CSCE 463/612
Networks and Distributed Processing
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Transport Layer II

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Chapter 3: Roadmap

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]

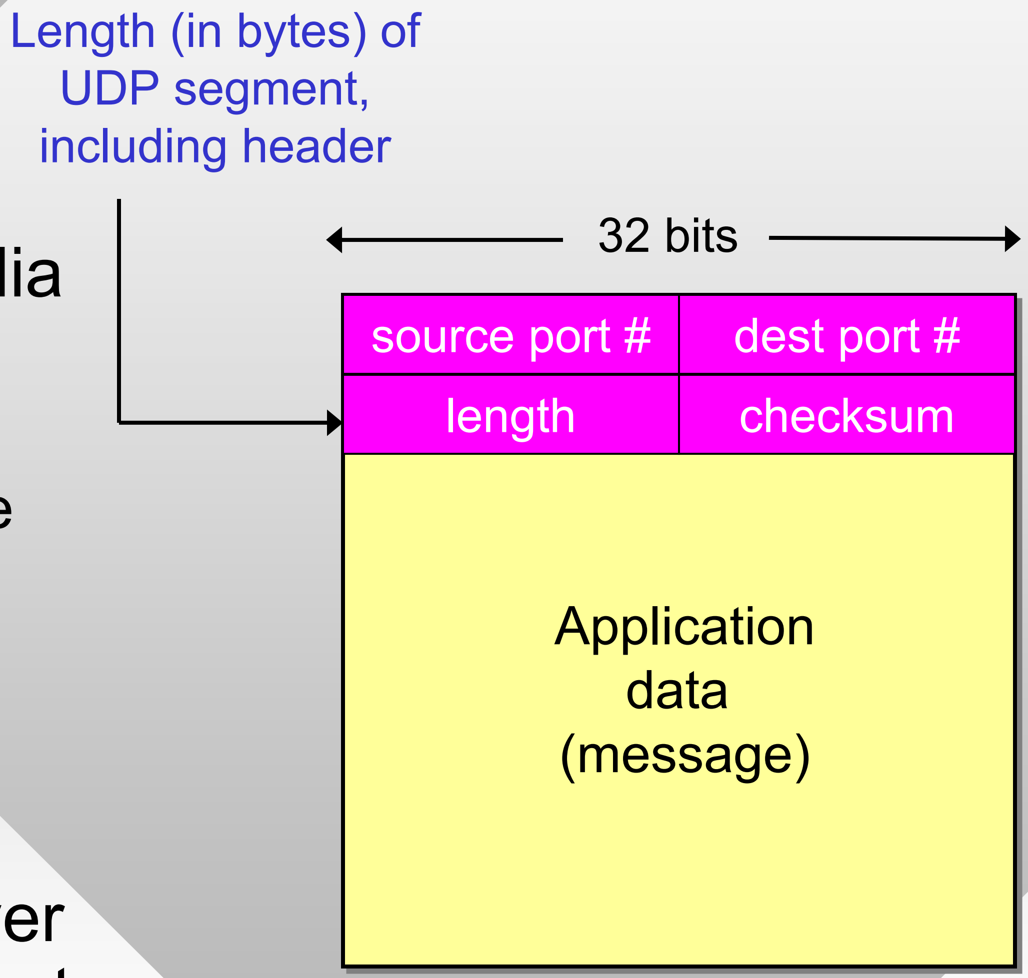
- Standardized in 1980
  - Hasn't changed since
- Best-effort service
- UDP segments may be:
  - Lost or corrupted
  - Delivered out of order to the application
- Connectionless:
  - No handshaking between UDP sender and receiver
  - Each UDP segment handled independently of others

Why is there a UDP?

- Low overhead: no connection establishment or retransmission
- Simplicity: no connection state at sender/receiver
- Small segment header
- No congestion control
  - For short transfers, this is completely unnecessary
  - In other cases, desirable to control rate directly from application

UDP: More

- Often used for streaming multimedia or online gaming
  - Loss tolerant
  - Rate/delay sensitive
- Other UDP uses
  - DNS
  - SNMP
  - NFSv2 (1989)
- 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 (packet)

Sender (simplified):

- Set checksum = 0 in hdr
- Treat packet contents as a sequence of 16-bit integers (padded with 0s to 2-byte boundary)
- Checksum: add all integers, then XOR with 0xffff
- Sender puts checksum value into UDP checksum field

Receiver:

- Sum all 16-bit words in entire received segment (including the checksum field in the header)
- Check if result = 0xffff
  - NO - error detected
  - YES - no error detected
- Idea: (x XOR 0xffff) + x = 0xffff
- *Are undetected errors possible nonetheless?*

UDP Checksum Example

- Note on 1’s complement addition:
  - 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
-------------------------------------------------
wraparound  1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1
-------------------------------------------------
       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 1 1
```

UDP Checksum (Cont)

- How many corrupted bits does UDP detect?
- Example of undetected single-bit corruption?
  - Not possible
- Example of undetected 2-bit corruption?
  - Two words (0, 5) result in sum = 5
  - Suppose 0 is corrupted to become 1 and 5 is corrupted to become 4, then the checksum is the same
- Example of undetected 3-bit corruption w/two words?
  - Two words (1, 1) → (0, 2)
- What if the transmitted words are 0 and 12?
  - Can two-bit corruption produce the same checksum?
  - If yes, how many ways can (0,12) be affected by 2-bit corruption so as to avoid detection?

UDP Checksum (Cont)

- Is there a pair of integers (x,y) that allow the UDP checksum to detect any 2-bit corruption?
- Data-link and physical layers are often assumed to have their own checksums and error correction
  - Why is transport-level checksum important then?
- Reasons:

1) Lower layers do not always run error checking
  - Even then, implementation bugs may affect the result

2) Corruption may occur in router RAM or faulty hardware, outside the control of data-link protocols

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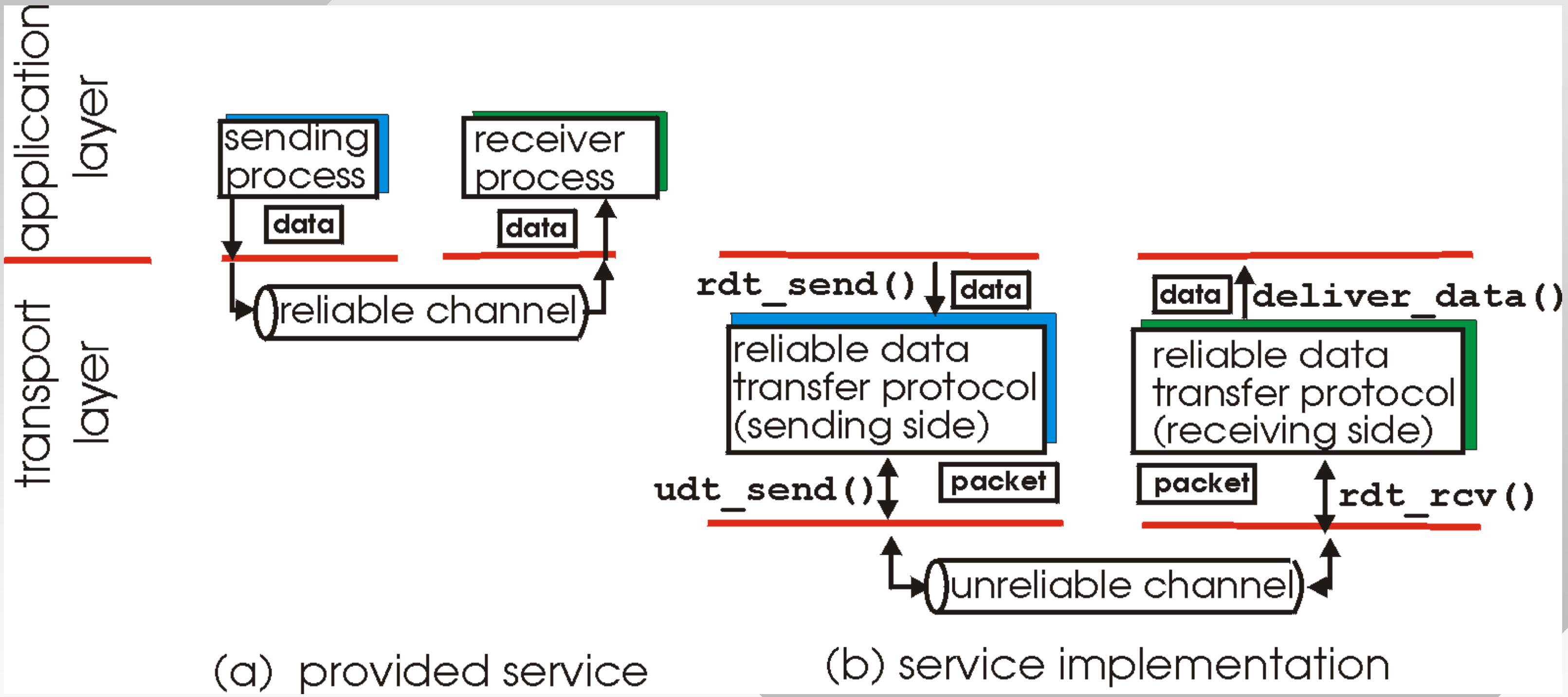
Principles of Reliable Data Transfer

- Important in application, transport, link layers



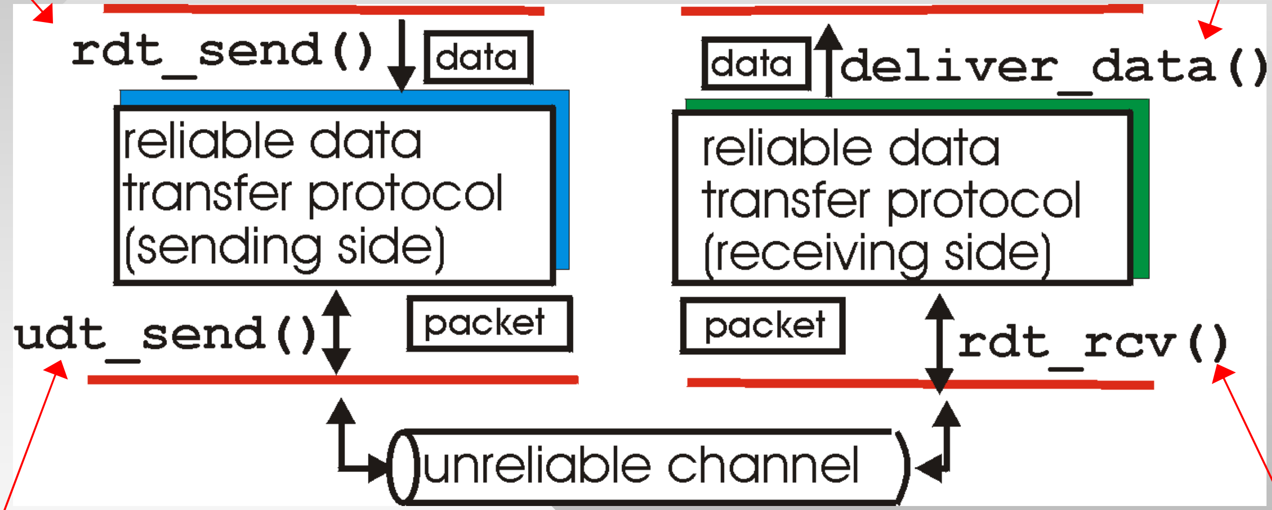
- Characteristics of unreliable channel will determine complexity of reliable data transfer (rdt) protocol

Reliable Data Transfer: Getting Started

rdt_send(): called by layer above to pass data to **rdt**

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

send side



receive side

udt_send(): called by **rdt** to pass packets to lower layer

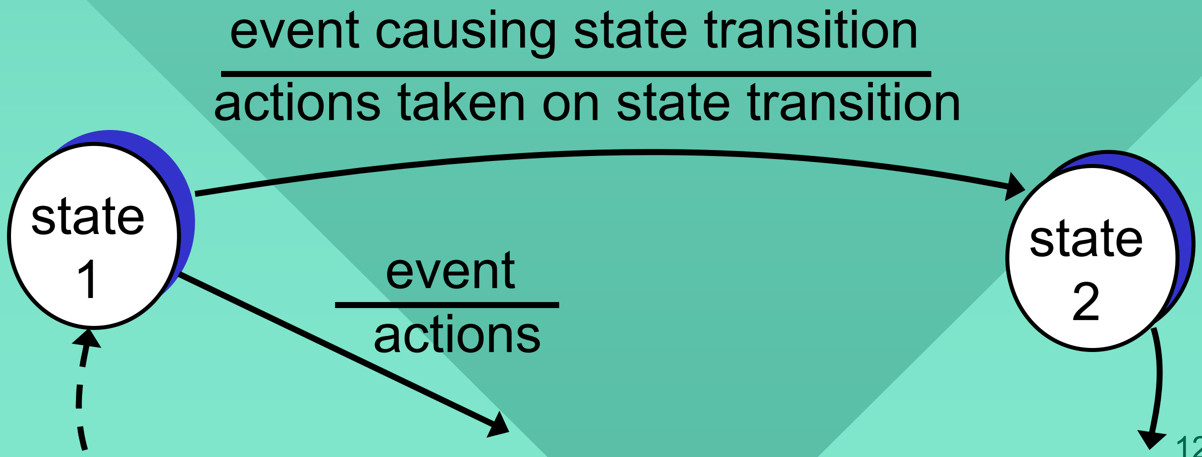
rdt_rcv(): called by lower layer when it has a packet to deliver to **rdt**

Reliable Data Transfer: Getting Started

We will:

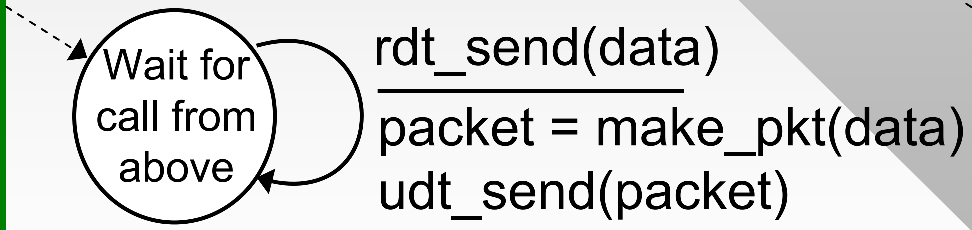
- Incrementally develop sender, receiver sides of *reliable data transfer* protocol (rdt)
- Consider only unidirectional data transfer
  - With receiver feedback, packets travel in both directions!
- Use finite state machines (FSM) to specify both sender and receiver

- From any state, the next state is uniquely determined by next event



Rdt1.0: Transfer Over a Reliable Channel

- Underlying channel perfectly reliable
  - No bit errors
  - No loss of packets
  - No reordering
- Separate FSMs for sender and receiver:
  - Sender transmits app data into underlying channel
  - Receiver passes data from underlying channel to app

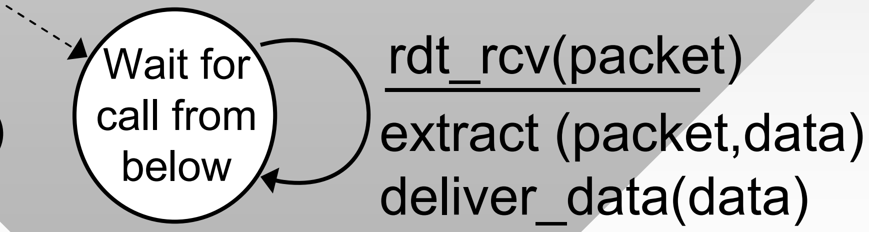


Wait for call from above

rdt_send(data)

packet = make_pkt(data)
udt_send(packet)

sender



Wait for call from below

rdt_rcv(packet)

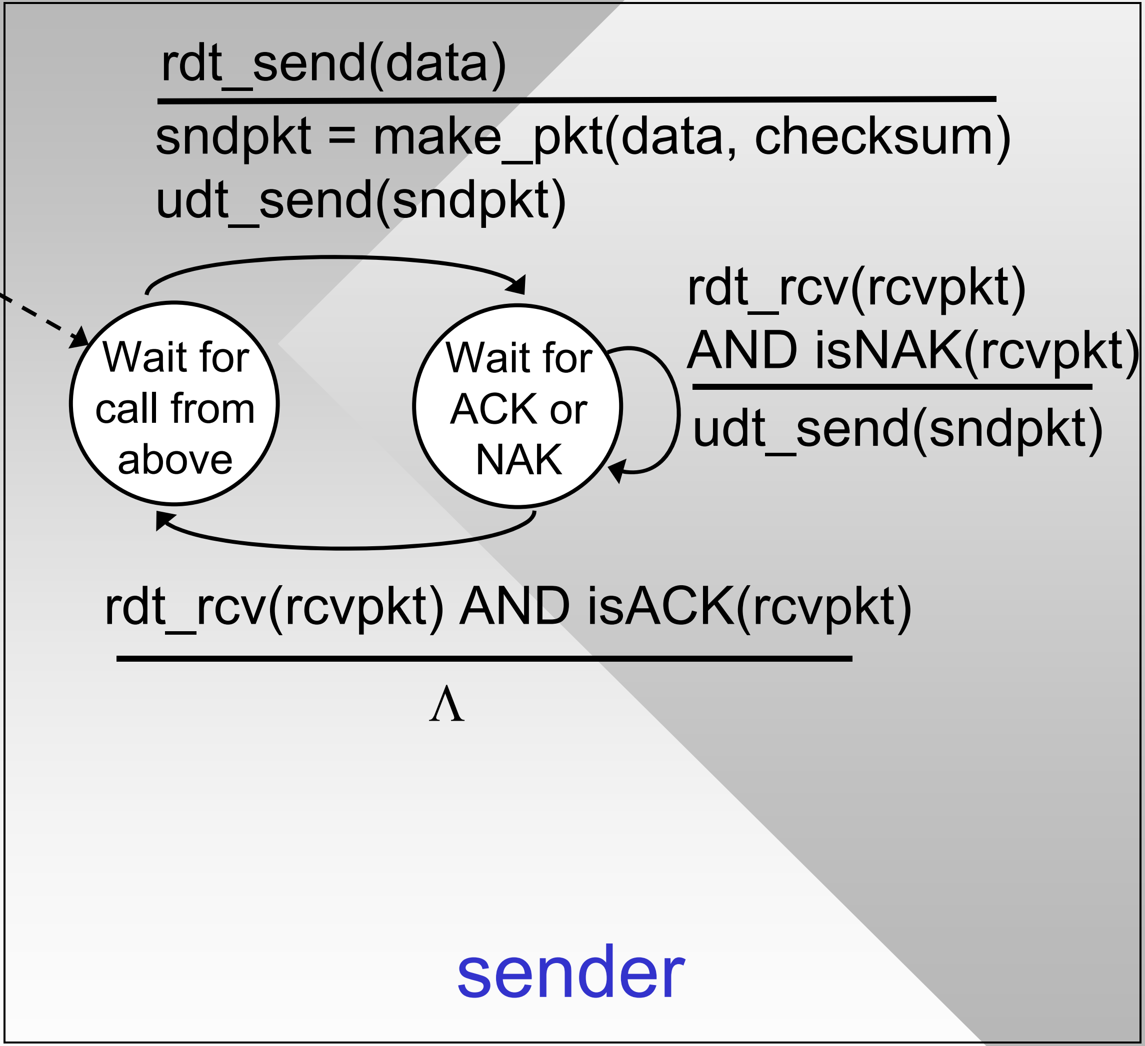
extract (packet,data)
deliver_data(data)

receiver

Rdt2.0: Channel With Bit Errors

- Underlying channel may flip bits in packet (no loss)
  - Checksum to detect bit errors (assume perfect detection)
- Question: how to recover from errors?
- One possible approach is to use two feedback msgs:
  - *Positive acknowledgments (ACKs):* receiver explicitly tells sender that packet was received OK
  - *Negative acknowledgments (NAKs):* receiver explicitly tells sender that packet had errors
  - Sender retransmits packet on receipt of NAK
- New mechanisms in rdt 2.0 (beyond rdt 1.0):
  - Error detection
  - Receiver feedback (control msgs ACK/NAK)
  - Retransmission

Rdt2.0: FSM Specification



rdt_send(data)

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

Wait for call from above

Wait for ACK or NAK

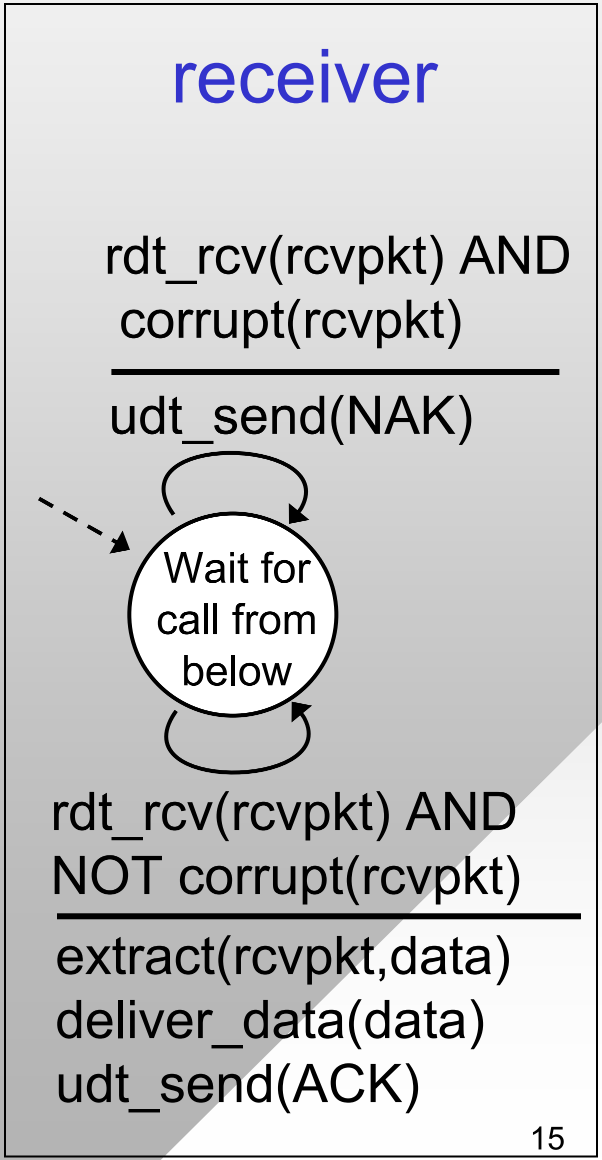
rdt_rcv(rcvpkt) AND isNAK(rcvpkt)

udt_send(sndpkt)

rdt_rcv(rcvpkt) AND isACK(rcvpkt)

Λ

sender



receiver

rdt_rcv(rcvpkt) AND corrupt(rcvpkt)

udt_send(NAK)

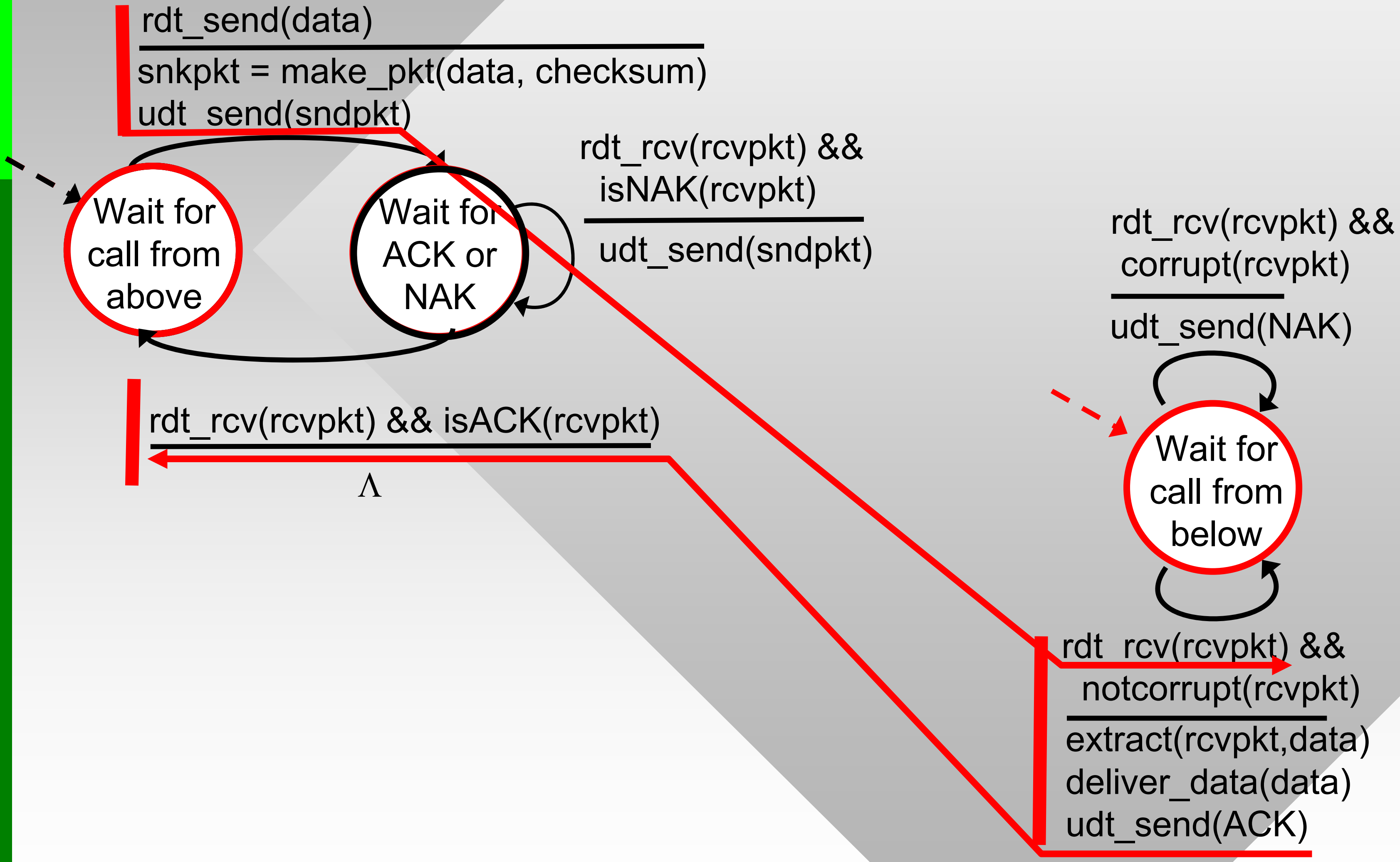
Wait for call from below

rdt_rcv(rcvpkt) AND NOT corrupt(rcvpkt)

extract(rcvpkt,data)
deliver_data(data)
udt_send(ACK)

Λ = empty action, i.e., do nothing

Rdt2.0: Operation With No Errors



rdt_send(data)

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

rdt_rcv(rcvpkt) &&
isNAK(rcvpkt)

udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
corrupt(rcvpkt)

udt_send(NAK)

Wait for
call from
above

Wait for
ACK or
NAK

rdt_rcv(rcvpkt) && isACK(rcvpkt)

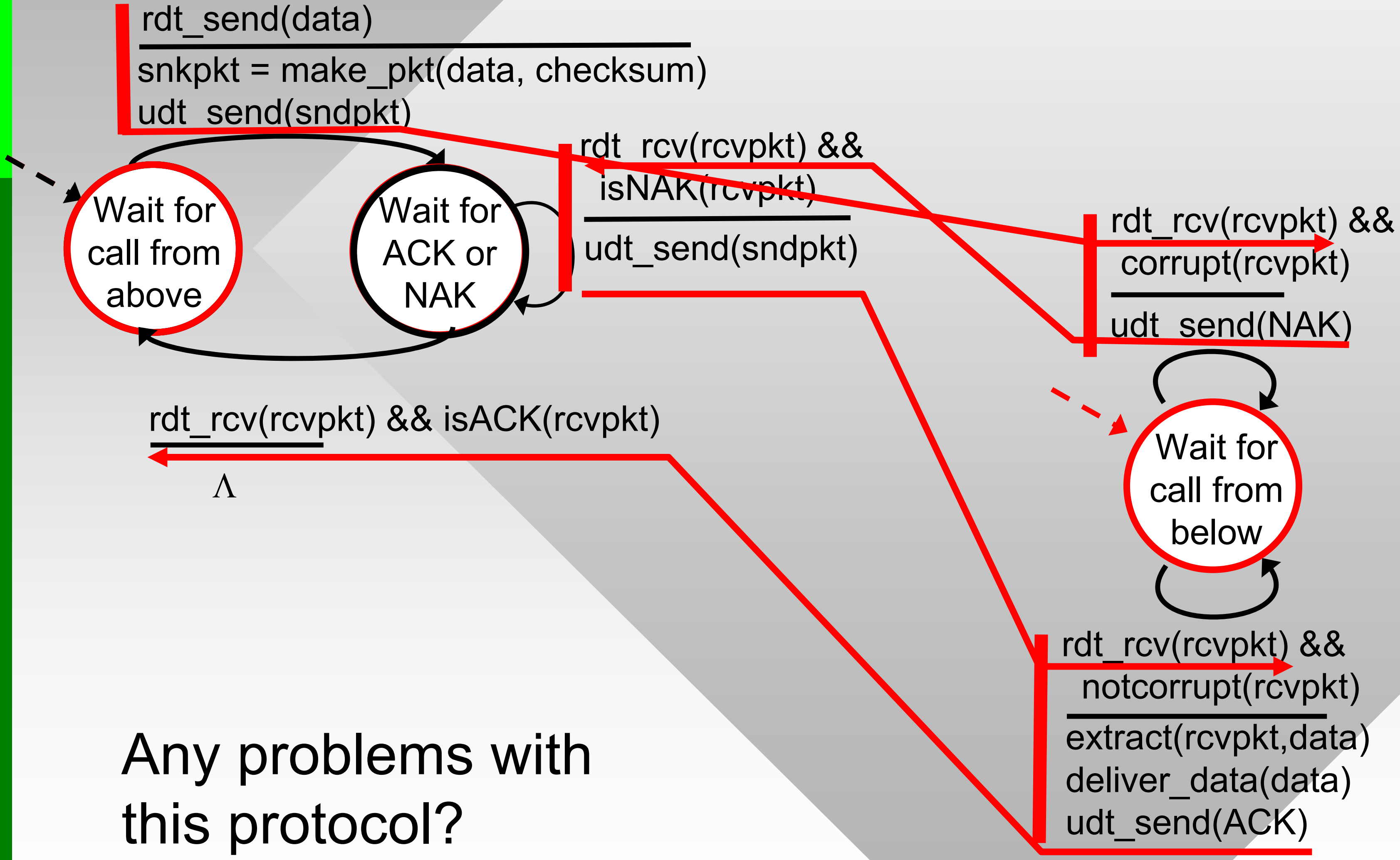
Λ

Wait for
call from
below

rdt_rcv(rcvpkt) &&
notcorrupt(rcvpkt)

extract(rcvpkt,data)
deliver_data(data)
udt_send(ACK)

Rdt2.0: Error Scenario



rdt_send(data)
snkpkt = make_pkt(data, checksum)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
isNAK(rcvpkt)
udt_send(sndpkt)

rdt_rcv(rcvpkt) &&
corrupt(rcvpkt)
udt_send(NAK)

rdt_rcv(rcvpkt) && isACK(rcvpkt)
Λ

rdt_rcv(rcvpkt) &&
notcorrupt(rcvpkt)
extract(rcvpkt,data)
deliver_data(data)
udt_send(ACK)

Any problems with this protocol?