

Chapter 3

Transport Layer

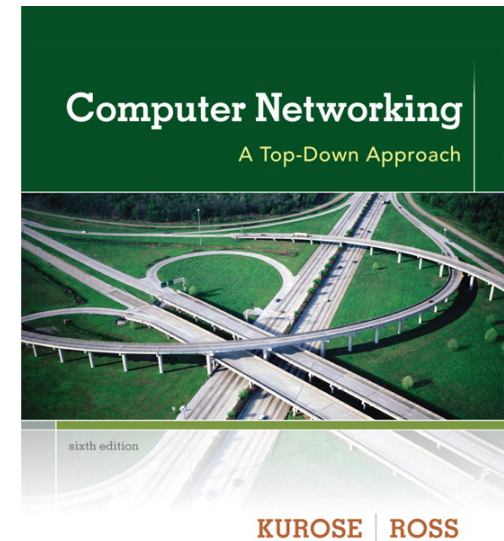
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Computer Networking: A Top Down Approach

6th edition

Jim Kurose, Keith Ross
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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

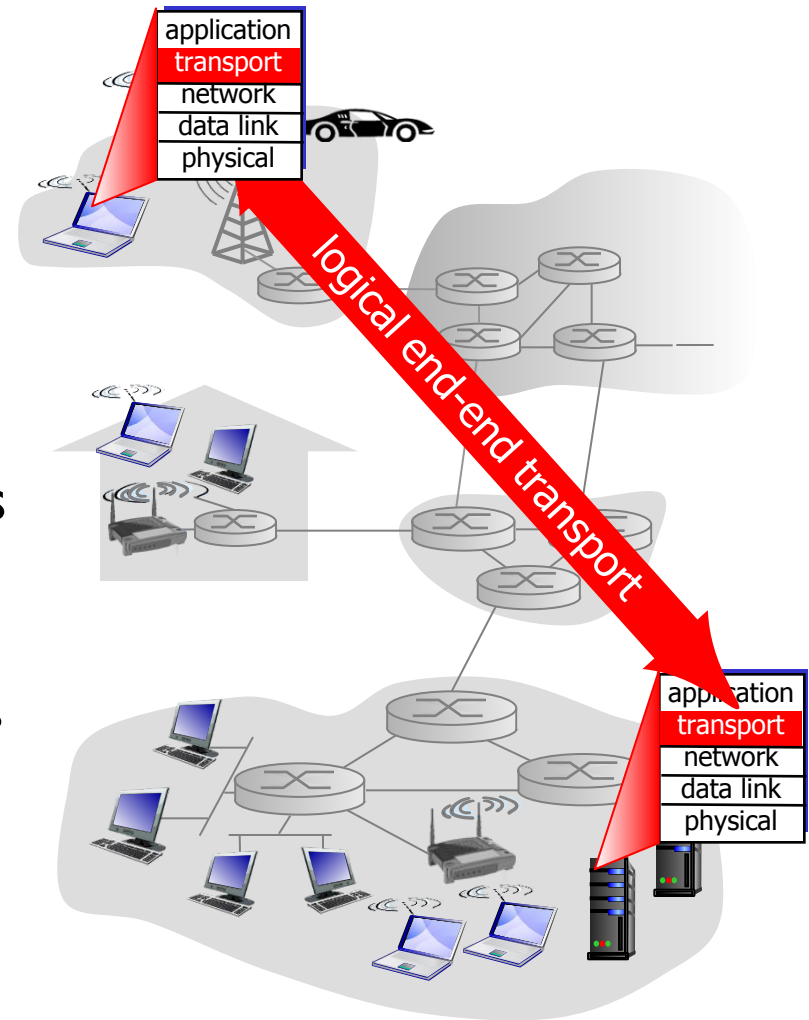
- segment structure
- reliable data transfer
- flow control
- connection management

3.6 principles of congestion control

3.7 TCP congestion control

Transport services and protocols

- ❖ A transport-layer protocol provides for **logical communication** between application processes running on different hosts transport protocols run in end systems
 - send side: breaks app messages into **segments**, passes to network layer
 - rcv side: reassembles segments into messages, passes to app layer



Transport vs. network layer

- ❖ *network layer:*
logical
communication
between hosts
- ❖ *transport layer:*
logical
communication
between processes
 - relies on, enhances,
network layer
services

household analogy:

*12 kids in Ann's house sending
letters to 12 kids in Bill's
house:*

- ❖ hosts = houses
- ❖ processes = kids
- ❖ app messages = letters in envelopes
- ❖ transport protocol = Ann and Bill who demux to in-house siblings
- ❖ network-layer protocol = postal service

Internet transport protocols services

TCP service:

- ❖ *reliable transport* between sending and receiving process
- ❖ *flow control*: sender won't overwhelm receiver
- ❖ *congestion control*: throttle sender when network overloaded
- ❖ *connection-oriented*: setup required between client and server processes

UDP service:

- ❖ *unreliable data transfer* between sending and receiving process
- ❖ *does not provide*: reliability, flow control, congestion control, timing, throughput guarantee, security, or connection setup,

Q: why bother? Why is there a UDP?

TCP and UDP

a **TCP connection** is said to exist between the sockets of the two processes. The connection is a full-duplex connection in that the two processes can send messages to each other over the connection at the same time. When the application finishes sending messages, it must tear down the connection.

UDP is connectionless, so there is no handshaking before the two processes start to communicate. UDP provides an unreliable data transfer service—that is, when a process sends a message into a UDP socket, UDP provides *no* guarantee that the message will ever reach the receiving process. Furthermore, messages that do arrive at the receiving process may arrive out of order.

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Multiplexing/demultiplexing

multiplexing at

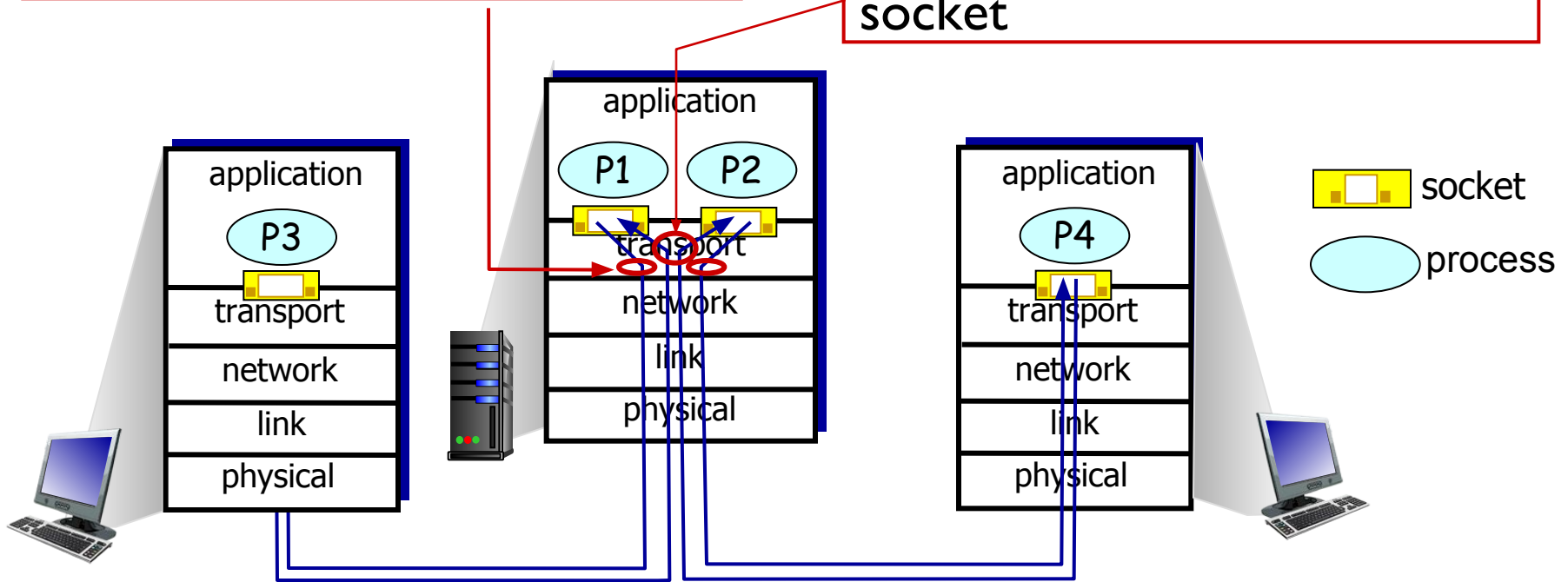
sender:

handle data from multiple sockets, add transport header (later used for demultiplexing)

demultiplexing at

receiver:

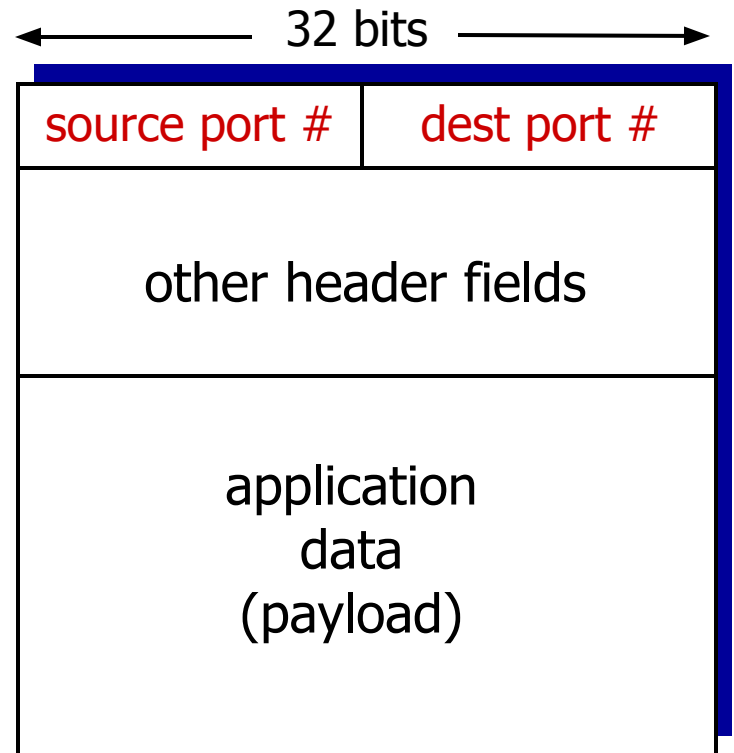
use header info to deliver received segments to correct socket



- ❖ The job of gathering data chunks at the source host from different sockets, encapsulating each data chunk with header information (that will later be used in demultiplexing) to create segments, and passing the segments to the network layer is called **multiplexing**
- ❖ The transport layer examines these fields to identify the receiving socket and then directs the segment to that socket. This job of delivering the data in a transport-layer segment to the correct socket is called **demultiplexing**.

How demultiplexing works

- ❖ Each port number is a 16-bit number, ranging from 0 to 65535. The port numbers ranging from 0 to 1023 are called **well-known port numbers** and are restricted.



TCP/UDP segment format

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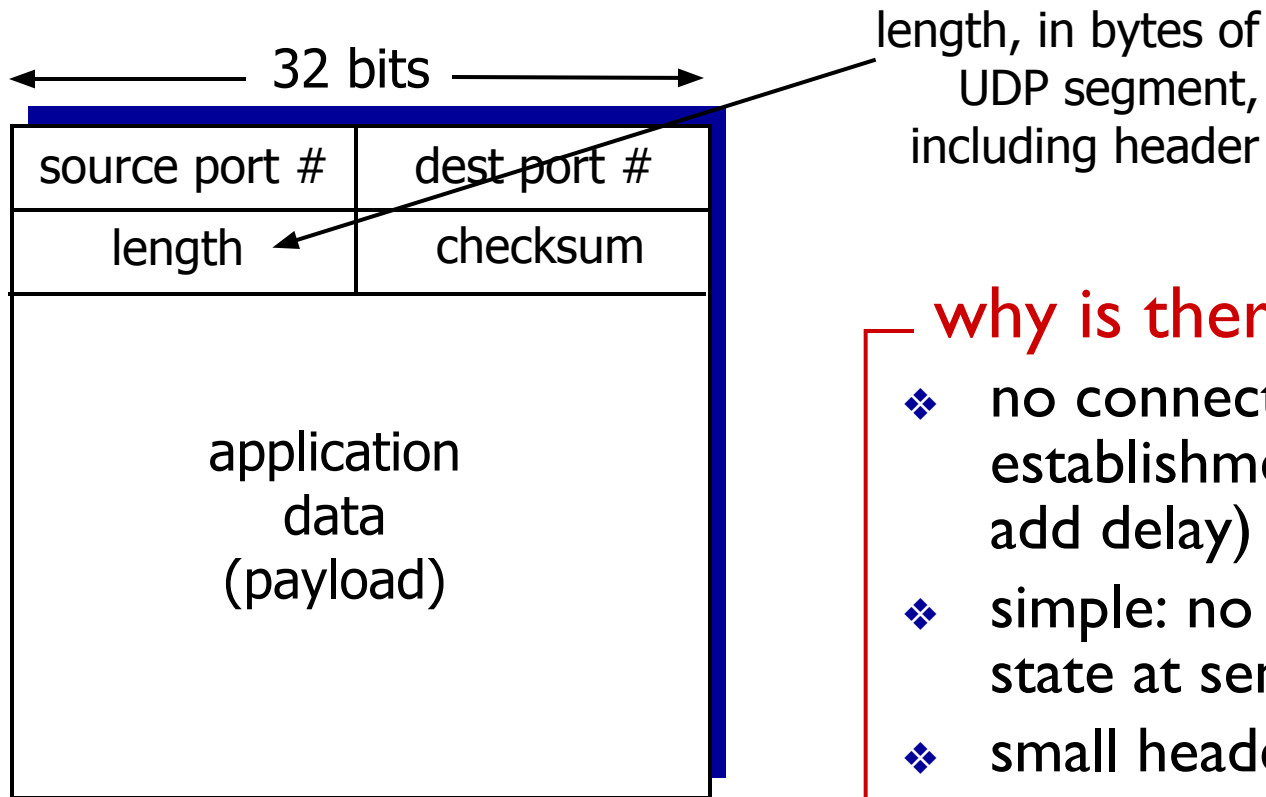
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UDP: User Datagram Protocol [RFC 768]

- ❖ 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
- ❖ UDP use:
 - DNS
 - SNMP
- ❖ *No connection establishment.* TCP uses handshake before it starts to transfer data. UDP just blasts away without any formal preliminaries. Thus UDP does not introduce any delay to establish a connection. This is probably the principal reason why DNS runs over UDP rather than TCP

UDP: segment header



UDP segment format

— why is there a UDP? —

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

Internet checksum: example

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
<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

Note: when adding numbers, a carryout from the most significant bit needs to be added to the result

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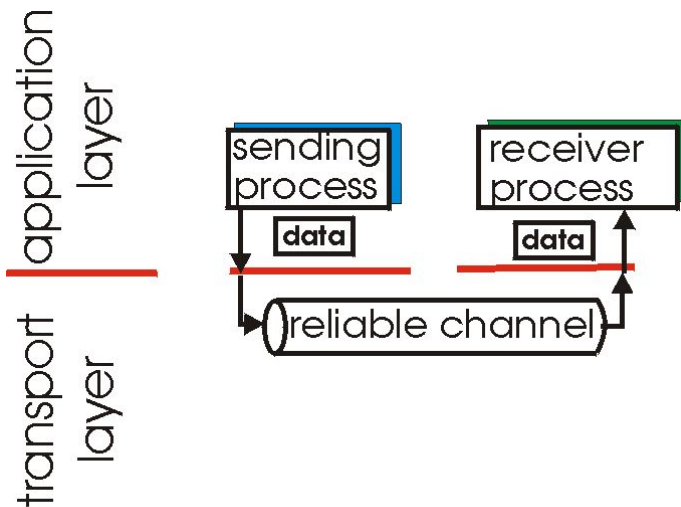
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Principles of reliable data transfer

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

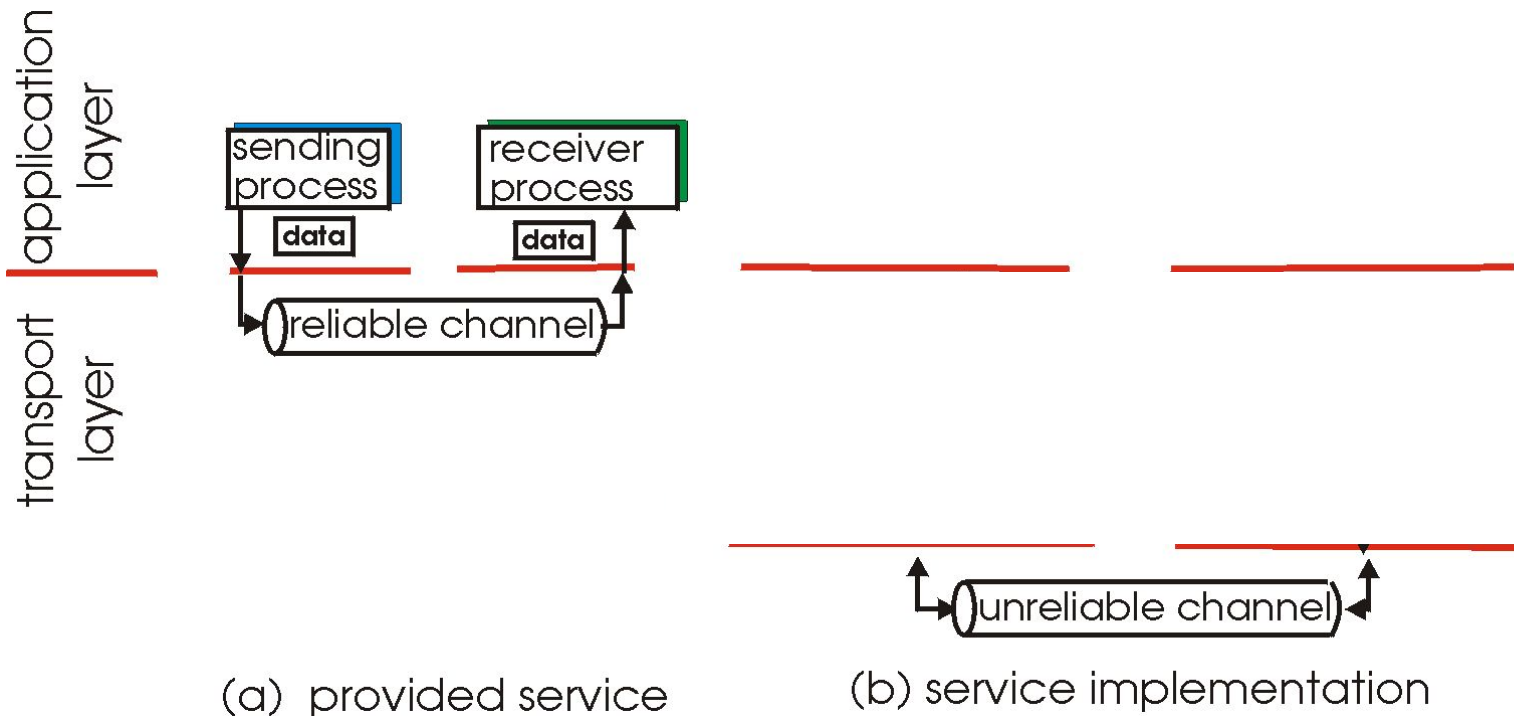


(a) provided service

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

Principles of reliable data transfer

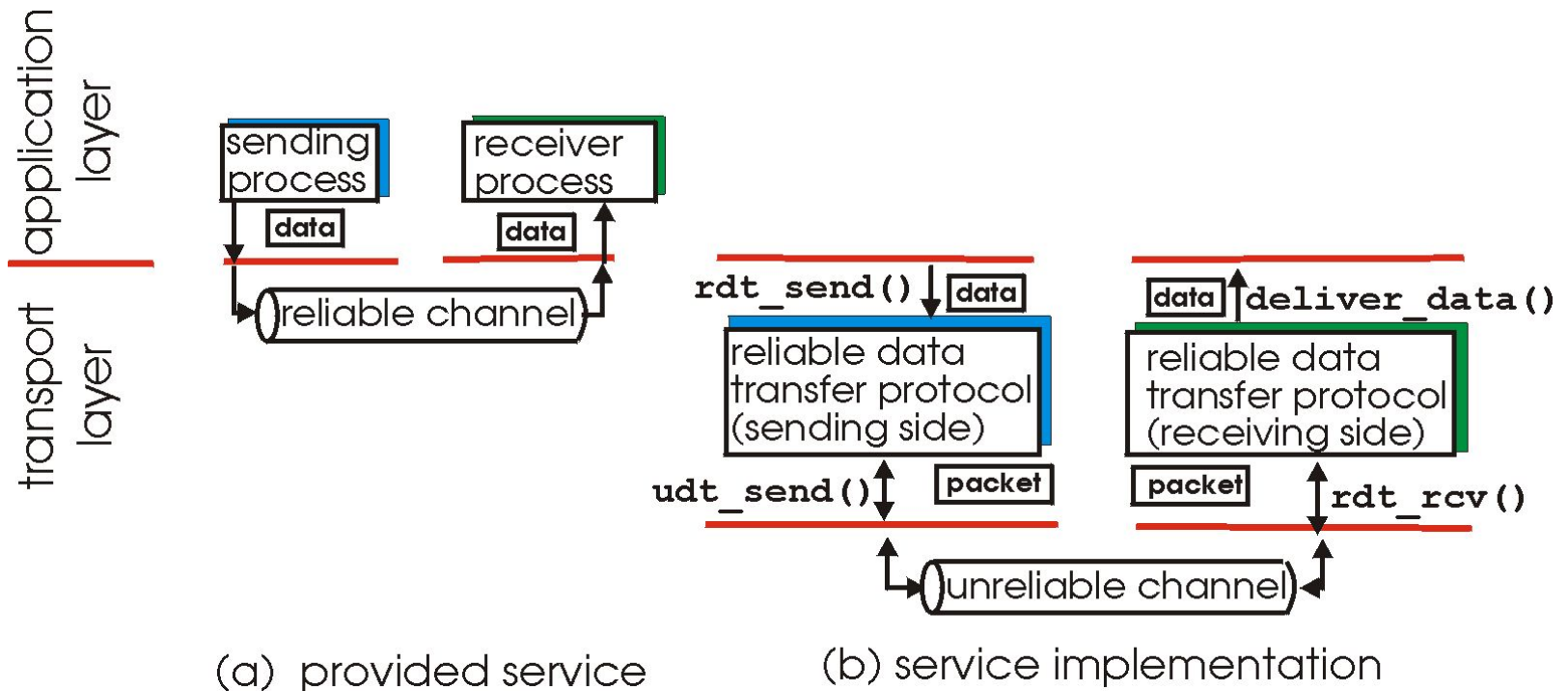
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Principles of reliable data transfer

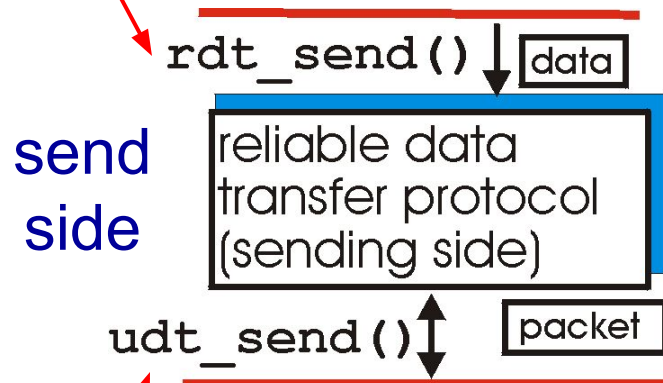
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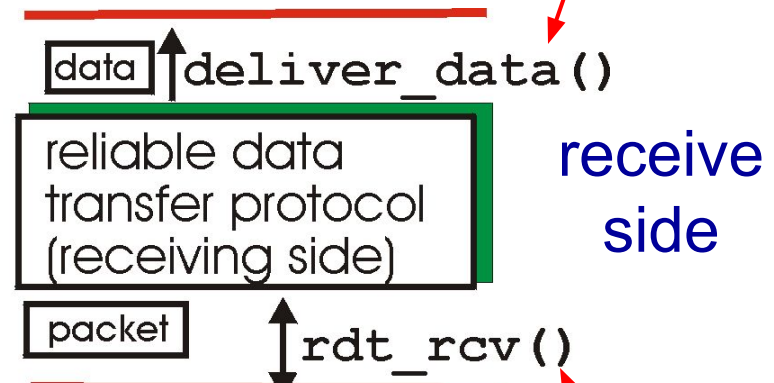
- ❖ characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

Reliable data transfer: getting started

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



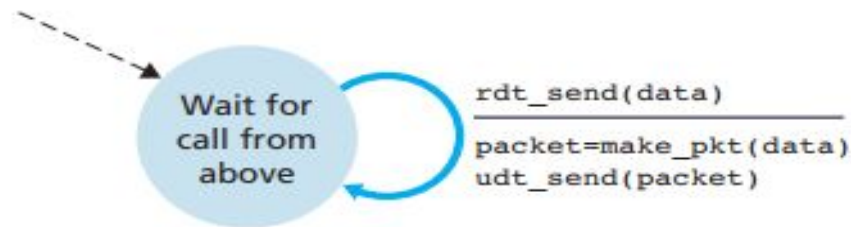
deliver_data() : called by
rdt to deliver data to upper



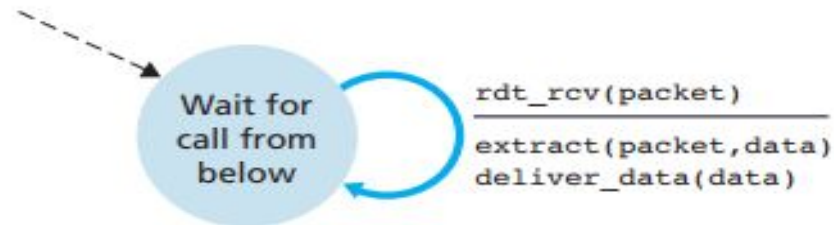
udt_send() : called by rdt,
to transfer packet over
unreliable channel to receiver

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

rdt 1.0



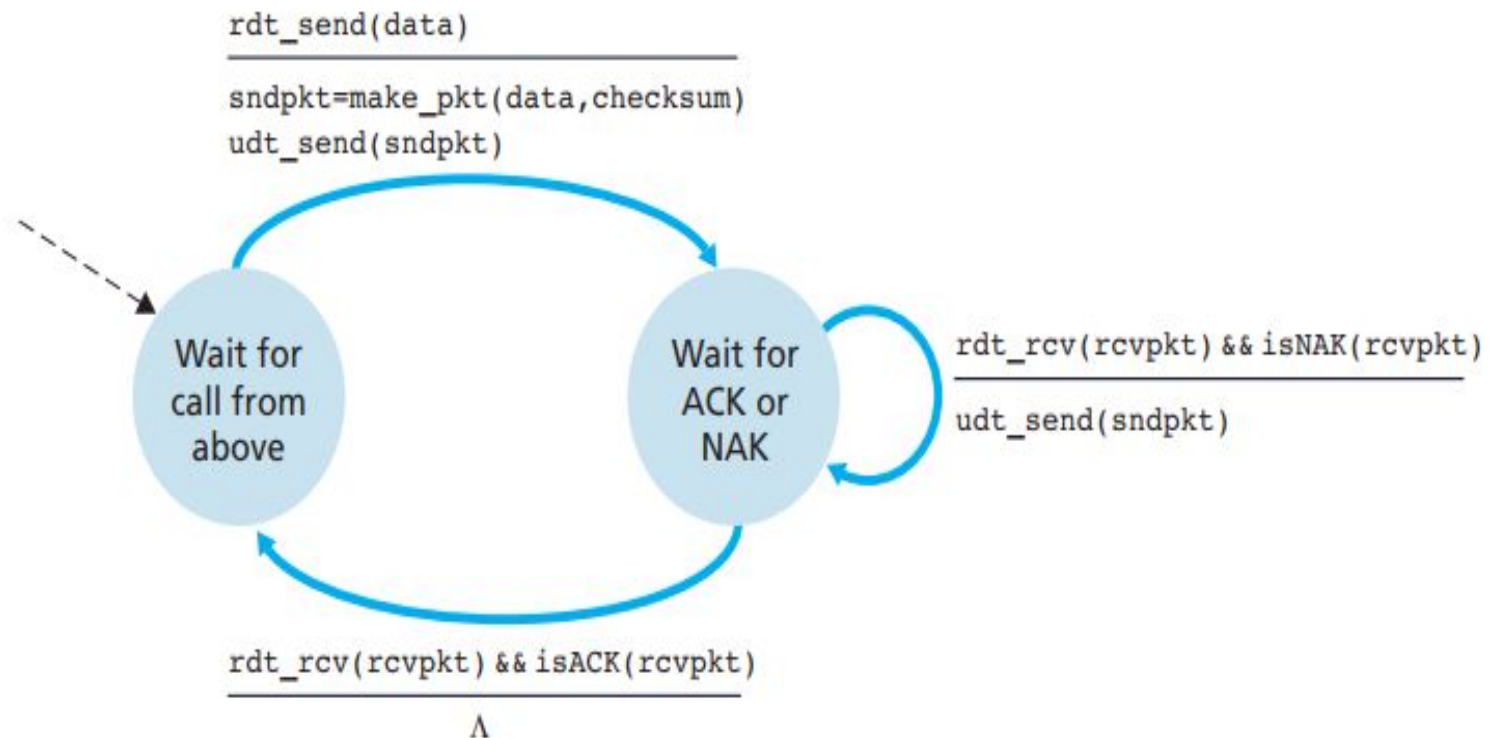
a. rdt1.0: sending side



b. rdt1.0: receiving side

Figure 3.9 ♦ rdt1.0 – A protocol for a completely reliable channel

rdt 2.0 : Sending side



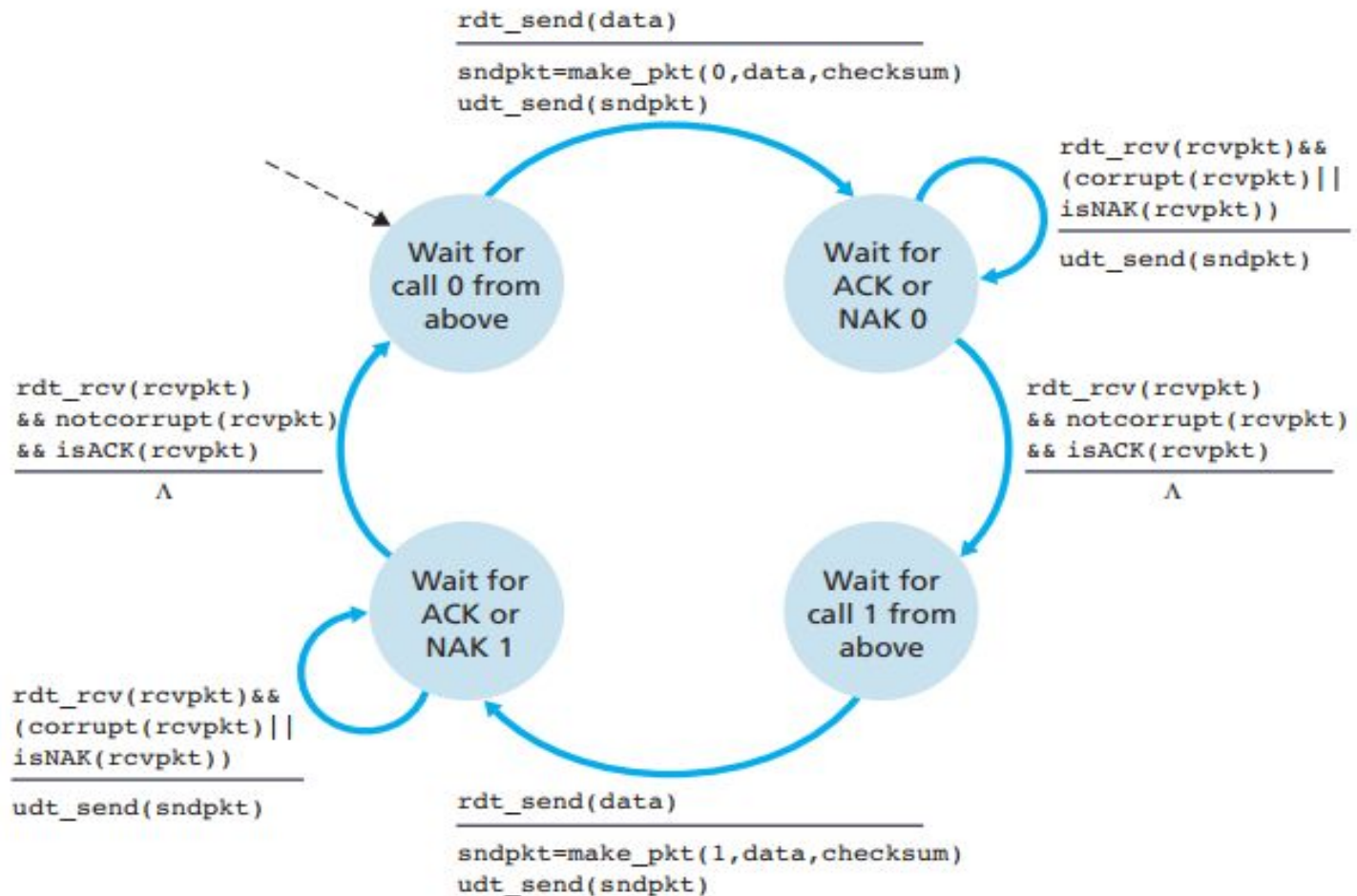
a. rdt2.0: sending side

Rdt 2.0: Receiving side



b. rdt2.0: receiving side

Rdt 2.1: sender side



Rdt 2.1: Receiving side

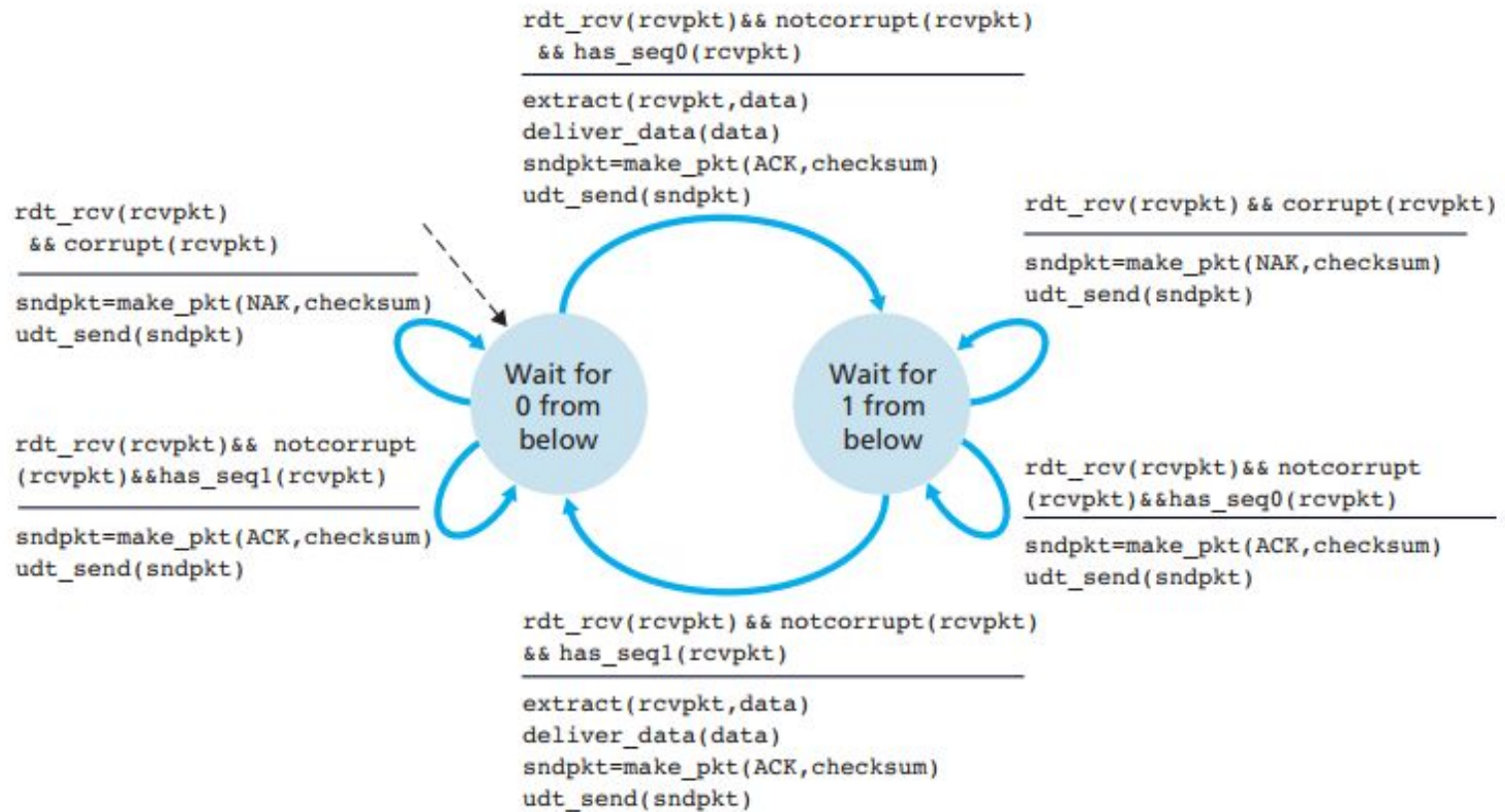
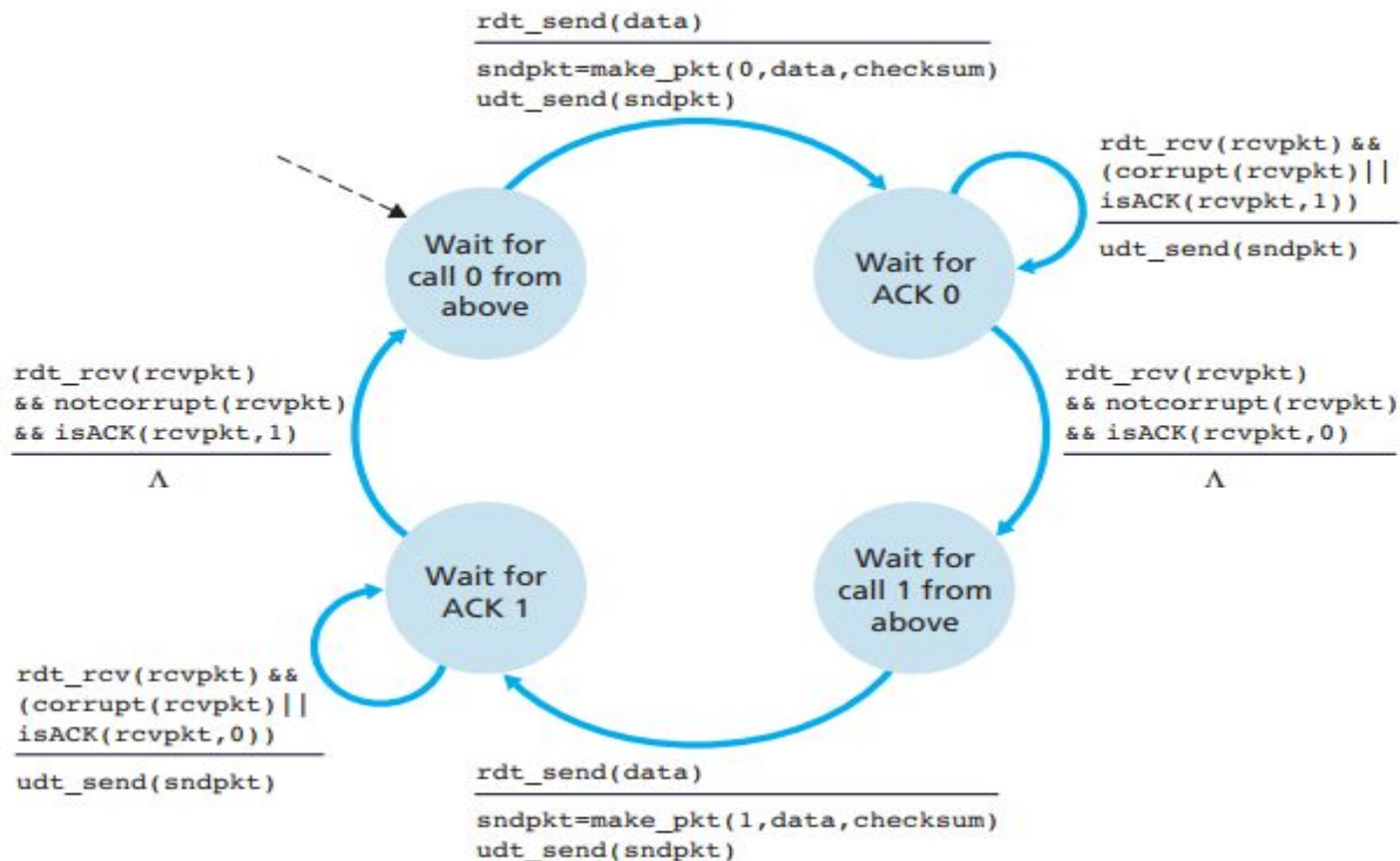


Figure 3.12 ♦ rdt2.1 receiver

Rdt 2.2: Sending side



Rdt 2.2: Receiving side

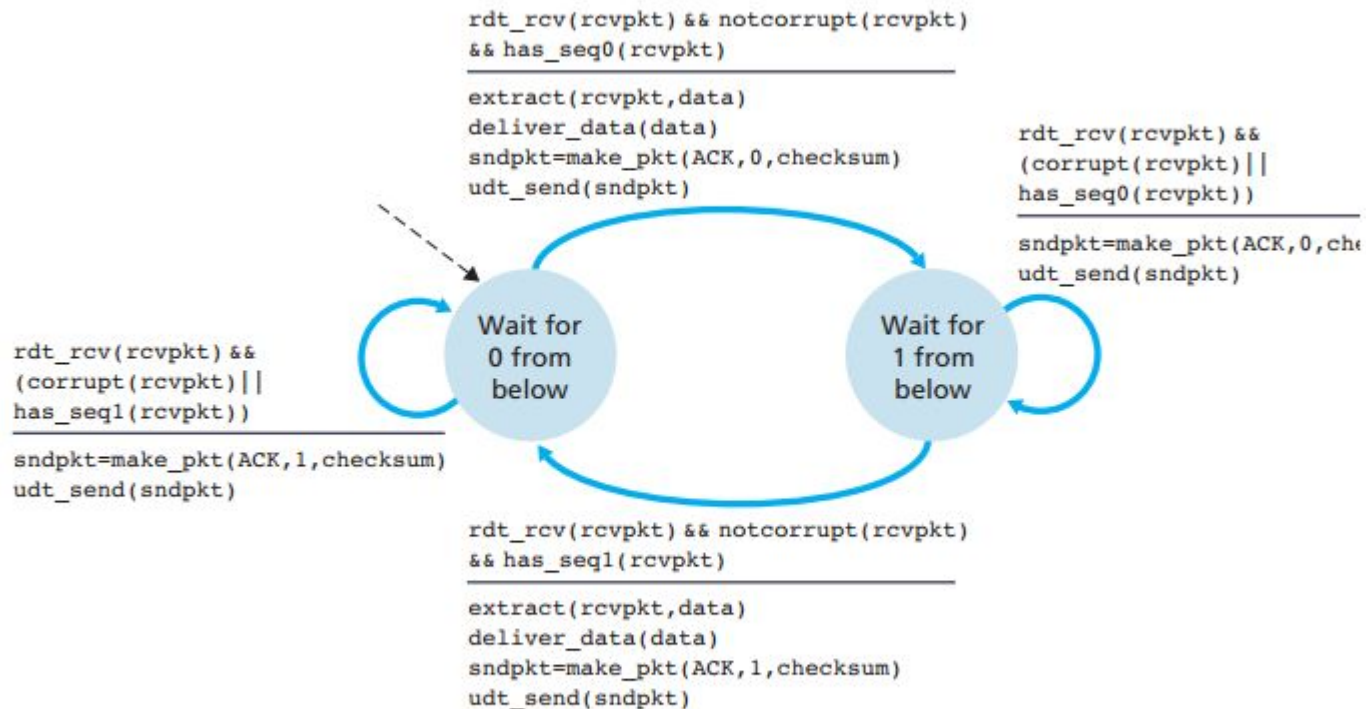
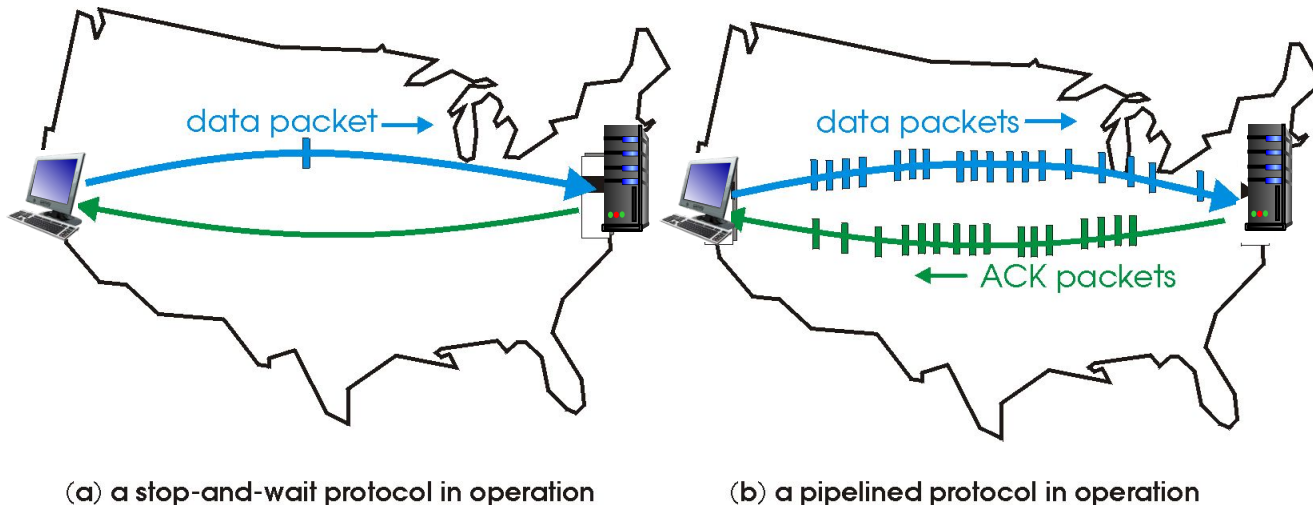


Figure 3.14 ♦ rdt2.2 receiver

Pipelined protocols

pipelining: sender allows multiple, “in-flight”, yet-to-be-acknowledged pkts

- range of sequence numbers must be increased
- buffering at sender and/or receiver



❖ two generic forms of pipelined protocols: *go-Back-N*, *selective repeat*

Pipelined protocols: overview

Go-back-N:

- ❖ sender can have up to N unacked packets in pipeline
- ❖ receiver only sends *cumulative ack*
 - doesn't ack packet if there's a gap
- ❖ sender has timer for oldest unacked packet
 - when timer expires, retransmit *all* unacked packets

Selective Repeat:

- ❖ sender can have up to N unack'ed packets in pipeline
- ❖ rcvr sends *individual ack* for each packet
- ❖ sender maintains timer for each unacked packet
 - when timer expires, retransmit only that unacked packet

GBN in action

sender window (N=4)

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

sender

send pkt0

send pkt1

send pkt2

send pkt3

(wait)

rcv ack0, send pkt4

rcv ack1, send pkt5

ignore duplicate ACK



pkt 2 timeout

send pkt2

send pkt3

send pkt4

send pkt5

receiver

receive pkt0, send ack0

receive pkt1, send ack1

receive pkt3, discard,
(re)send ack1

receive pkt4, discard,
(re)send ack1

receive pkt5, discard,
(re)send ack1

rcv pkt2, deliver, send ack2

rcv pkt3, deliver, send ack3

rcv pkt4, deliver, send ack4

rcv pkt5, deliver, send ack5

Selective repeat

- ❖ receiver *individually* acknowledges all correctly received pkts
 - buffers pkts, as needed, for eventual in-order delivery to upper layer
- ❖ sender only resends pkts for which ACK not received
 - sender timer for each unACKed pkt
- ❖ sender window
 - N consecutive seq #'s
 - limits seq #'s of sent, unACKed pkts

Selective repeat in action

sender window (N=4)

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

sender

send pkt0

send pkt1

send pkt2

send pkt3

(wait)

rcv ack0, send pkt4

rcv ack1, send pkt5

record ack3 arrived



pkt 2 timeout

send pkt2

record ack4 arrived

record ack5 arrived

receiver

receive pkt0, send ack0

receive pkt1, send ack1

receive pkt3, buffer,
send ack3

receive pkt4, buffer,
send ack4

receive pkt5, buffer,
send ack5

rcv pkt2; deliver pkt2,
pkt3, pkt4, pkt5; send ack2

Q: what happens when ack2 arrives?