Topic 3: Transport Layer

Part 2: Reliable Data Transfer

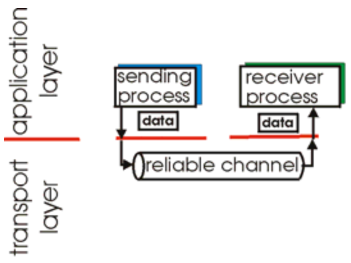
- Principles of Reliable Data Transfer
- RDT for channels without errors and loss
- RDT for channels with errors but no loss

Kurose & Ross: Chapter 3

Section 3.4: 3.4.1

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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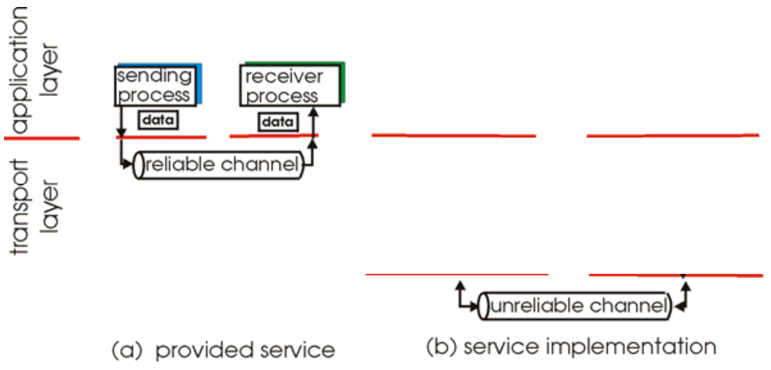
  - top-10 list of important networking topics!



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Principles of reliable data transfer

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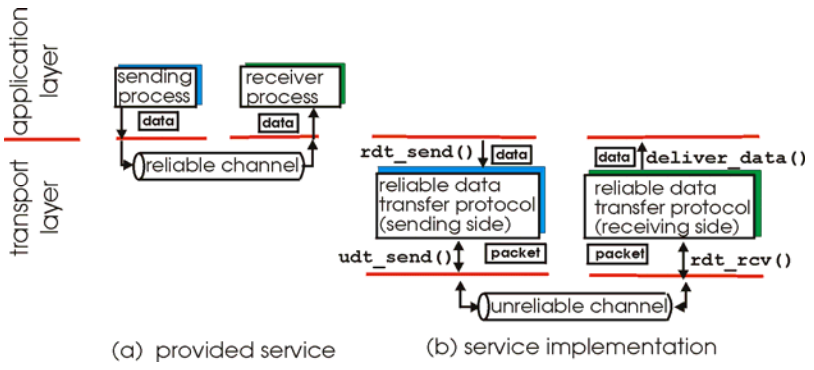
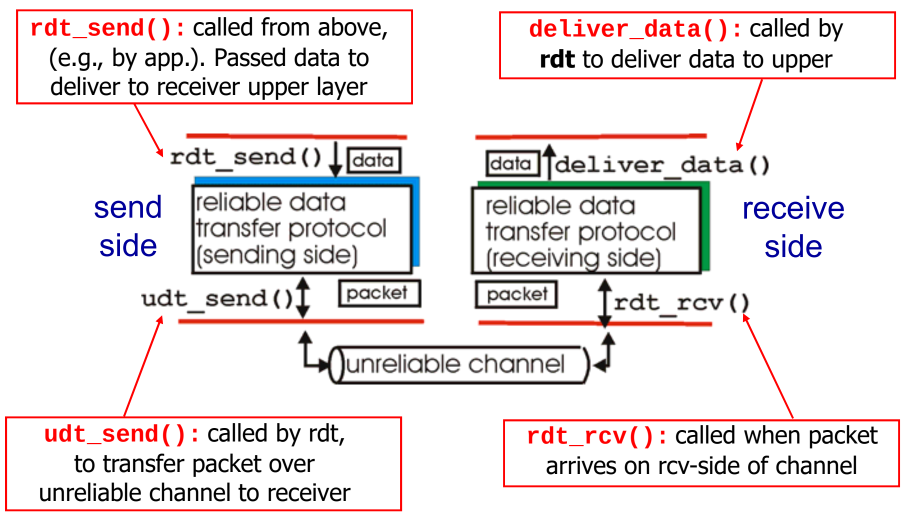
  - top-10 list of important networking topics!



- 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

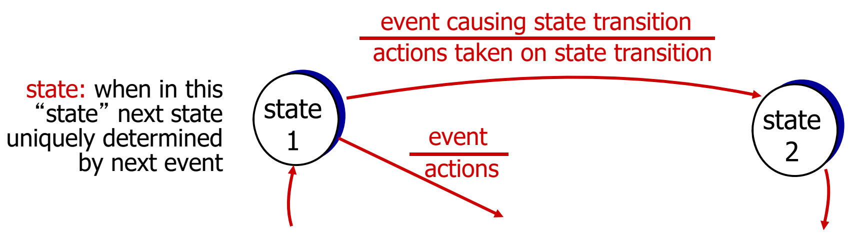
udt_send(): called by rdt, to transfer packet over unreliable channel to receiver

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

Reliable data transfer: getting started

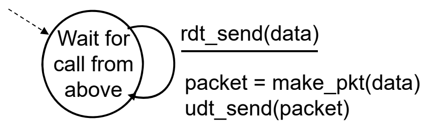
We will:

- 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

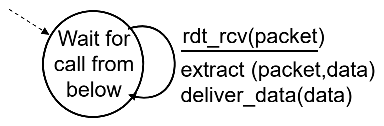

event causing state transition
actions taken on state transition
state: when in this "state" next state uniquely determined by next event
state 1
event
actions
state 2

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



sender



receiver

Transport Layer 2-7

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?

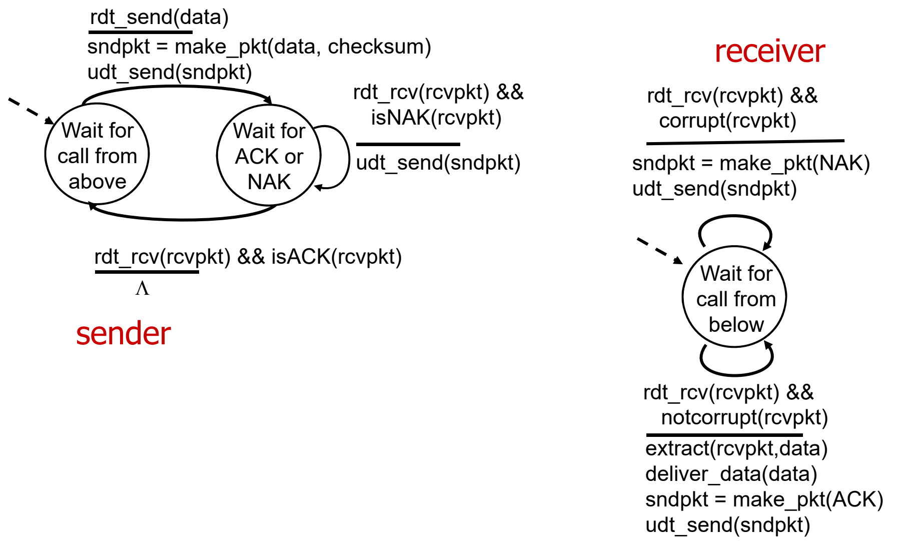
Transport Layer 2-8

rdt2.0: channel with bit errors

- underlying channel may flip bits in packet
- *the* question: how to recover from errors:
  - Error Detection: use checksum to detect bit errors
  - Receiver Feedback (ACK/NAK):
    - *Acknowledgements (ACKs):* receiver explicitly tells sender that pkt received OK
    - *Negative Acknowledgements (NAKs):* receiver explicitly tells sender that pkt had errors
  - Sender Retransmission: sender retransmits pkt if NAK
- new mechanisms in **`rdt2.0`** (beyond **`rdt1.0`**):
  - error detection
  - feedback: control msgs (ACK,NAK) from receiver to sender

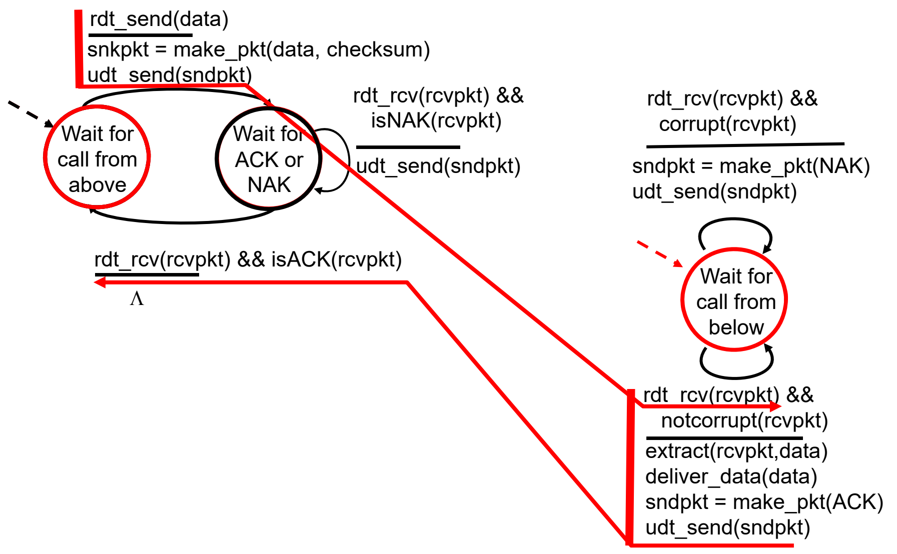
Transport Layer 2-9

rdt2.0: FSM specification



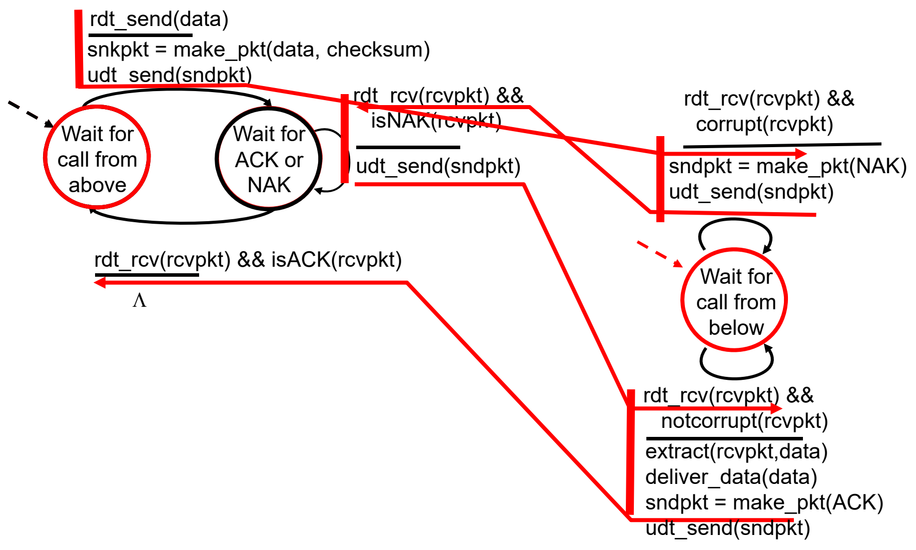
Transport Layer 2-10

rdt2.0: operation with no errors



rdt2.0: operation with no errors

rdt2.0: error scenario



Transport Layer 2-13

rdt2.0: error scenario

Transport Layer 2-14

rdt2.0 has a fatal flaw!

rdt2.0 has a fatal flaw!

Solutions ?

-

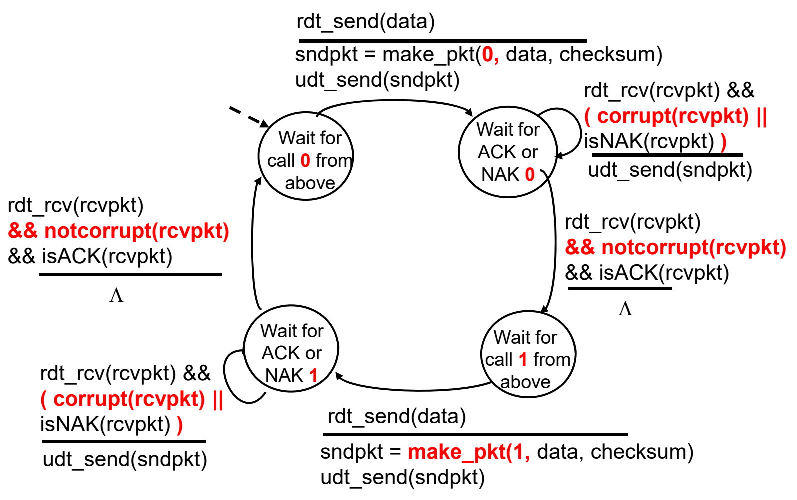
- What should sender do if ACK/NAK has errors ?

handling duplicates:

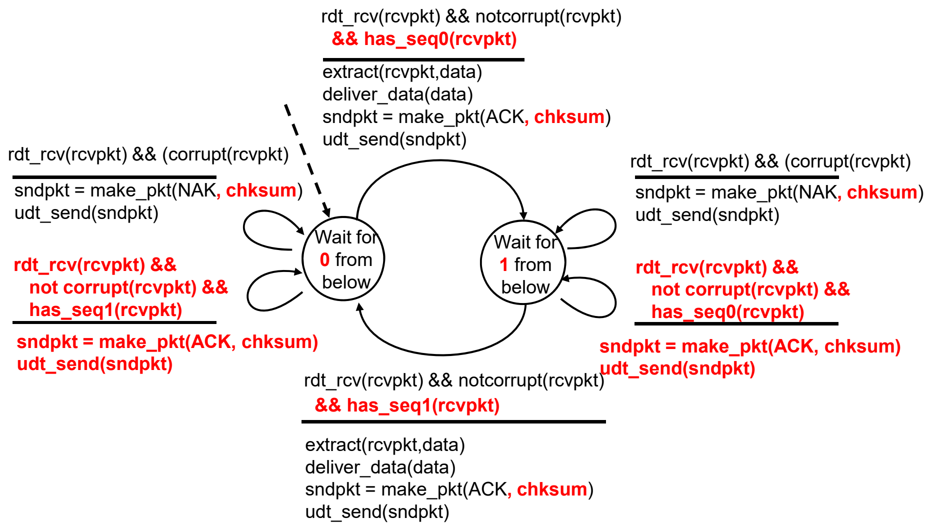
rdt2.1

- Uses checksums on both data packets and ACK/NAKs
- Sequence numbers on data packets
- Retransmission of data packet if sender receives garbled ACK/NAK

rdt2.1: sender, handles garbled ACK/NAKs



rdt2.1: receiver, handles 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) && (corrupt(rcvpkt)
sndpkt = make_pkt(NAK, chksum)
udt_send(sndpkt)
Wait for 0 from below
Wait for 1 from below
rdt_rcv(rcvpkt) && not corrupt(rcvpkt) && has_seq1(rcvpkt)
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)
rdt_rcv(rcvpkt) && not corrupt(rcvpkt) && has_seq0(rcvpkt)
sndpkt = make_pkt(ACK, chksum)
udt_send(sndpkt)
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?
- must check if received ACK/NAK corrupted
- twice as many states
  - state must "remember" whether "current" pkt has 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

rdt2.1: discussion

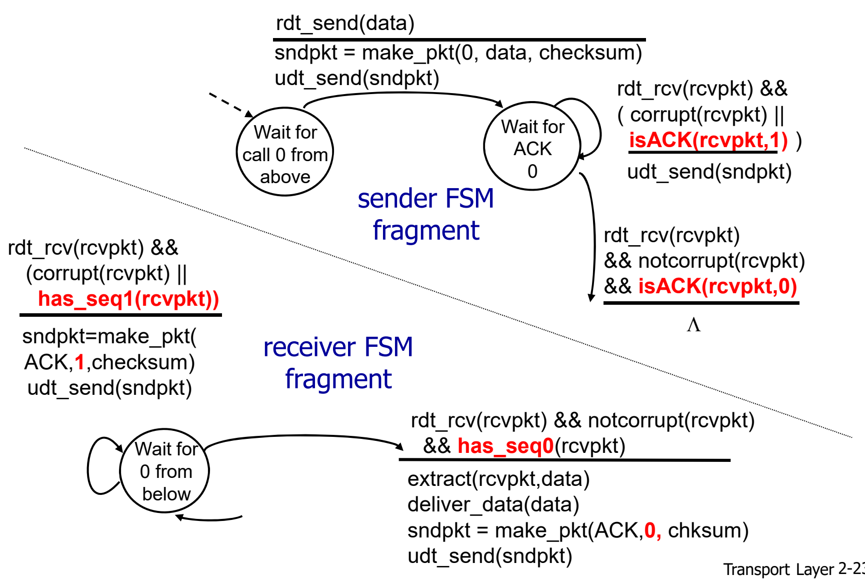
Question:

- If receiver is waiting for packet 1, but receives packet 0, should it return an ACK or a NAK ?

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



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))
sndpkt=make_pkt(ACK,1,checksum)
udt_send(sndpkt)
receiver FSM fragment
Wait for 0 from below
rdt_rcv(rcvpkt) && notcorrupt(rcvpkt) && has_seq0(rcvpkt)
extract(rcvpkt,data)
deliver_data(data)
sndpkt = make_pkt(ACK,0, chksum)
udt_send(sndpkt)

rdt2.2: discussion

Question:

- If receiver is waiting for packet 1, but receives packet 0, what response should it return?