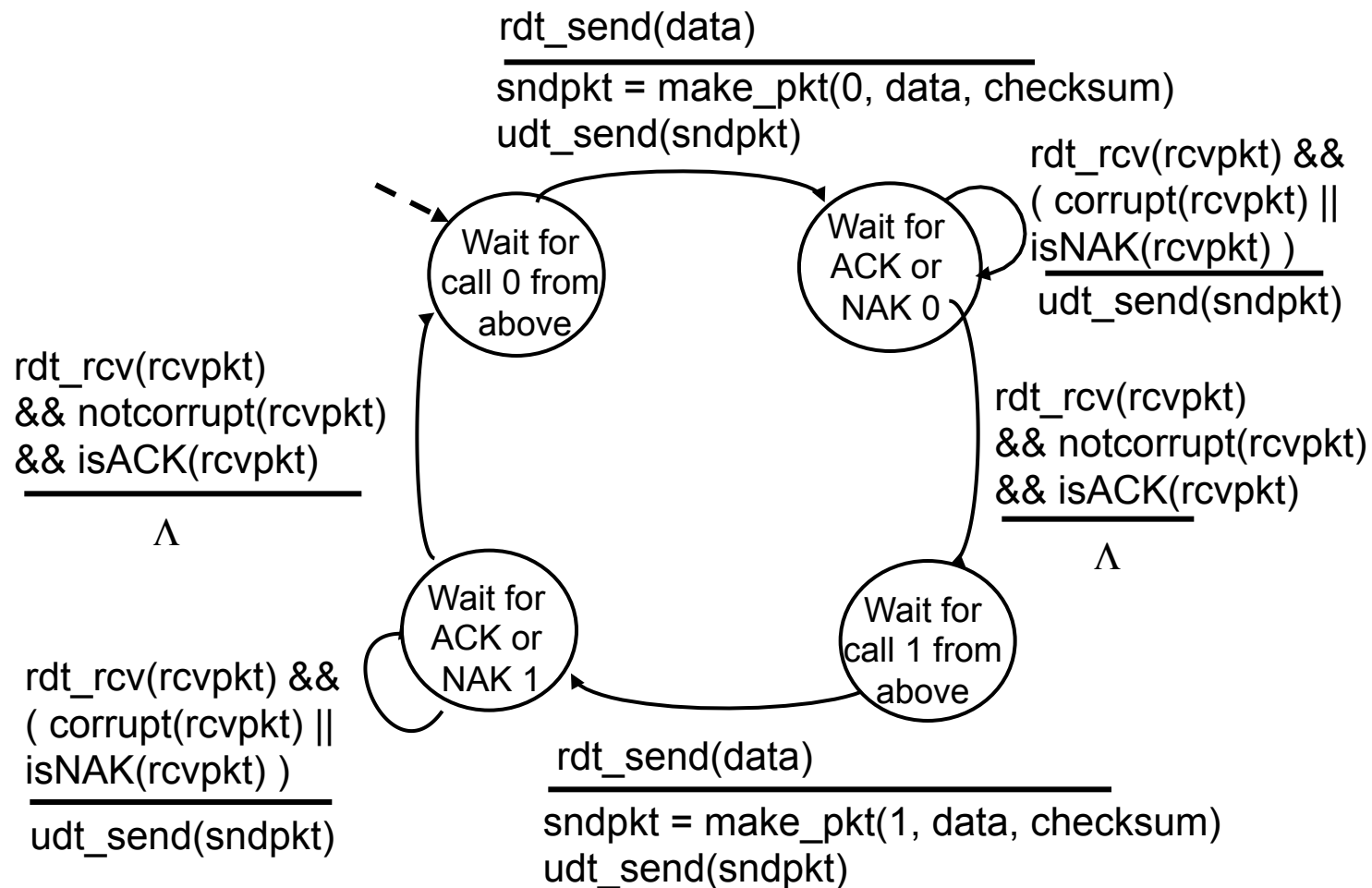
Handling duplicates:

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

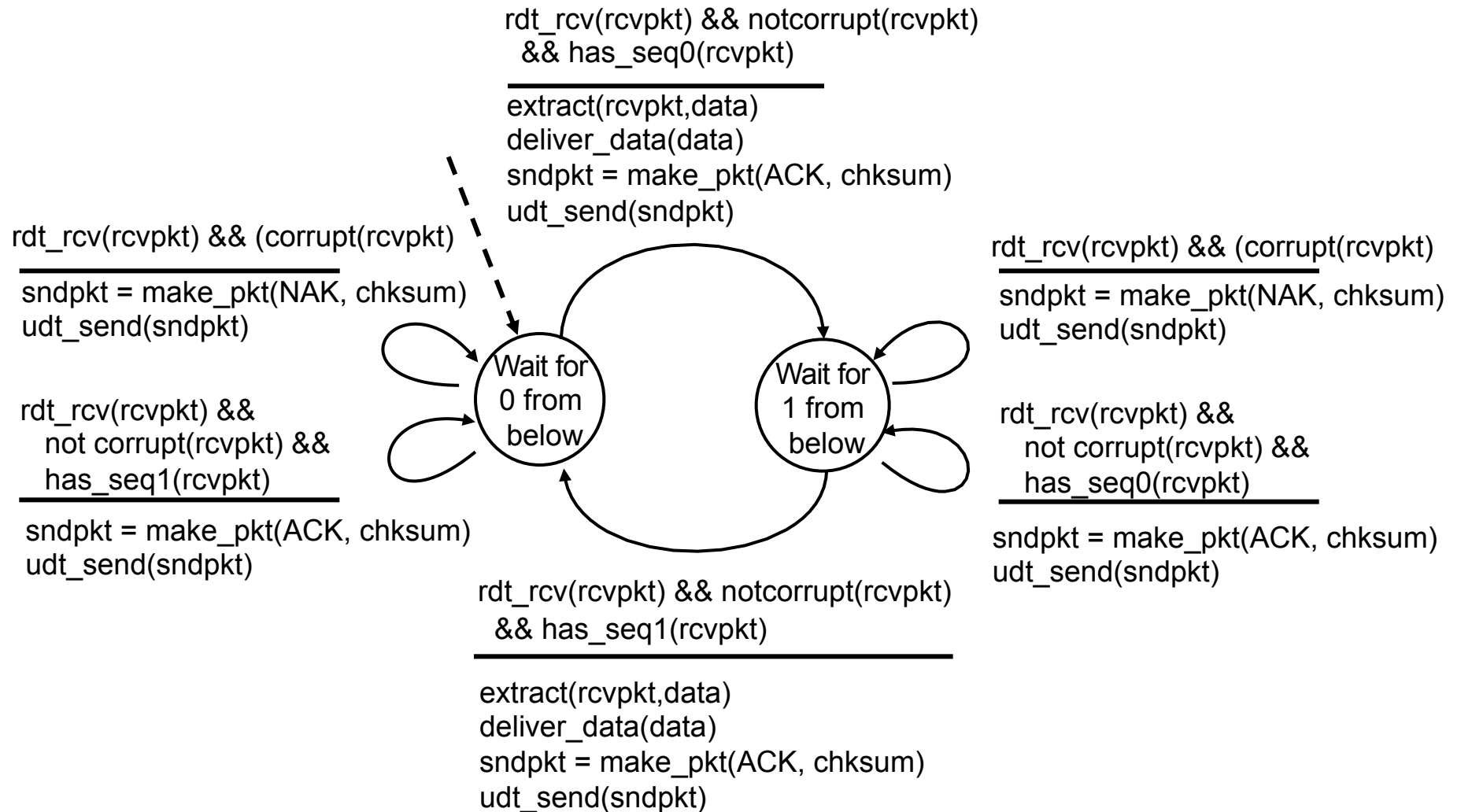
stop and wait

Sender sends one packet, then waits for receiver response

rdt2.1: sender, handles garbled ACK/NAKs



rdt2.1: receiver, handles garbled ACK/NAKs



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. #

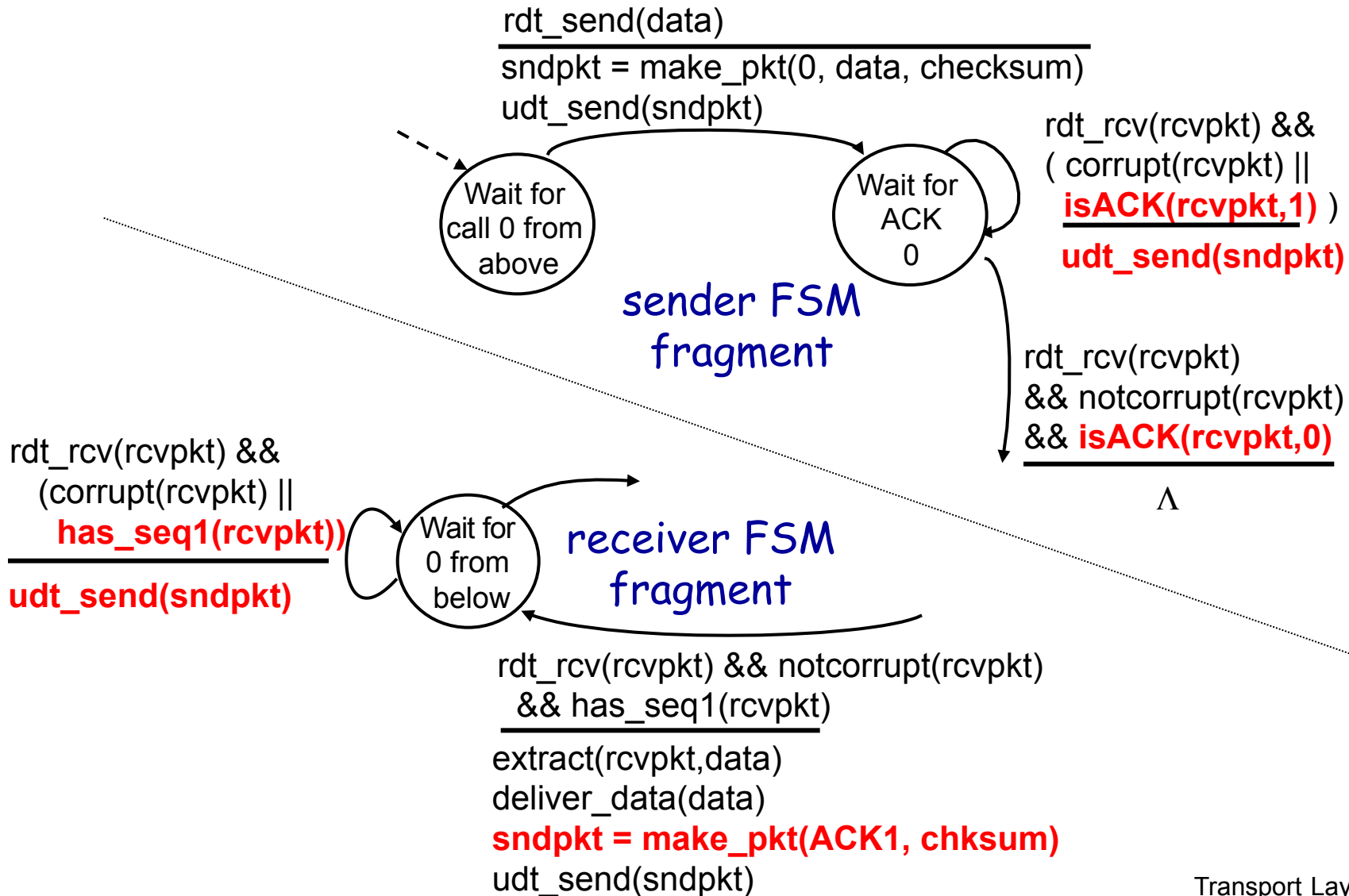
Receiver:

- ❖ 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

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 or 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 use of seq. #'s already handles this
 - receiver must specify seq # of pkt being ACKed
- ❖ requires countdown timer