CSCE 463/612
Networks and Distributed Processing
Fall 2020

Transport Layer II

Dmitri Loguinov
Texas A&M University

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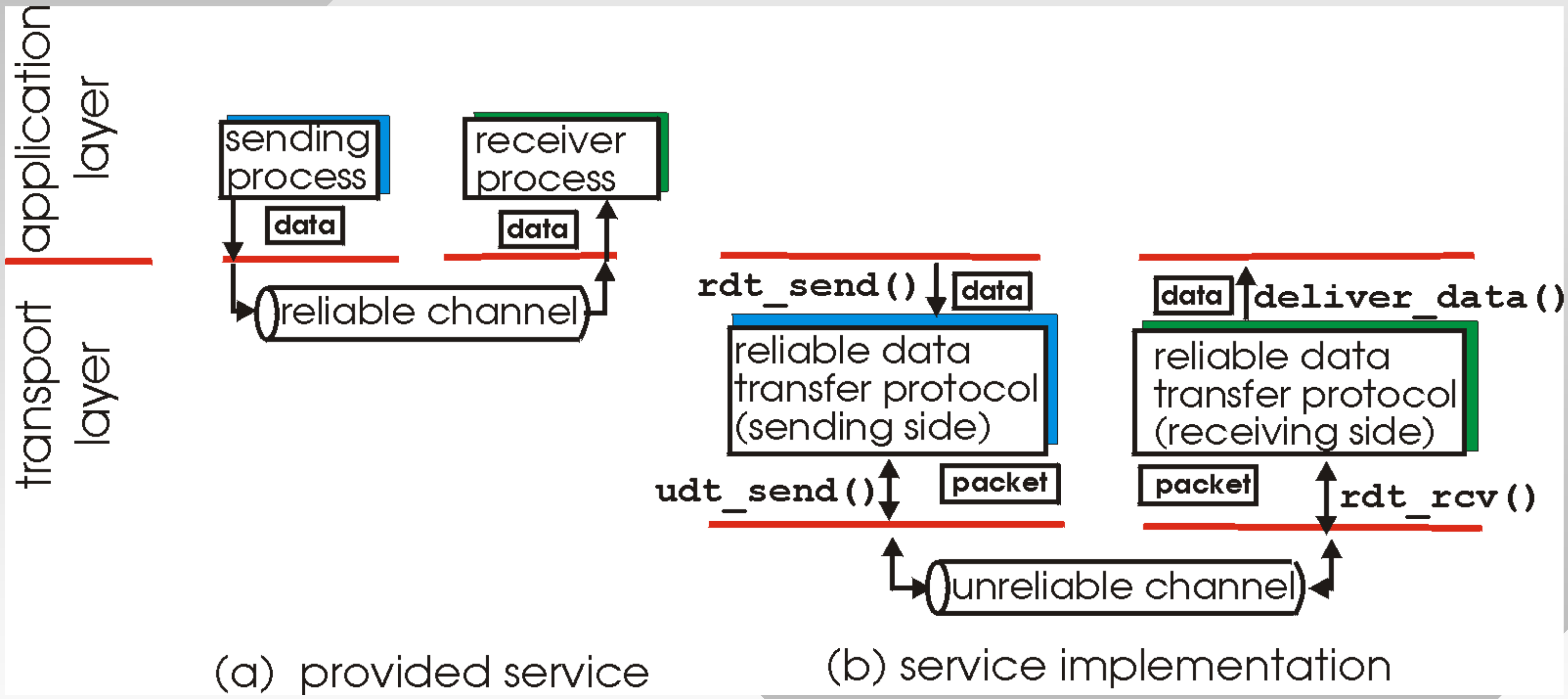
Chapter 3: Roadmap

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

Principles of Reliable Data Transfer

- Important in application, transport, link layers



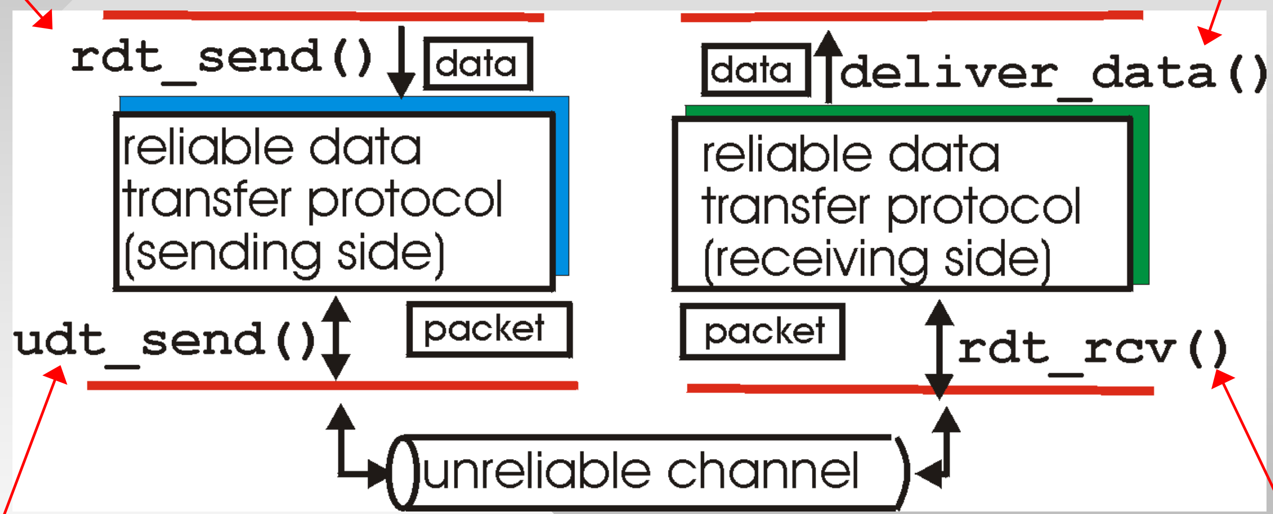
- Characteristics of unreliable channel will determine complexity of reliable data transfer (rdt) protocol

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

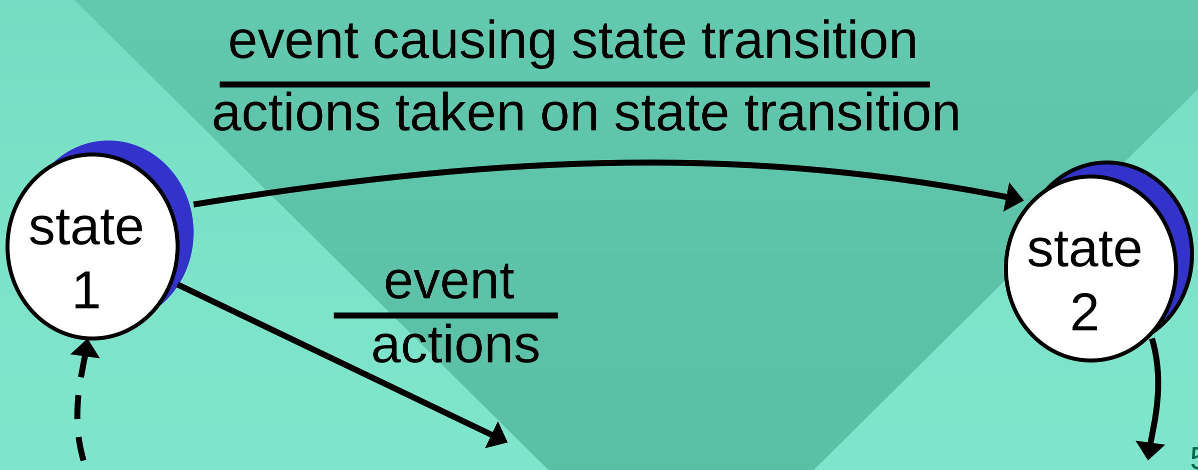
rdt_rcv(): called by lower layer when it has a packet to deliver to **rdt**

Reliable Data Transfer: Getting Started

We will:

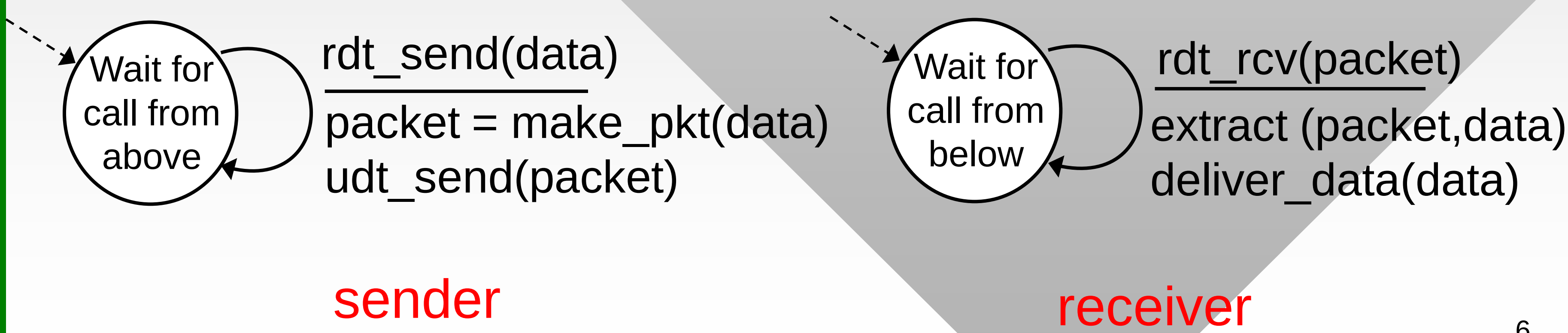
- Incrementally develop sender, receiver sides of reliable data transfer protocol (rdt)
- Consider only unidirectional data transfer
  - With receiver feedback, packets travel in both directions!
- Use finite state machines (FSM) to specify both sender and receiver

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



Rdt1.0: Transfer Over a Reliable Channel

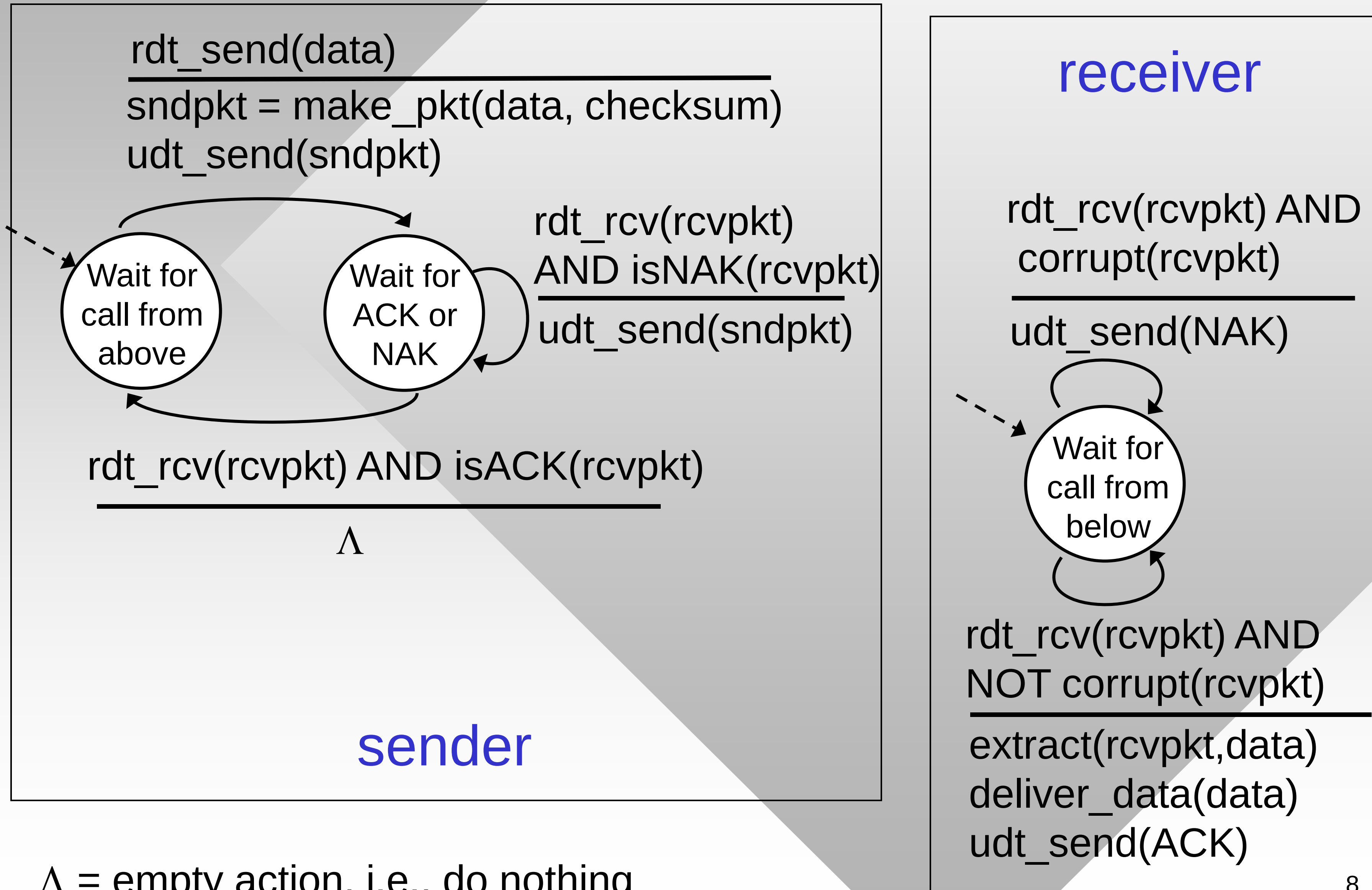
- Underlying channel perfectly reliable
  - No bit errors
  - No loss of packets
  - No reordering
- Separate FSMs for sender and receiver:
  - Sender transmits app data into underlying channel
  - Receiver passes data from underlying channel to app



Rdt2.0: Channel With Bit Errors

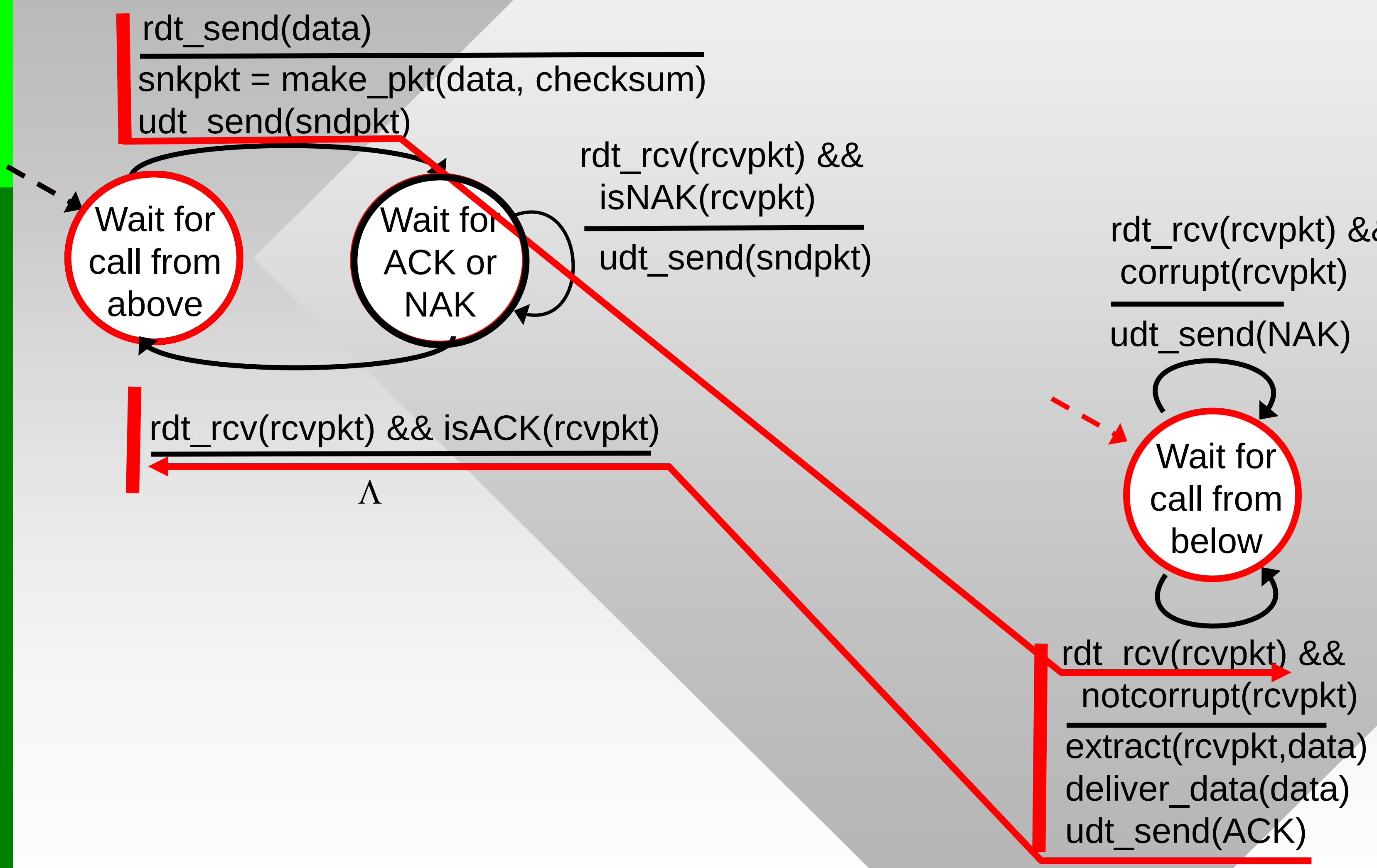
- Underlying channel may flip bits in packet (no loss)
  - Checksum to detect bit errors (assume perfect detection)
- Question: how to recover from errors?
- One possible approach is to use two feedback msgs:
  - *Positive acknowledgments (ACKs):* receiver explicitly tells sender that packet was received 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

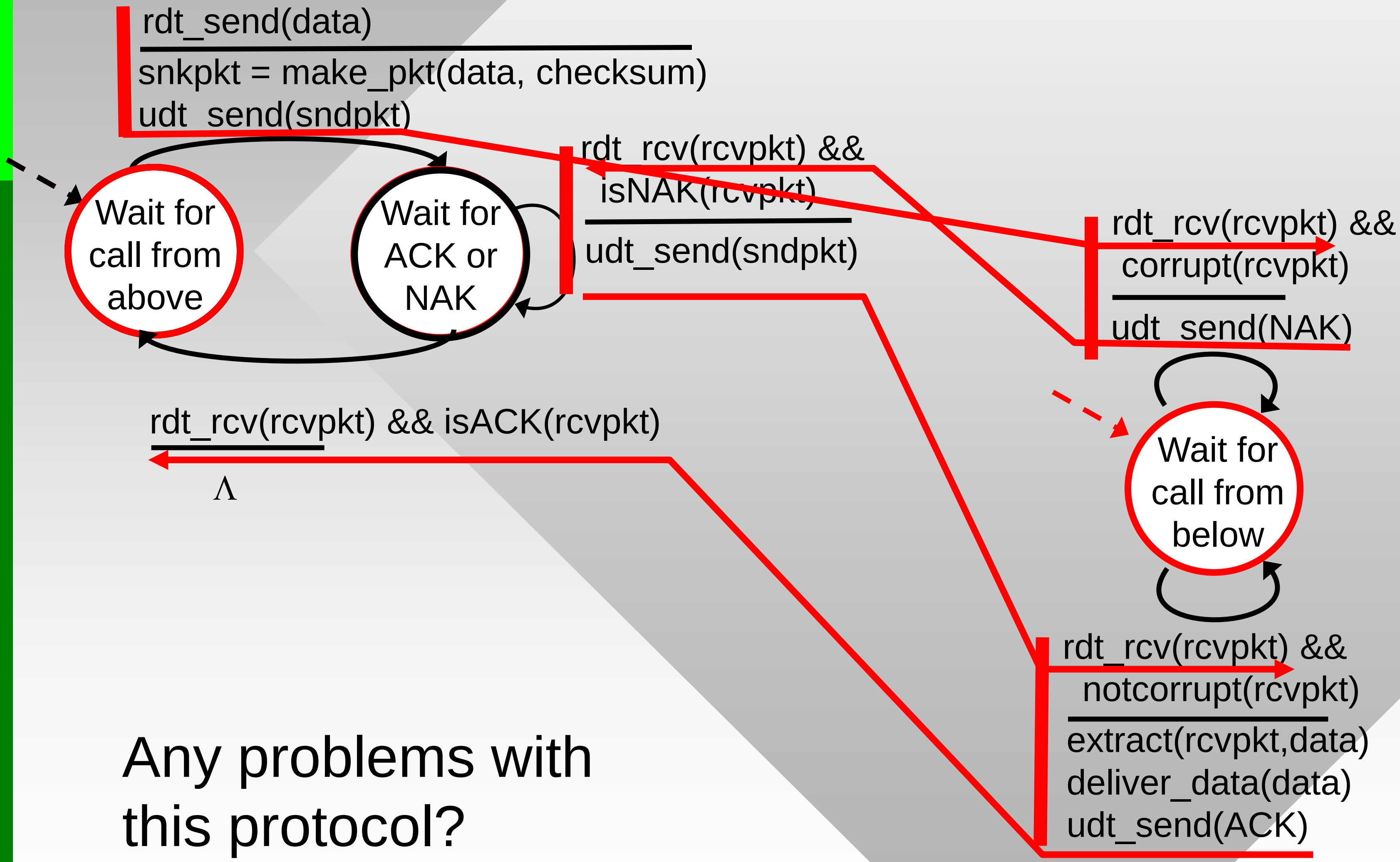


Λ = empty action, i.e., do nothing

Rdt2.0: Operation With No Errors

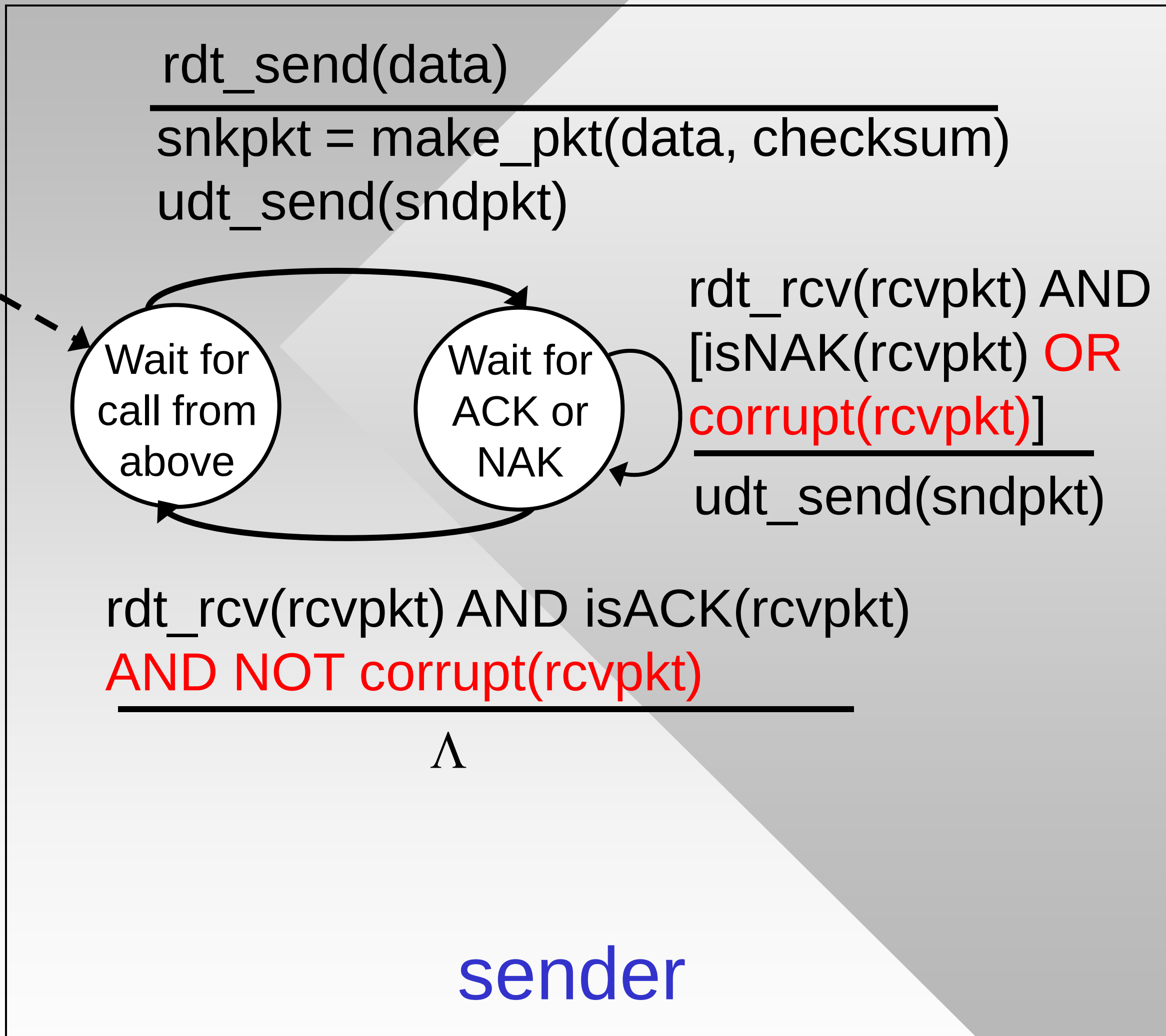


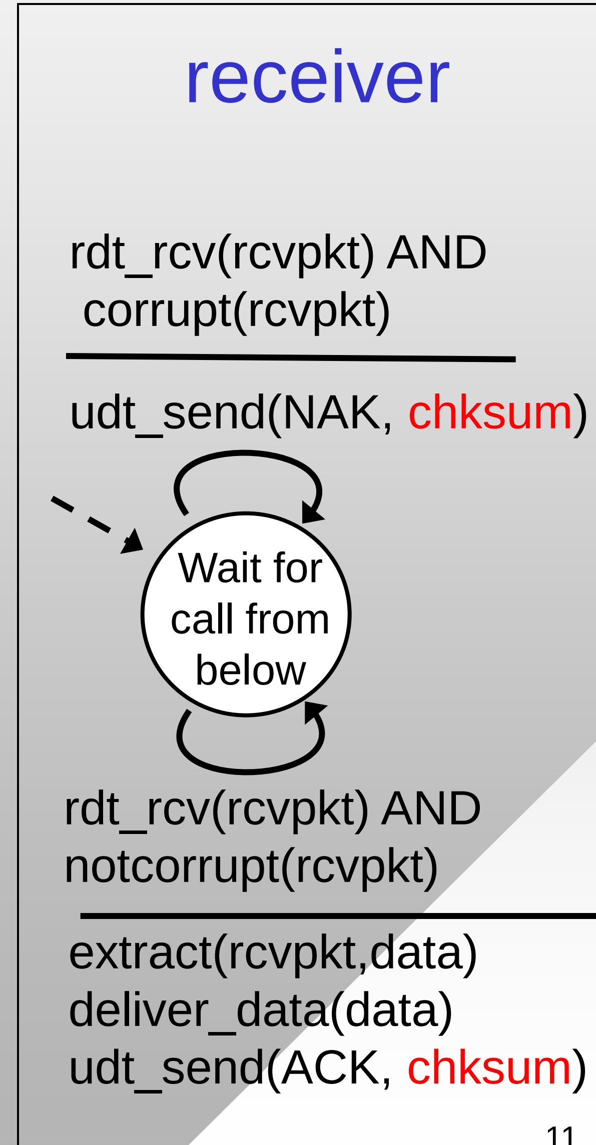
Rdt2.0: Error Scenario



Any problems with this protocol?

Rdt2.0a: Handles Corrupted Feedback





Any problems?

Rdt2.0 and Rdt2.0a Have Fatal Flaws

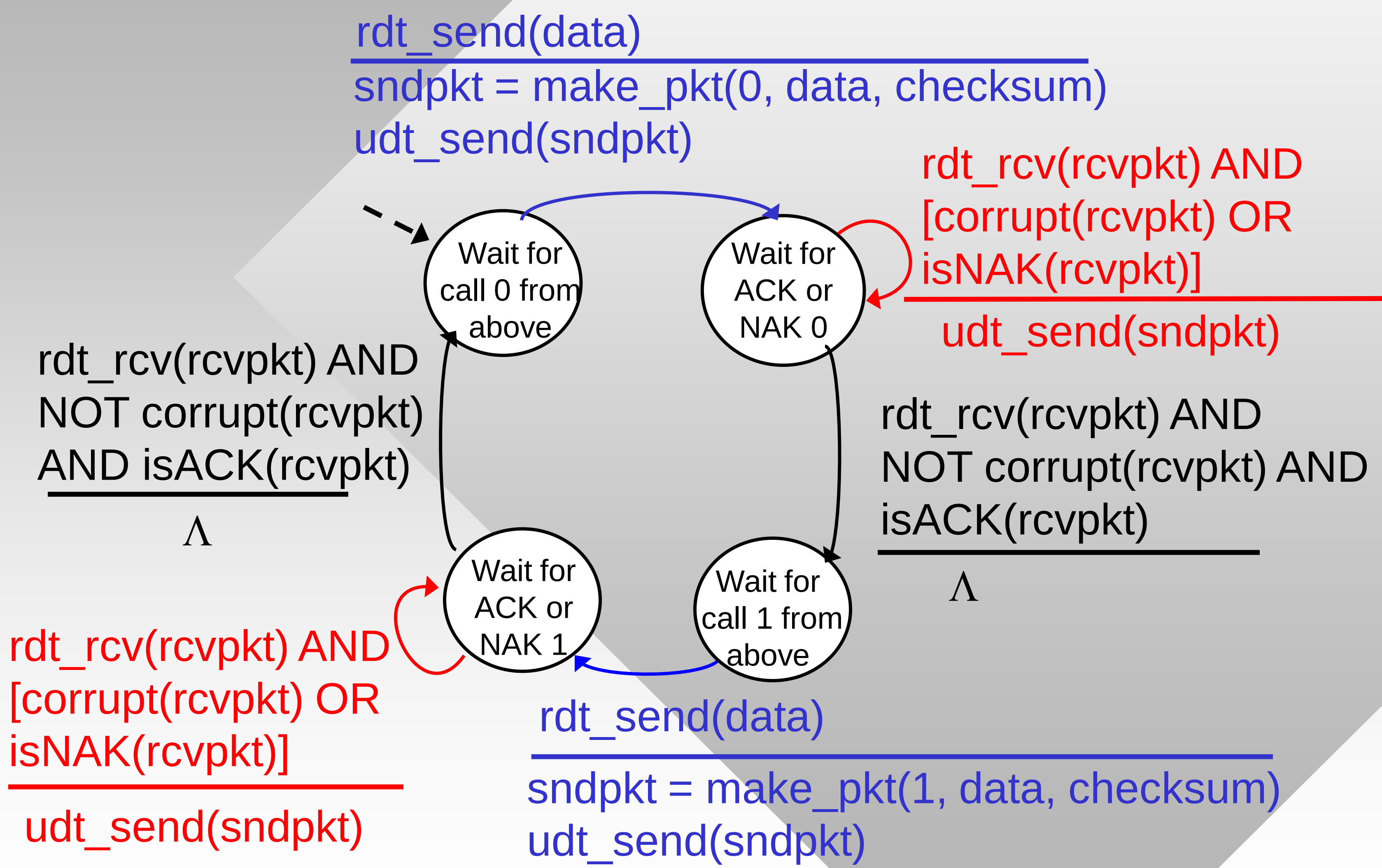
- Rdt 2.0 does not work when ACK/NAK is corrupted
  - Sender doesn't know what happened at receiver!
- Rdt 2.0a delivers duplicate packets to application

Proper algorithm:

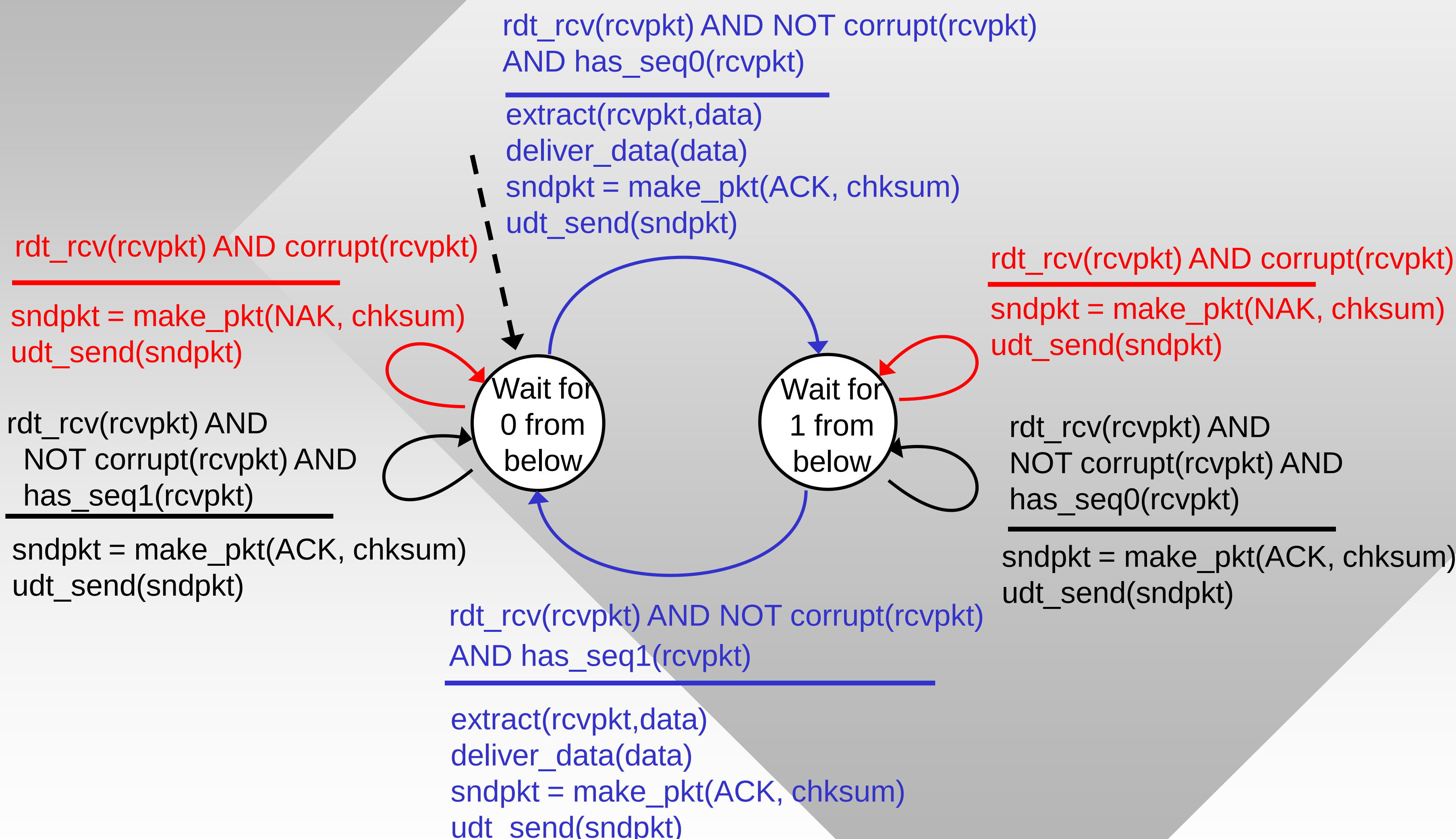
- Sender adds *sequence number* to each pkt
- Sender retransmits current pkt if ACK/NAK is garbled
- Receiver discards (doesn't deliver up) duplicate pkt

Stop-and-Wait protocol: sender sends one packet, then waits for receiver's 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
  - Protocol must remember whether current pkt has 0 or 1 sequence number

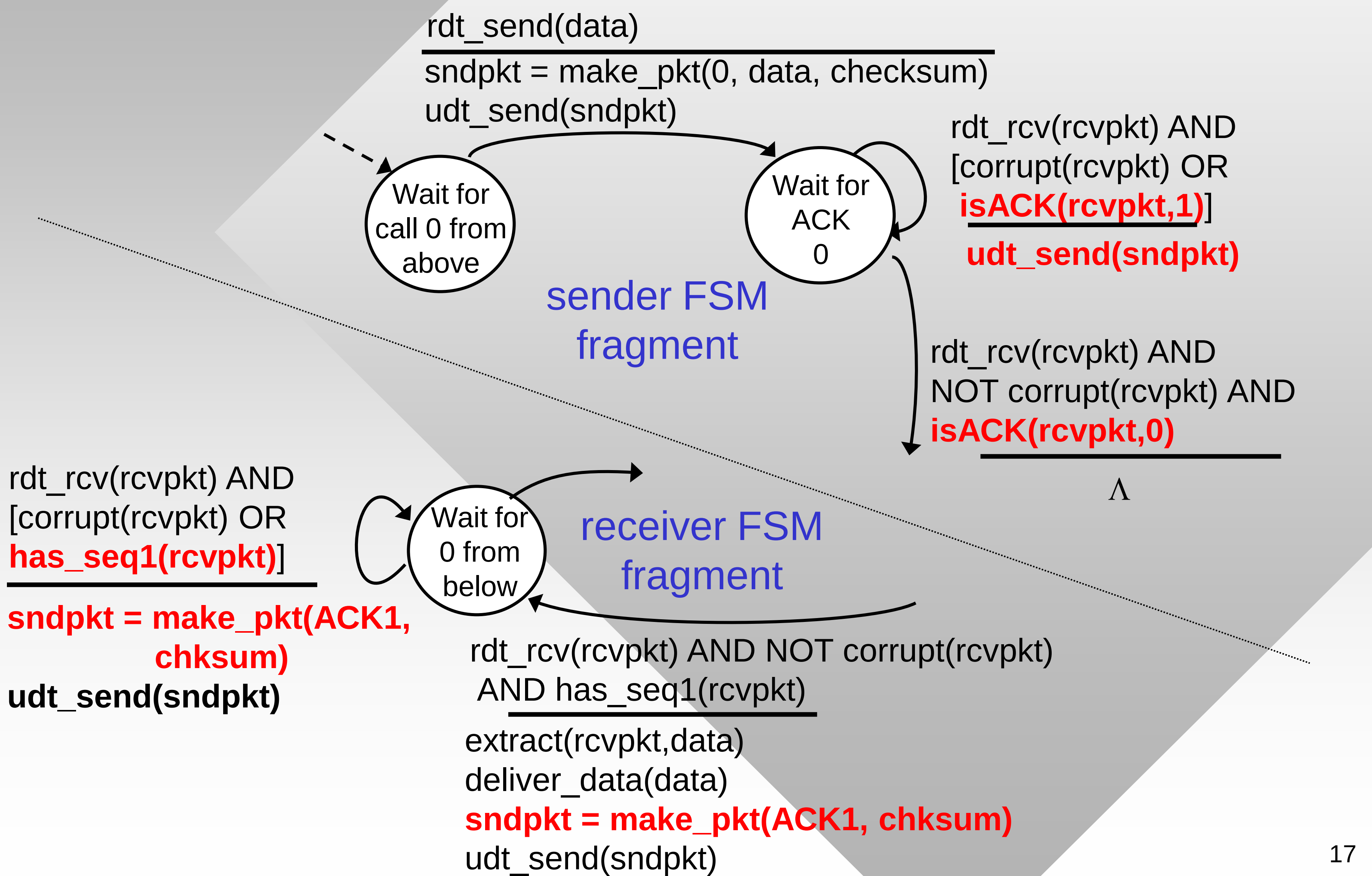
Receiver:

- Must check if received packet is duplicate
  - State indicates whether 0 or 1 is the expected packet seq #
- Note: receiver *cannot* know if its last ACK/NAK was received correctly at sender

Rdt2.2: NAK-free Protocol

- Same functionality as rdt2.1, using ACKs only
  - Most protocols are easier to generalize without NAKs
- Instead of NAKs, receiver sends an ACK for last packet received correctly
  - 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

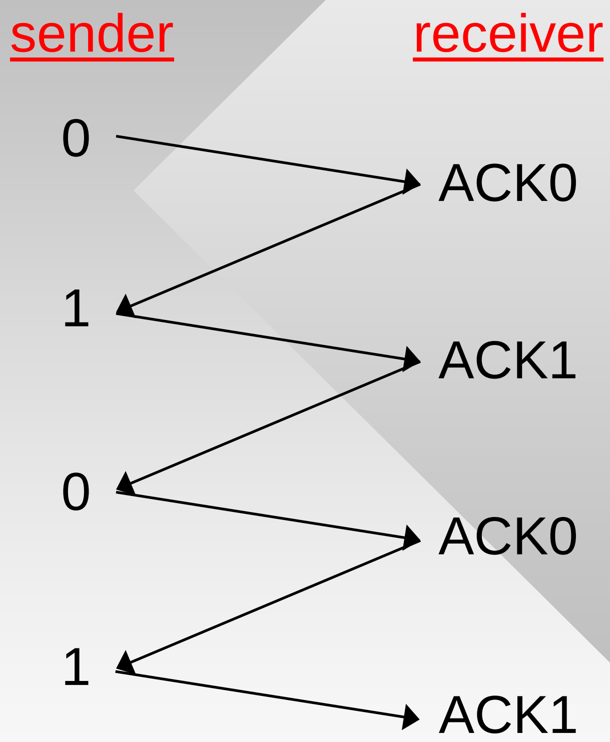


Rdt3.0: Channels With Errors *and* Loss

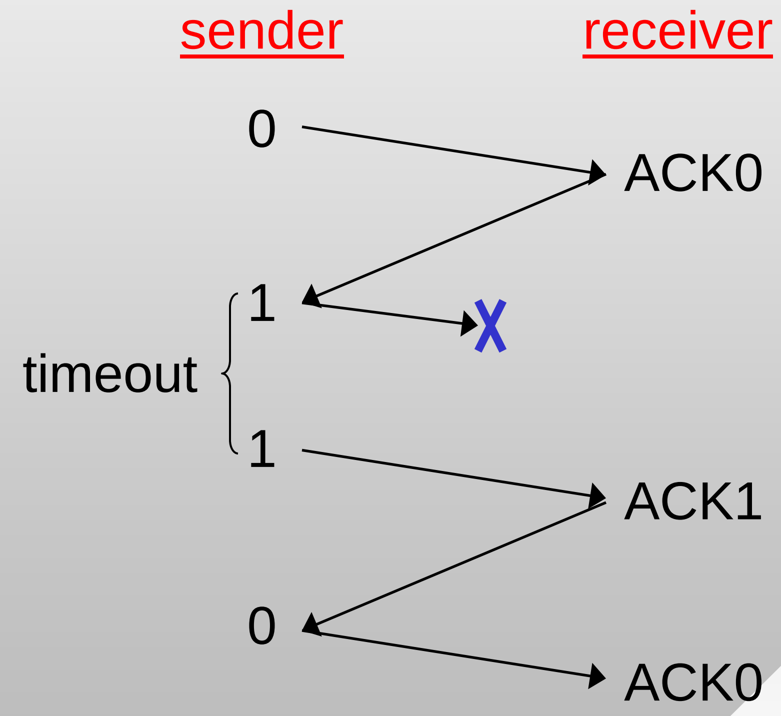
- New assumption: underlying channel can also lose packets (data or ACKs)
  - Still no reordering
- Checksum, sequence numbers, ACKs, retransmissions will be of help, but not enough
- Why not?

- Approach: sender waits a “reasonable” amount of time for ACK
  - Retransmits if no ACK received in this time
  - Sender requires a timer
- If packet (or ACK) is delayed beyond the timer:
  - Retransmission will be duplicate, but the use of seq. #’s already handles this
  - Receiver must specify seq # of packet being ACKed

Rdt3.0 in Action (No Corruption)

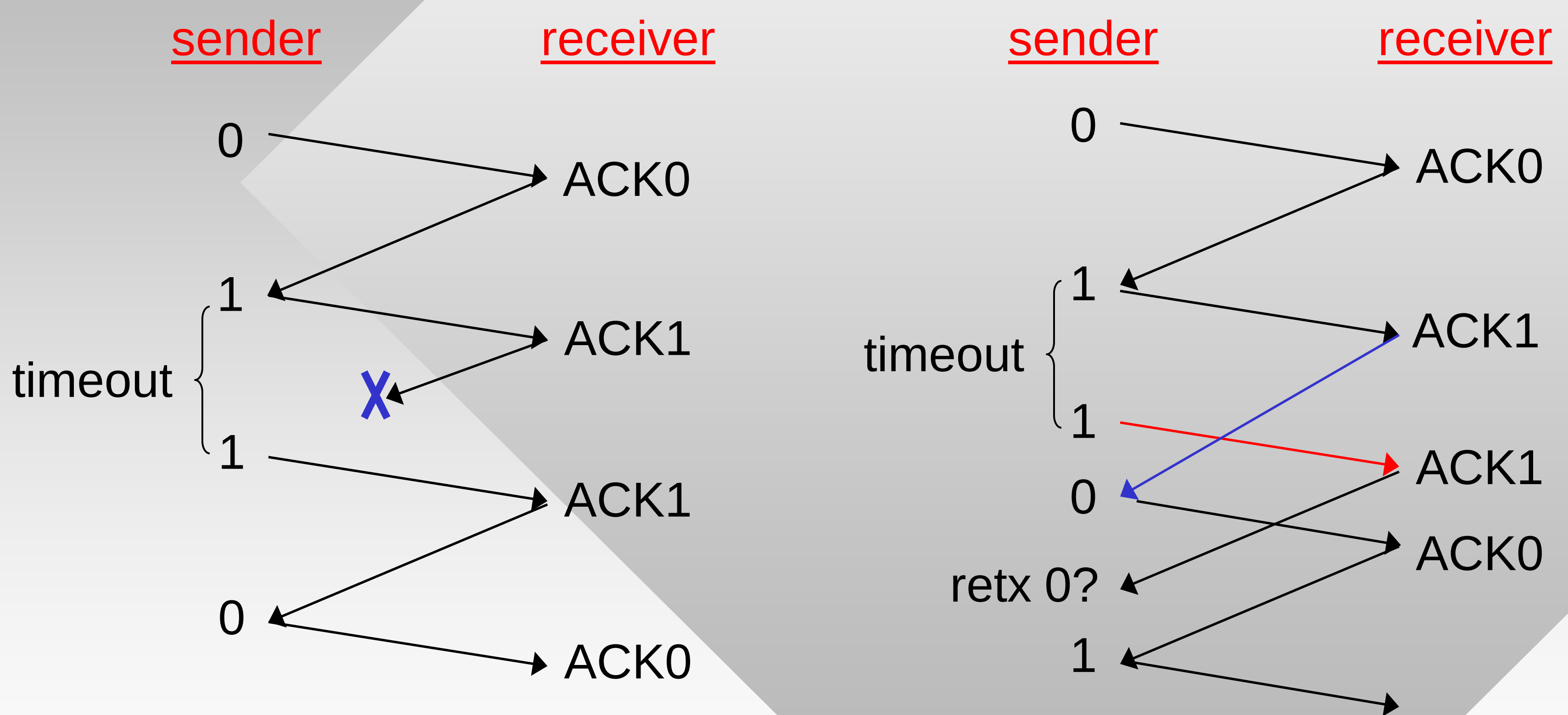


no loss



forward loss

Rdt3.0 in Action (No Corruption)

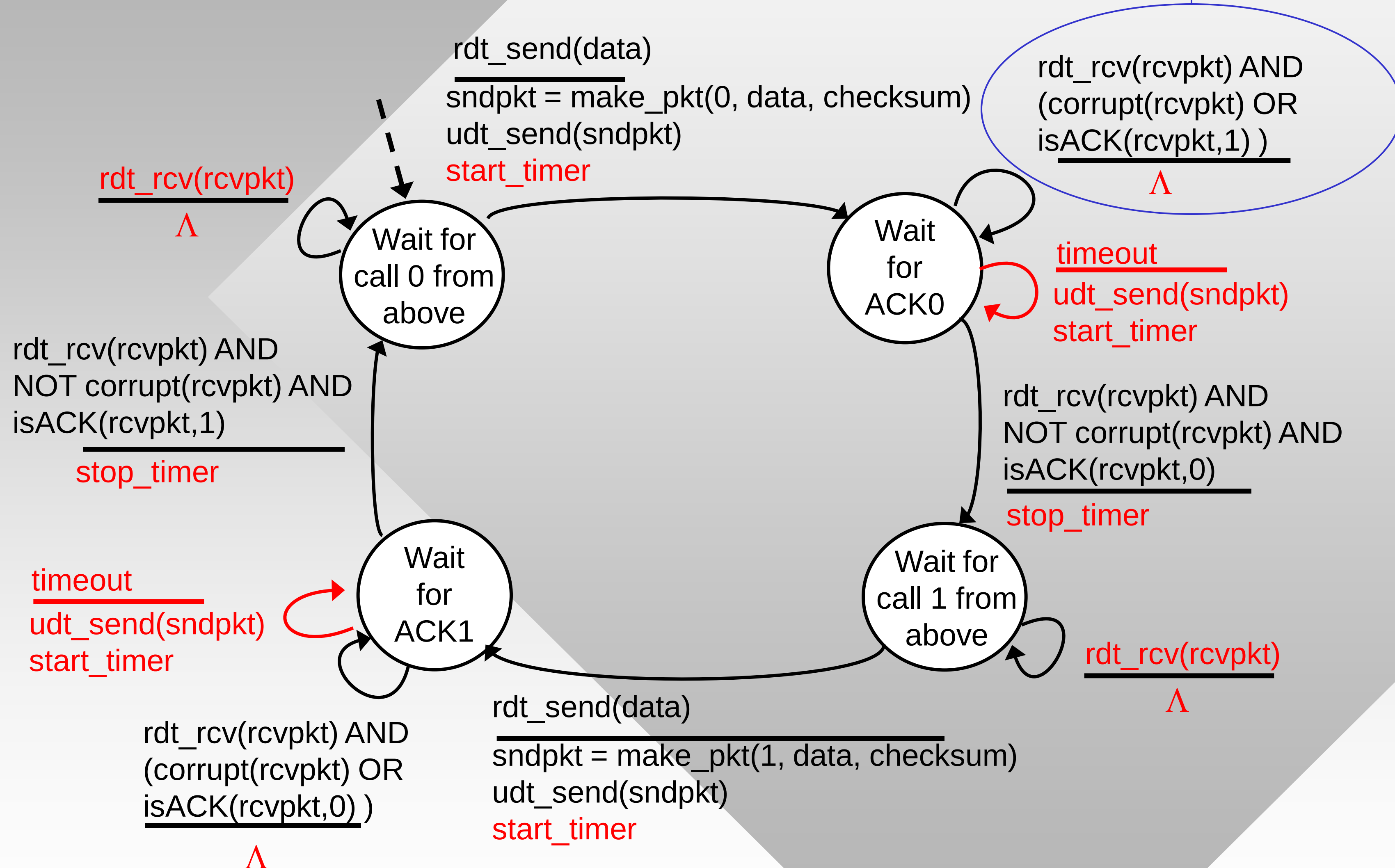


reverse loss

premature timeout

Rdt3.0 Sender

Must not retx: ACK1 may be from a premature timeout on pkt1



Performance of Rdt3.0

Notation: KB = Kilobyte;
Kbps = Kilobits/sec
Gbps = Gigabits/sec

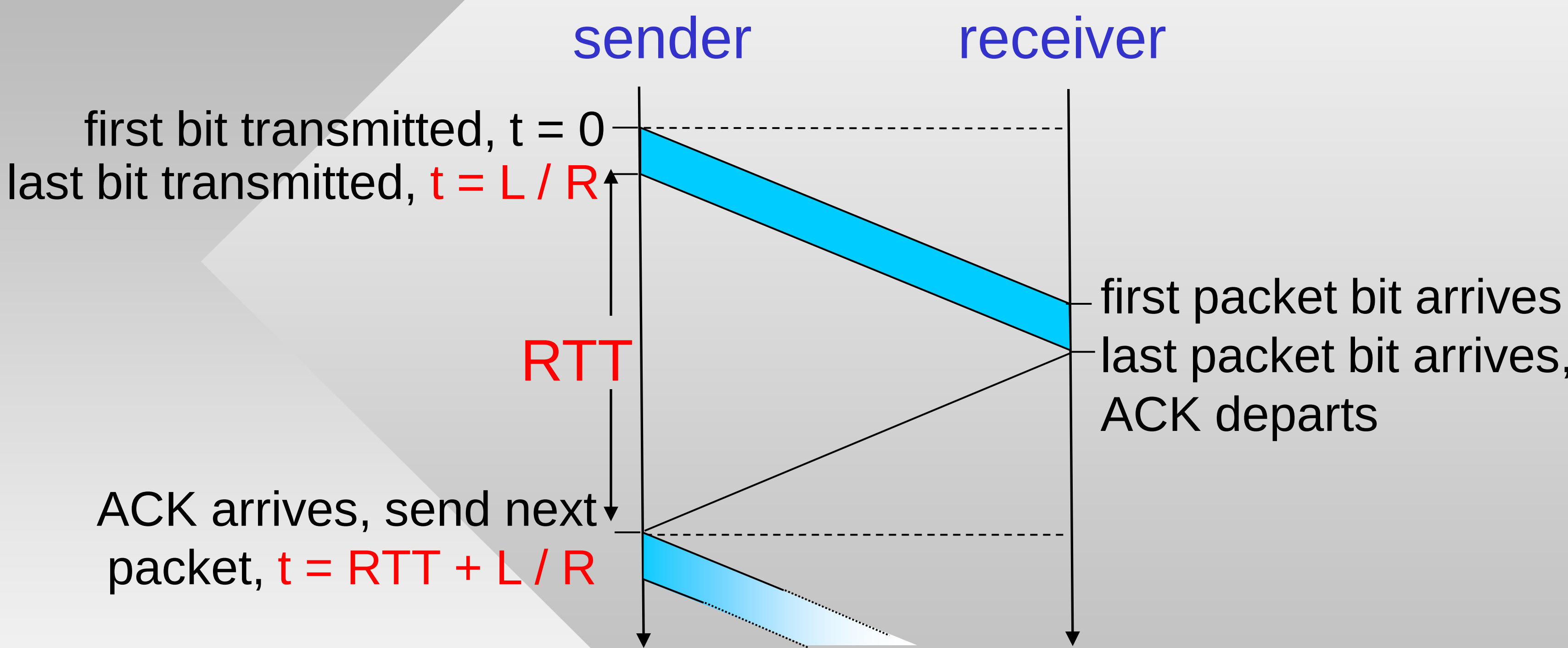
- Rdt 3.0 works, but performance is low
- Example: 1 Gbps link, 15 ms end-to-end propagation delay, 1 KB packets, no loss or corruption:

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

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

- Server spends 0.008 ms being busy and 30 ms being idle, thus its link utilization is only 0.027%
- 1-KB pkt every 30 ms → 264 Kbps throughput
- *Network protocol limits use of physical resources!*

Rdt3.0: Stop-and-Wait Operation



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

Performance of Rdt3.0

- Next assume that 10% of data packets are corrupted/lost (no loss in retransmissions or ACKs) and the timeout is 1 second
  - 90% of packets take (RTT + L/R) $\approx$ 30 ms to complete, while 10% require [timeout + RTT + 2L/R] $\approx$ 1.03 sec
  - Average per-packet delay 0.9*0.03 +0.1*1.03 sec =130 ms
  - Average rate 7.7 pkts/s or 61.5 Kbps
- Rdt3.0 similar to HTTP 1.0 or non-pipelined HTTP 1.1
- Next time we'll improve this using pipelining, which allows multiple unack'ed packets at any time
- Quiz #2: chapter 2 problems and system notes
  - P1, P3-P11, P13-P14, P20-P21