CC231

Introduction to Networks

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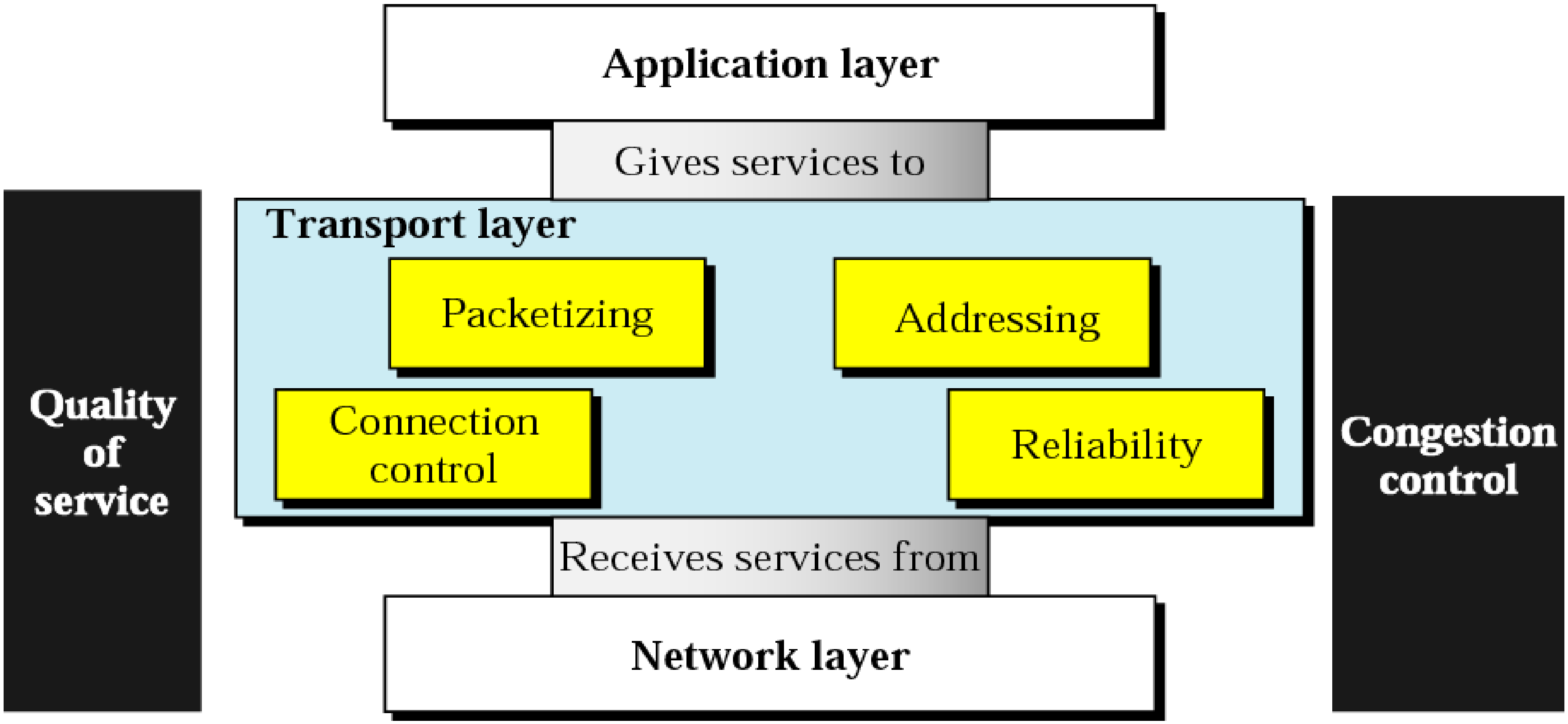
CCIT - AASTMT

Transmission Control Protocol (TCP)

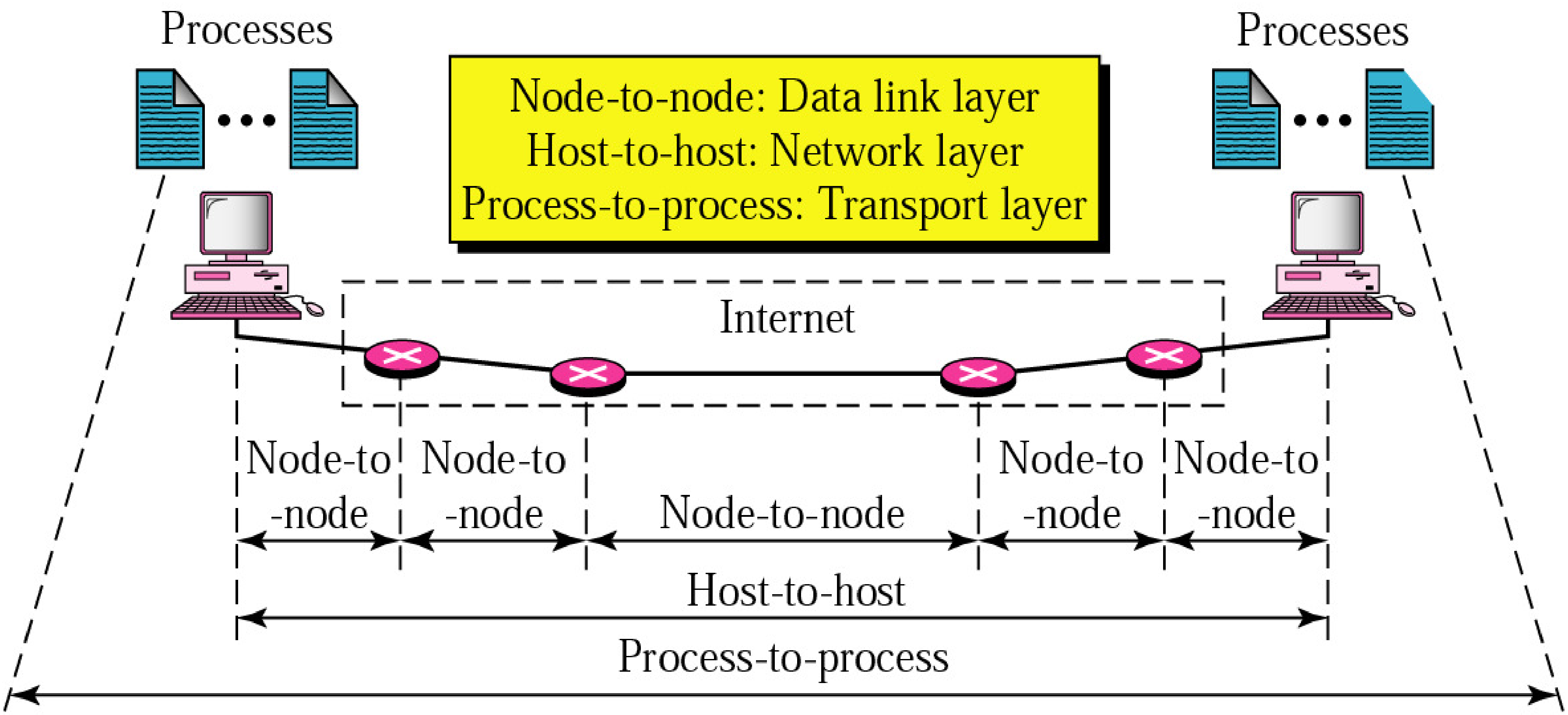
Outline

- Transmission Control Protocol

Transport Layer 1/2



Transport Layer 2/2

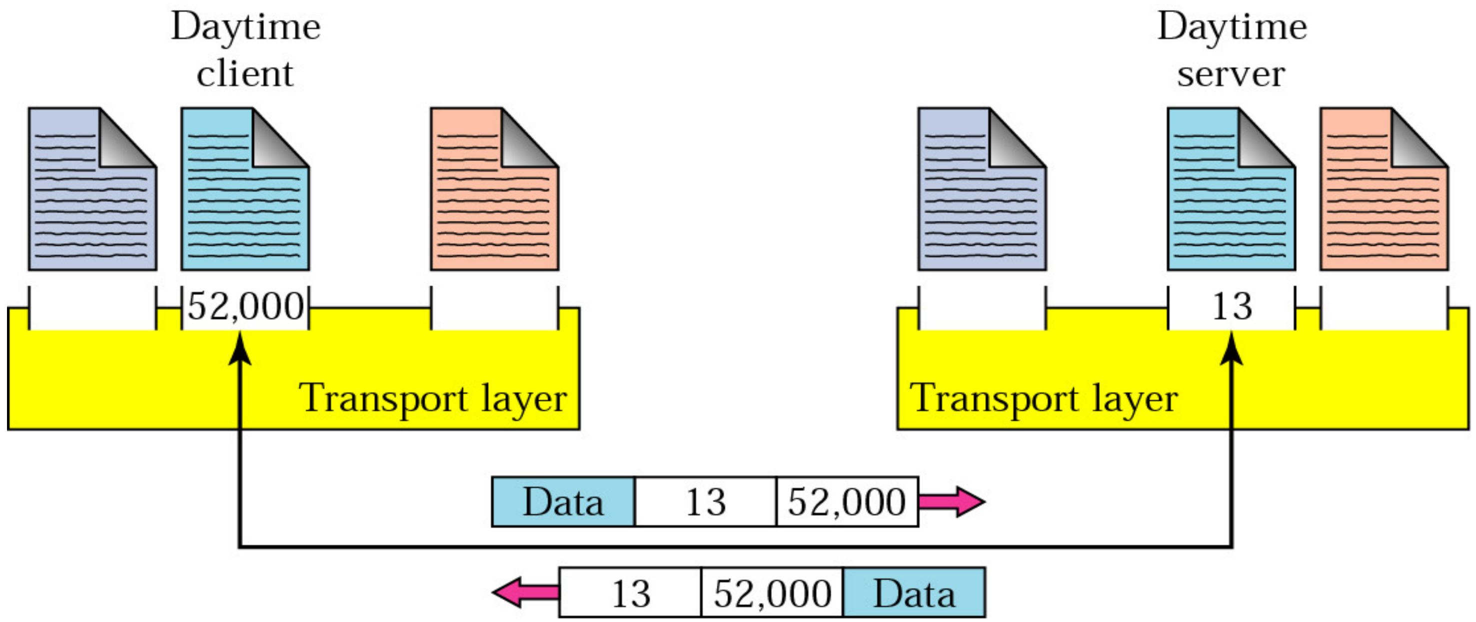


Process-to-process delivery

Transport Layer Addressing

Addresses

- Data link layer → MAC address
- Network layer → IP address
- Transport layer → *Port number* (choose among multiple processes running on destination host)



Port Numbers

- Port numbers are 16-bit integers (0 → 65,535)
  - Servers use *well know ports*, 0-1023 are privileged
  - Clients use *ephemeral* (short-lived) ports
- *Internet Assigned Numbers Authority* (IANA) maintains a list of port number assignment
  - Well-known ports (0-1023) → controlled and assigned by IANA
  - Registered ports (1024-49151) → IANA registers and lists use of ports as a convenience (49151 is ¾ of 65536)
  - Dynamic ports (49152-65535) → ephemeral ports
- For well-known port numbers, see /etc/services on a UNIX or Linux machine

Socket Addressing

- Process-to-process delivery needs *two* identifiers
  - IP address and Port number
  - Combination of IP address and port number is called a socket address (a socket is a communication endpoint)
  - Client socket address uniquely identifies client process
  - Server socket address uniquely identifies server process
- Transport-layer protocol needs a *pair* of socket addresses
  - Client socket address
  - Server socket address
  - For example, socket pair for a TCP connection is a 4-tuple
    - ✓Local IP address, local port, and
    - ✓foreign IP address, foreign port

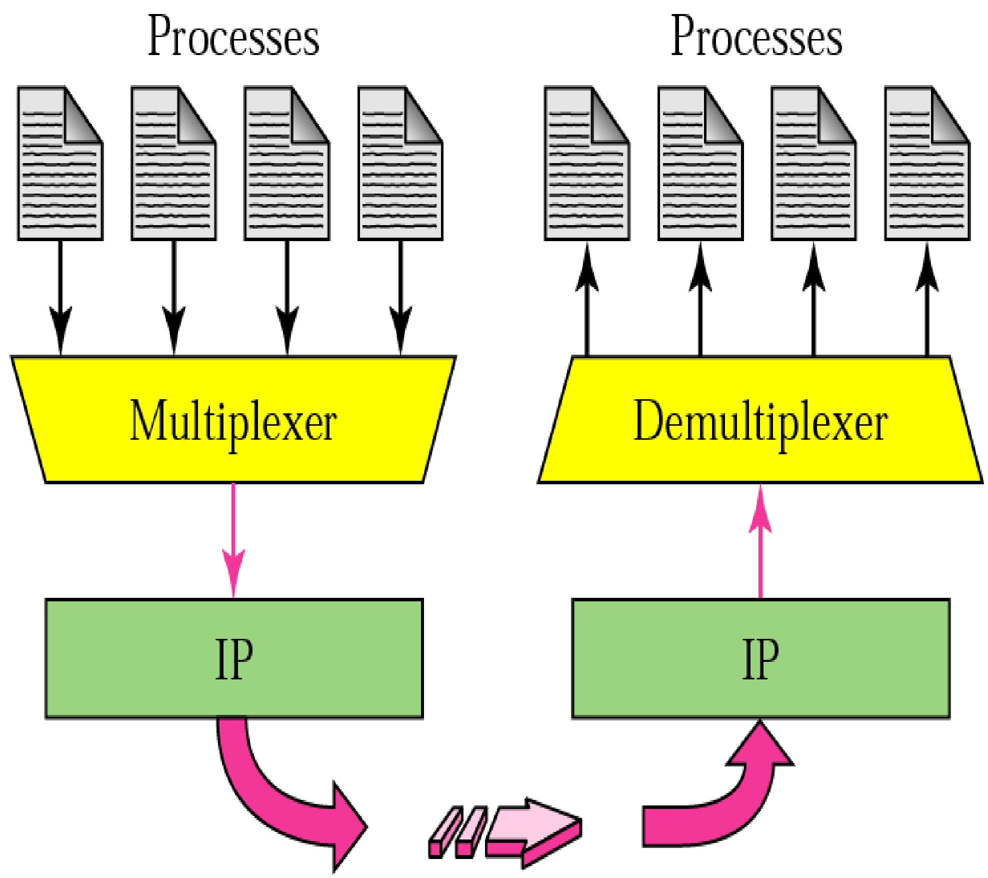
Multiplexing and Demultiplexing

Multiplexing

Sender side may have several processes that need to send packets (albeit only 1 transport-layer protocol)

Demultiplexing

At receiver side, after error checking and header dropping, transport-layer delivers each message to appropriate process



Transmission Control Protocol 1/13

- TCP must perform typical transport layer functions:
  - ➢Segmentation → breaks message into packets
  - ➢End-to-end error control →since IP is an unreliable Service
  - ➢End-to-end flow control → to avoid buffer overflow
  - ➢Multiplexing and demultiplexing sessions
- TCP is [originally described in RFC 793, 1981]
  - ➢Reliable
  - ➢Connection-oriented → virtual circuit
  - ➢Stream-oriented → users exchange streams of data
  - ➢Full duplex → concurrent transfers can take place in both directions
  - ➢Buffered → TCP accepts data and transmits when appropriate (can be overridden with "push")

Transmission Control Protocol 2/13

- Reliable
  - requires ACK and performs retransmission
  - If ACK not received, retransmit and wait a longer time for ACK. After a number of retransmissions, will give up
  - How long to wait for ACK? (dynamically compute RTT for estimating how long to wait for ACKs, might be ms for LANs or seconds for WANs)

    RTT = α * old RTT + (1- α)* new RTT where α usually 90%

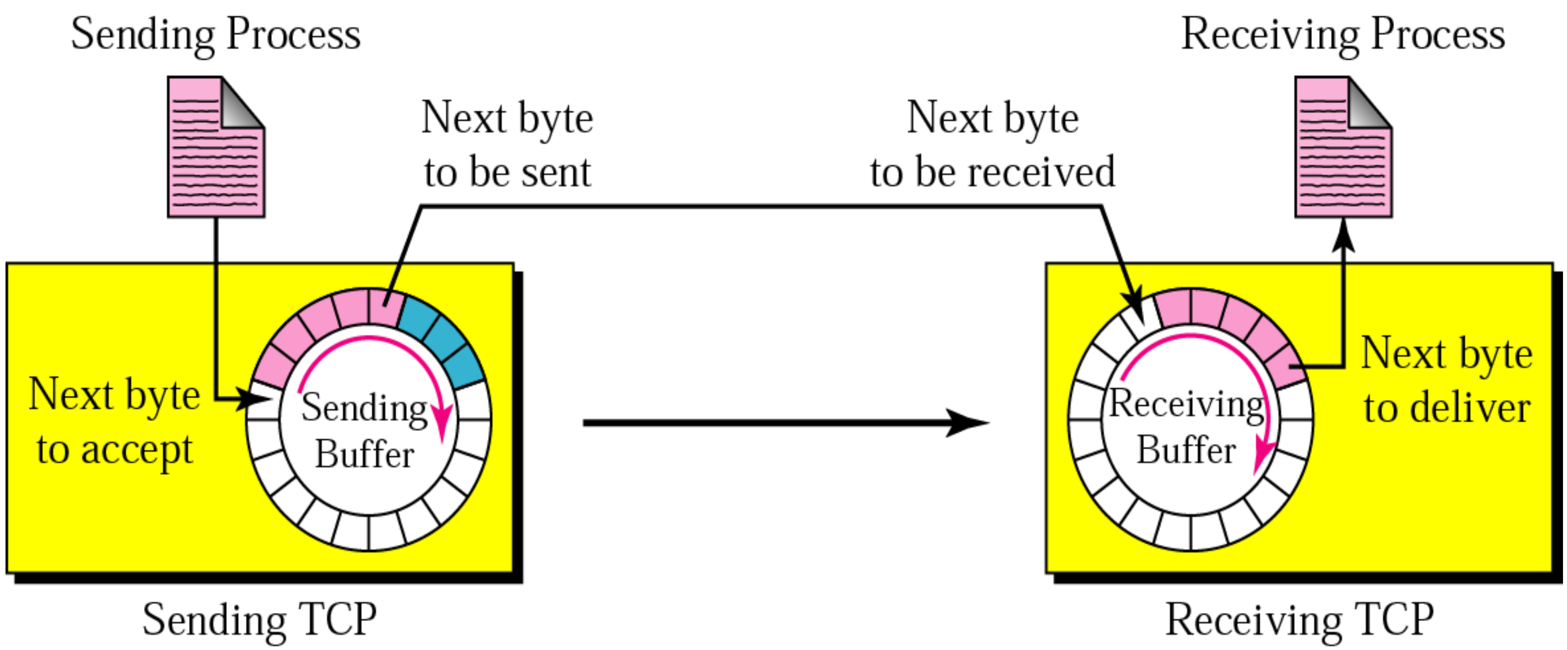
  - Most common, Retransmission time = 2* RTT
  - Acknowledgments can be “piggy-backed” on reverse direction data packets or sent as separate packets

Transmission Control Protocol 3/13

- Sequence Numbers
  - ➢Associated with every byte that it sends
  - ➢To detect packet loss, reordering and duplicate removal
  - ➢Two fields are used *sequence number* and *acknowledgment number*. Both refer to byte number and not segment number
  - ➢Sequence number for each segment is the number of the first byte carried in that segment
  - ➢The ACK number denotes the number of the next byte that this party expects to receive (cumulative)
    - ✓If an ACK number is 5643 → received all bytes from beginning up to 5642
    - ✓This acknowledges all previous bytes as received error-free

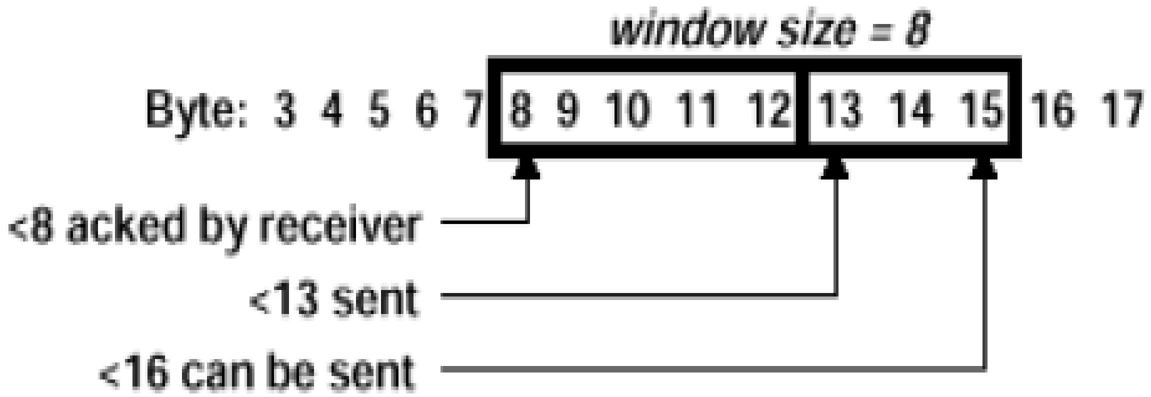
Transmission Control Protocol 4/13

- Sending and Receiving buffers
  - ➢Senders and receivers may not produce and consume data at same speed
  - ➢2 buffers for each direction (sending and receiving buffer)



Transmission Control Protocol 5/13

- TCP uses a sliding window mechanism for flow control
- Sender maintains 3 pointers for each connection
  - ➢Pointer to bytes sent and acknowledged
  - ➢Pointer to bytes sent, but not yet acknowledged
    - ✓*Sender window includes bytes sent but not acknowledged*
  - ➢Pointer to bytes that cannot yet be sent



Transmission Control Protocol 6/13

- Flow Control
  - Tell peer exactly how many bytes it is willing to accept (advertised window → sender can not overflow receiver buffer)
    - ✓ *Sender window includes bytes sent but not acknowledged*
    - ✓ *Receiver window (number of empty locations in receiver buffer)*
    - ✓ Receiver advertises window size in ACKs
  - Sender window <= receiver window (flow control)
    - ✓ Sliding sender window (without a change in receiver's advertised window)
    - ✓ Expanding sender window (receiving process consumes data faster than it receives → receiver window size increases)
    - ✓ Shrinking sender window (receiving process consumes data more slowly than it receives → receiver window size reduces)
    - ✓ Closing sender window (receiver advertises a window of zero)

Transmission Control Protocol 7/13

- Error Control
  - ➢Mechanisms for detecting corrupted segments, lost segments, out-of-order segments, and duplicated segments
  - ➢Tools: checksum (corruption), ACK, and time-out (one time-out counter per segment)
    - ✓*Lost segment or corrupted segment* are the same situation: segment will be retransmitted after time-out (no NACK in TCP)
    - ✓*Duplicate segment* (destination discards)
    - ✓*Out-of-order segment* (destination does not acknowledge, until it receives all segments that precede it)
    - ✓*Lost ACK* (loss of an ACK is irrelevant, since ACK mechanism is cumulative)

Transmission Control Protocol 8/13

- Congestion Control
  - ➢TCP assumes the cause of a lost segment is due to congestion in the network
  - ➢If the cause of the lost segment is congestion, retransmission of the segment does not remove the problem, it actually aggravates it
  - ➢The network needs to tell the sender to slow down (affects the sender window size in TCP)
  - ➢Actual window size = Min (receiver window size, congestion window size)
    - ✓The congestion window is flow control imposed by the sender
    - ✓The advertised window is flow control imposed by the receiver

Congestion Control 9/13

- Slow start

  - At start of connection, set congestion window size to maximum segment size

  - For each segment ACKed, increase congestion window size by 1 maximum segment size *until it reaches a threshold of one-half allowable window size*

  - Exponential increase in size

    - ✓Send 1 segment, receive 1 ACK, increase size to 2 segments

    - ✓Send 2 segments, receive 2 ACKs, increase size to 4 segments

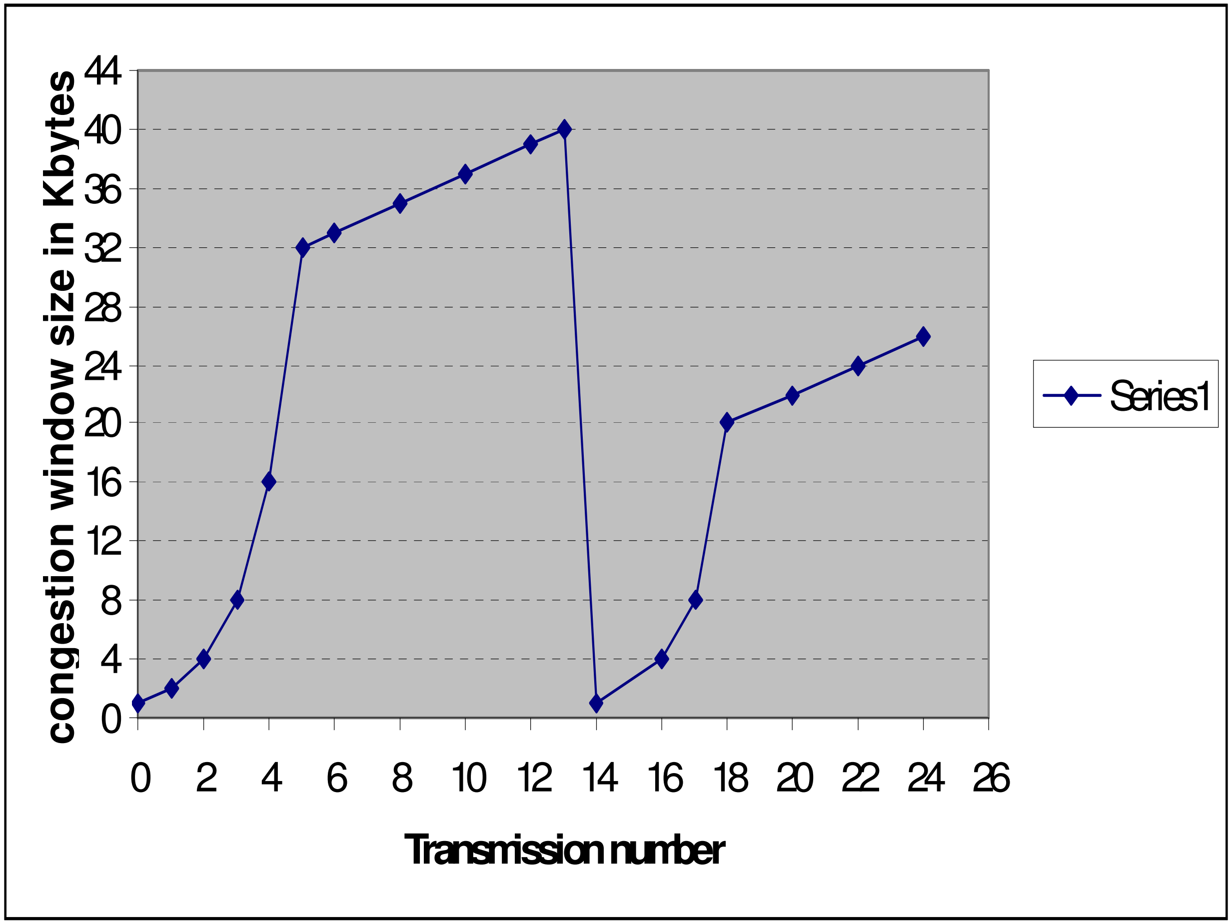
    - ✓Send 4 segments, receives 4 ACKs, increase size to 8 segments

Congestion Control 10/13

- Additive Increase (Congestion Avoidance phase)
  - After size reaches threshold, size is increased one segment for each ACK, even if ACK is for several segments (this continues as long as ACKs arrive before time-outs, or congestion window reaches the receiver window value)
- Multiplicative Decrease
  - If a time-out occurs, threshold set to one-half of last congestion window size, and congestion window size starts from 1 (return to slow start)
  - Threshold reduced to one-half current congestion window size every time a time-out occurs (exponential reduction)
  - Exponential growth stops when the threshold is hit
  - Afterwards, successful transmissions grow congestion window linearly
- Such congestion control often referred to as TCP Tahoe

Transmission Control Protocol 11/13

- Congestion Control



TCP Variants 12/13

- TCP Tahoe (first implemented in 4.3 BSD, 1988)
  - ➢Slow start + Congestion avoidance and fast retransmit
  - ➢Fast Retransmit
    - ✓Triggers the transmission of a dropped segment if three *dup ACKs* for a segment are received before the occurrence of the segment's timeout
    - ✓TCP required to immediately generate a dup ACK if an out-of-order segment is received (on receiving a dup ACK, cant tell if the reason is a reorder of segments or a lost segment, hence the wait to receive a number of dup ACKs)
    - ✓Fast Retransmit was incorrectly followed by slow start

Transmission Control Protocol 13/13

- Full-Duplex
  - ➢send and receive data in both directions.
  - ➢Keep sequence numbers and window sizes for each direction of data flow

TCP Connection Establishment

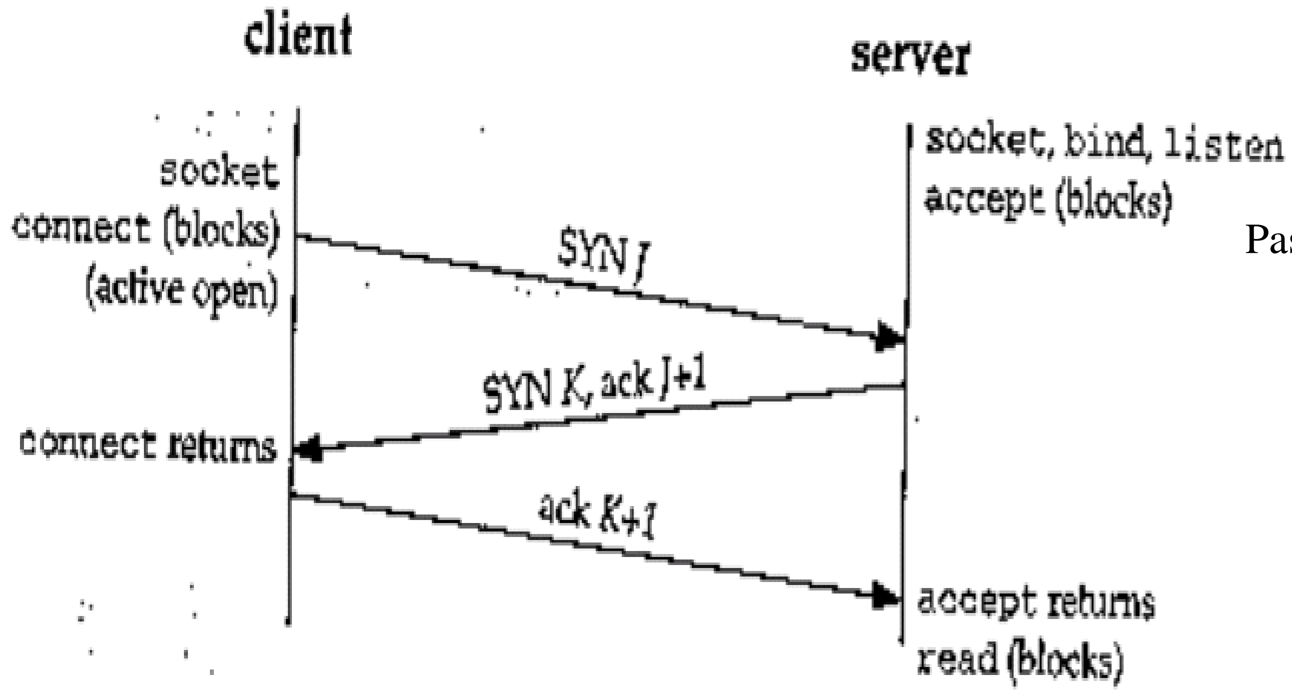


Figure 2.2 TCP three-way handshake.

Passive open

SYN: Synchronize

ACK: Acknowledge

TCP Options

Each SYN can contain TCP options

- MSS Option
  - ➢maximum segment → the maximum amount of data it is willing to accept in each TCP segment
  - ➢Sending TCP uses receiver's MSS as its MSS
- Window Scale Option
  - ➢maximum window is 65,535 bytes (corresponding field in TCP header occupies 16 bits)
  - ➢it can be scaled (left-shifted) by 0-14 bits providing a maximum of 65,535 * 2^{14} bytes (one gigabyte)
  - ➢Option needed for high-speed connections or long delay paths
  - ➢In this case, the other side must send the option with its SYN

TCP MSS and output

- TCP MSS is = (interface MTU – fixed sizes of IP and TCP headers (20 bytes))
  - MSS on an Ethernet (IPv4)= 1460 bytes (1500 (why?) - 40)
- Successful return from *write* implies you can reuse application buffer

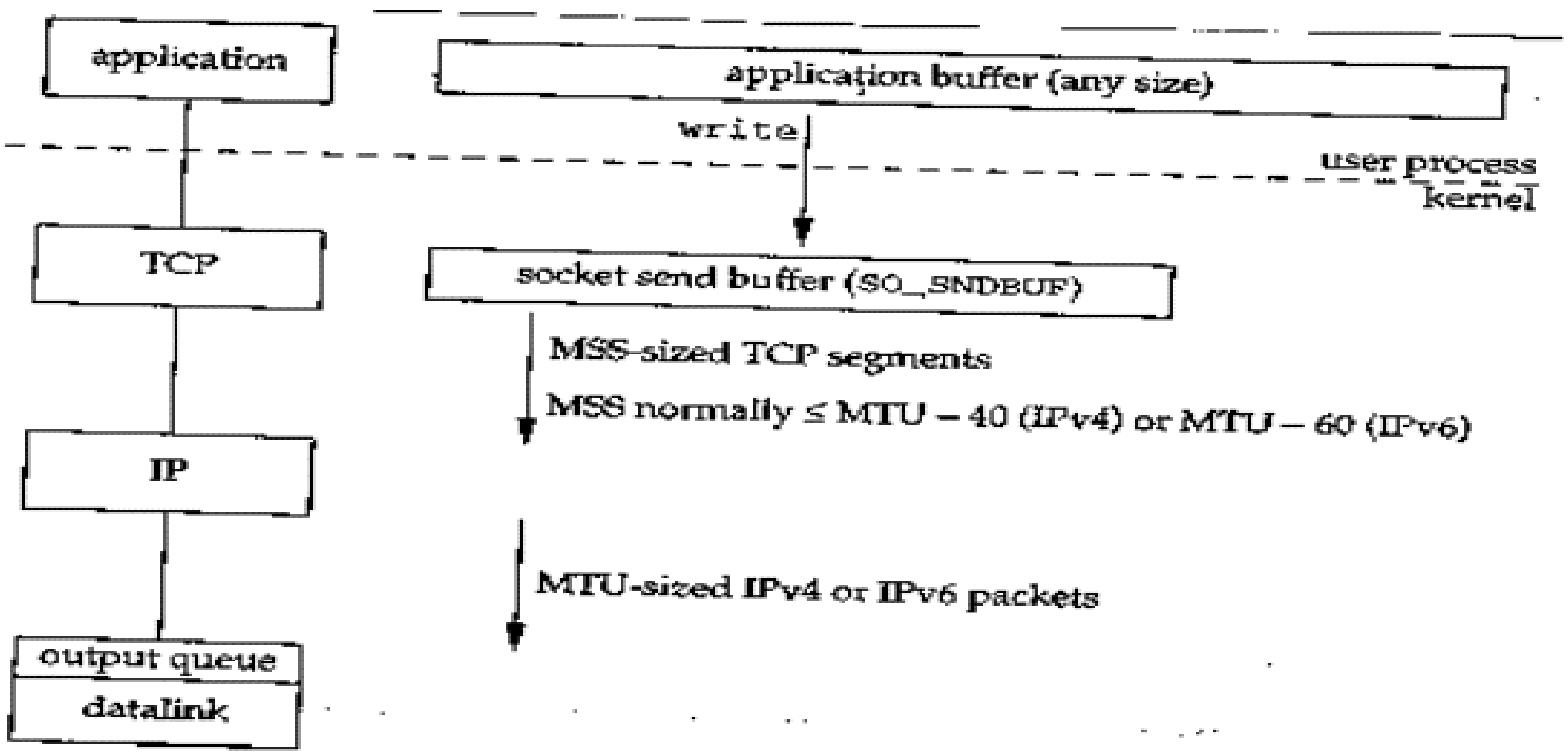


Figure 2.11 Steps and buffers involved when application writes to a TCP socket.

TCP Connection Termination

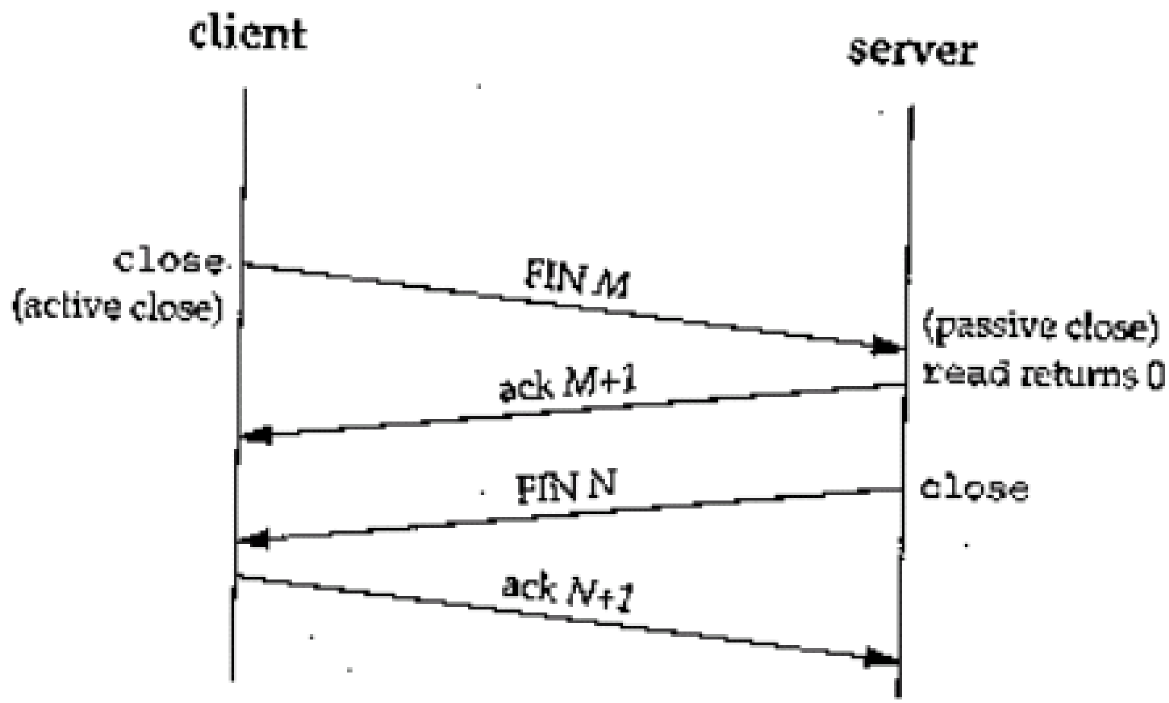
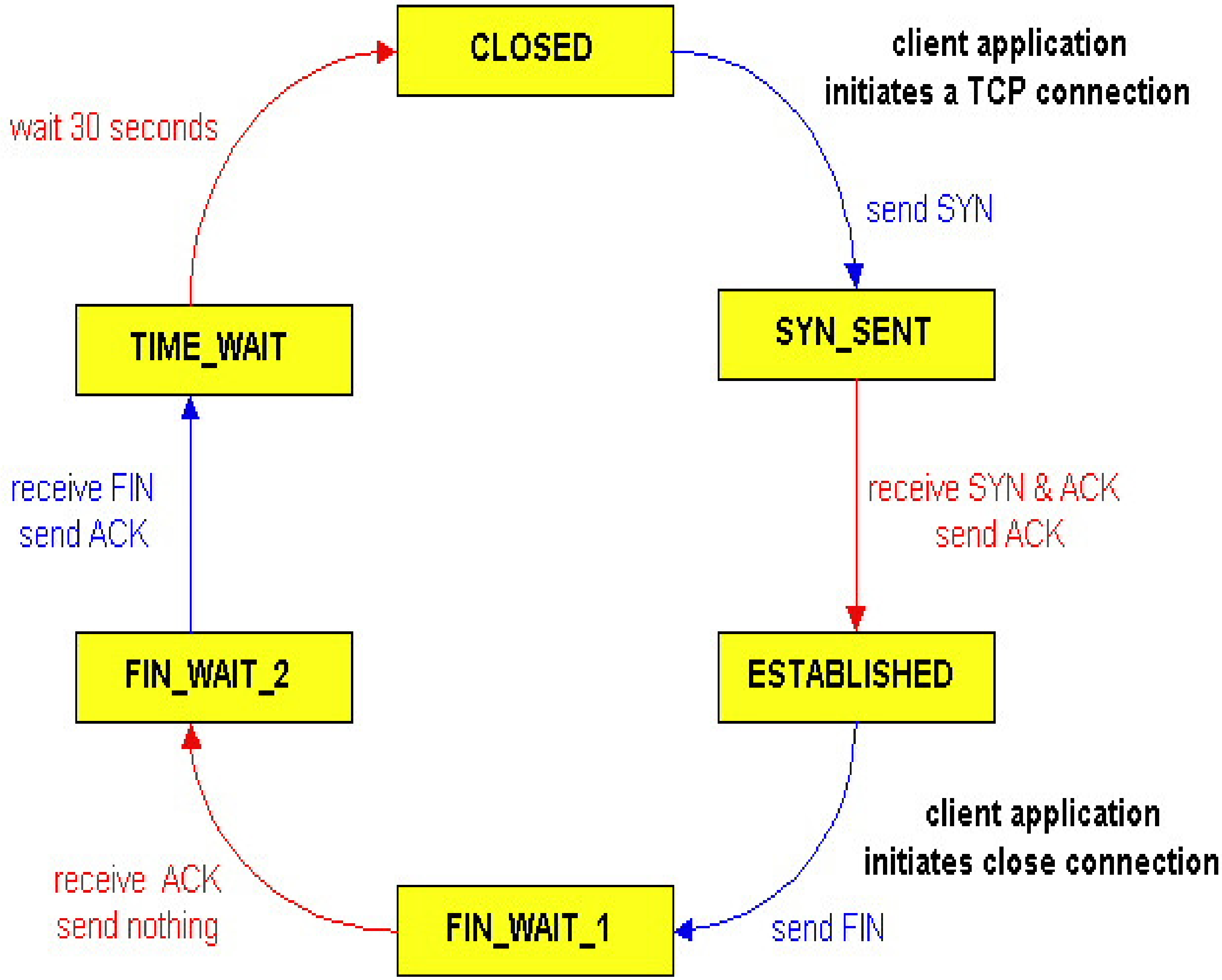


Figure 2.3 Packets exchanged when a TCP connection is closed.

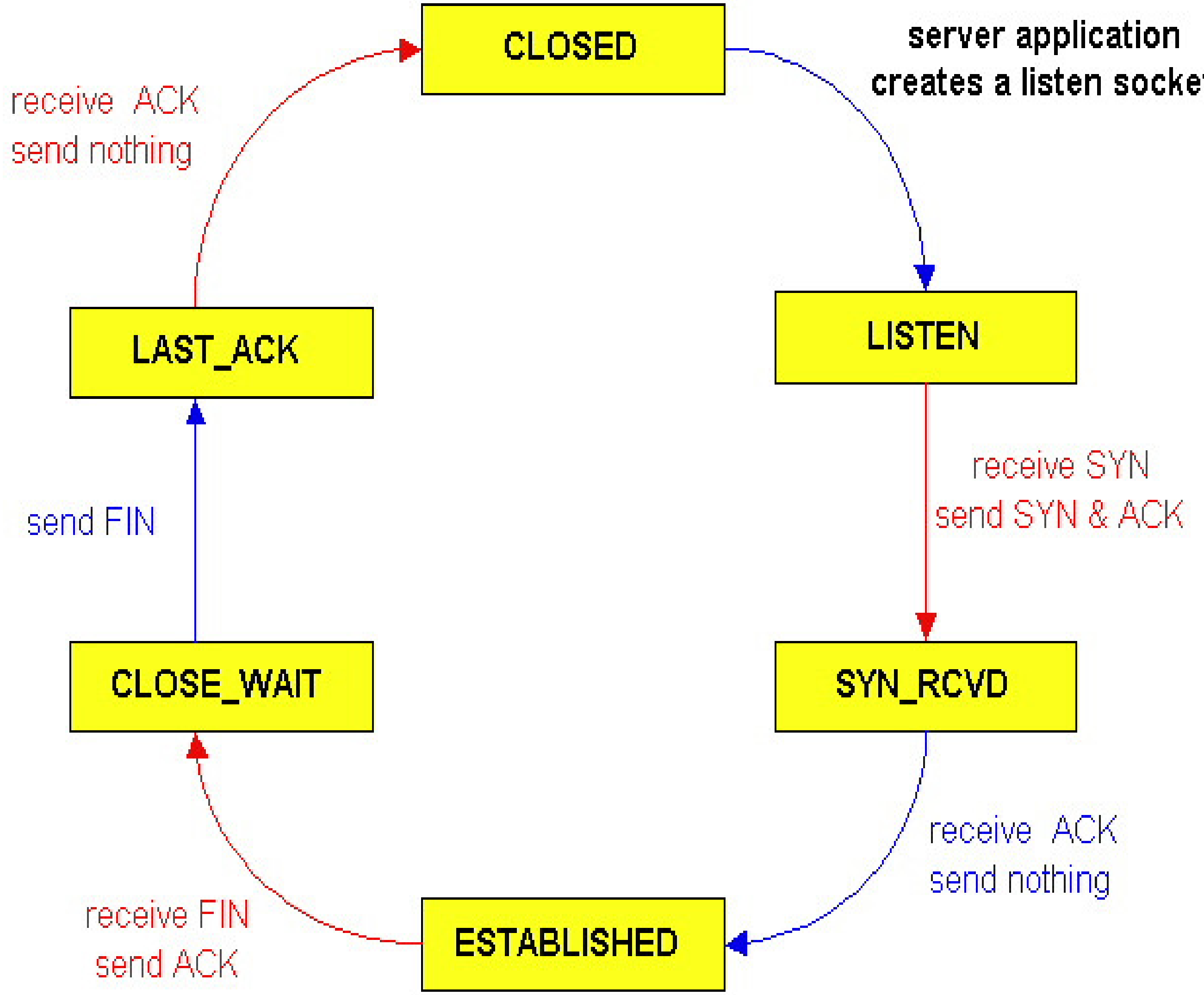
- FIN: Finish
- Step 1 can be sent with data
- Steps 2 and 3 can be combined into 1 segment

State Transition Diagram 1/4

Typical TCP states visited by a TCP client



State Transition Diagram 2/4



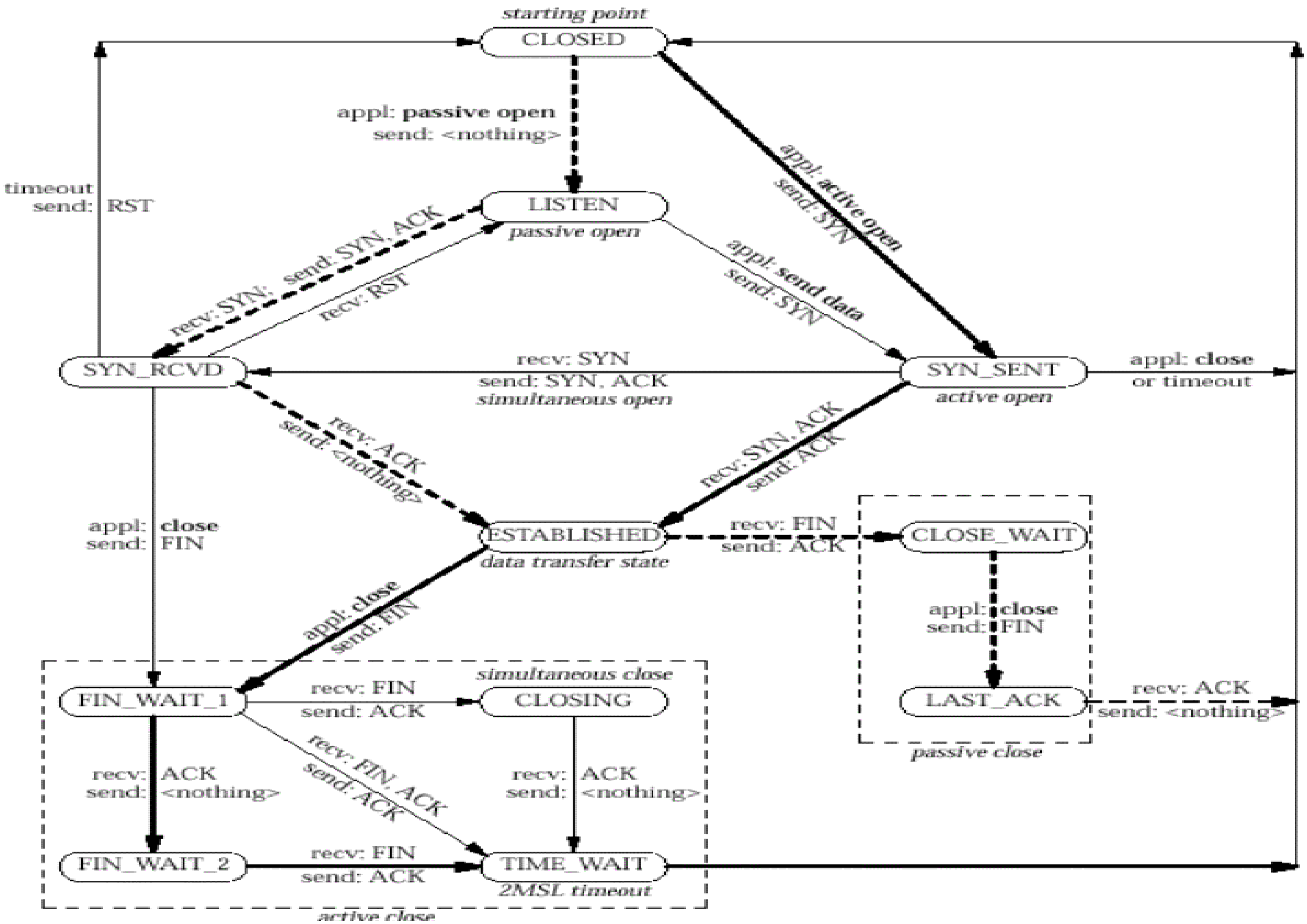
Typical TCP states visited by a TCP server

State Transition Diagram 3/4

State	Description
CLOSED	There is no connection.
LISTEN	The server is waiting for calls from the client.
SYN-SENT	A connection request is sent; waiting for acknowledgment.
SYN-RCVD	A connection request is received.
ESTABLISHED	Connection is established.
FIN-WAIT-1	The application has requested the closing of the connection.
FIN-WAIT-2	The other side has accepted the closing of the connection.
TIME-WAIT	Waiting for retransmitted segments to die.
CLOSE-WAIT	The server is waiting for the application to close.
LAST-ACK	The server is waiting for the last acknowledgment.

Can use *netstat* command to see some TCP states

State Transition Diagram 4/4



Packet Exchange

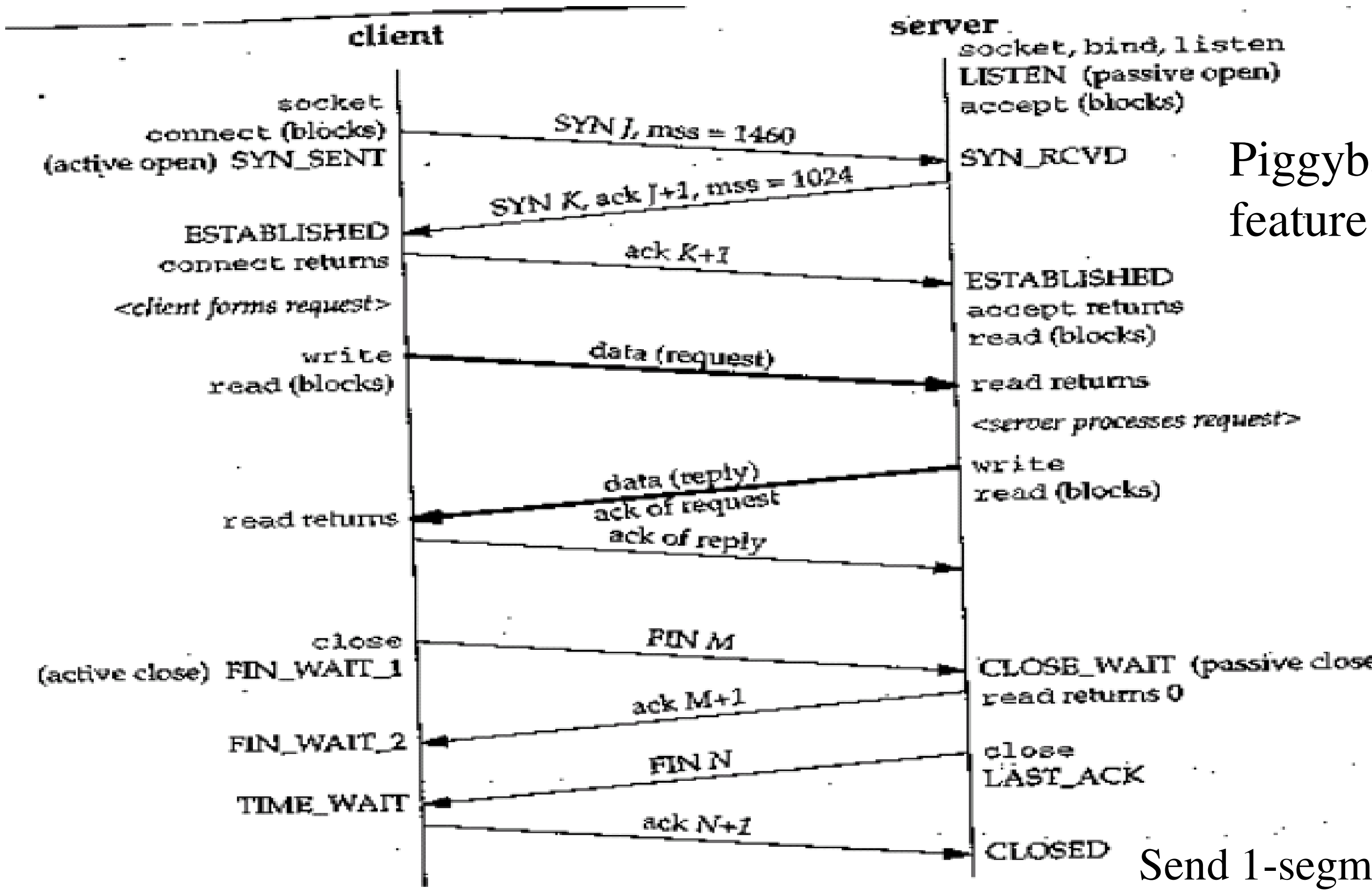


Figure 2.5 Packet exchange for TCP connection.

Piggybacking feature

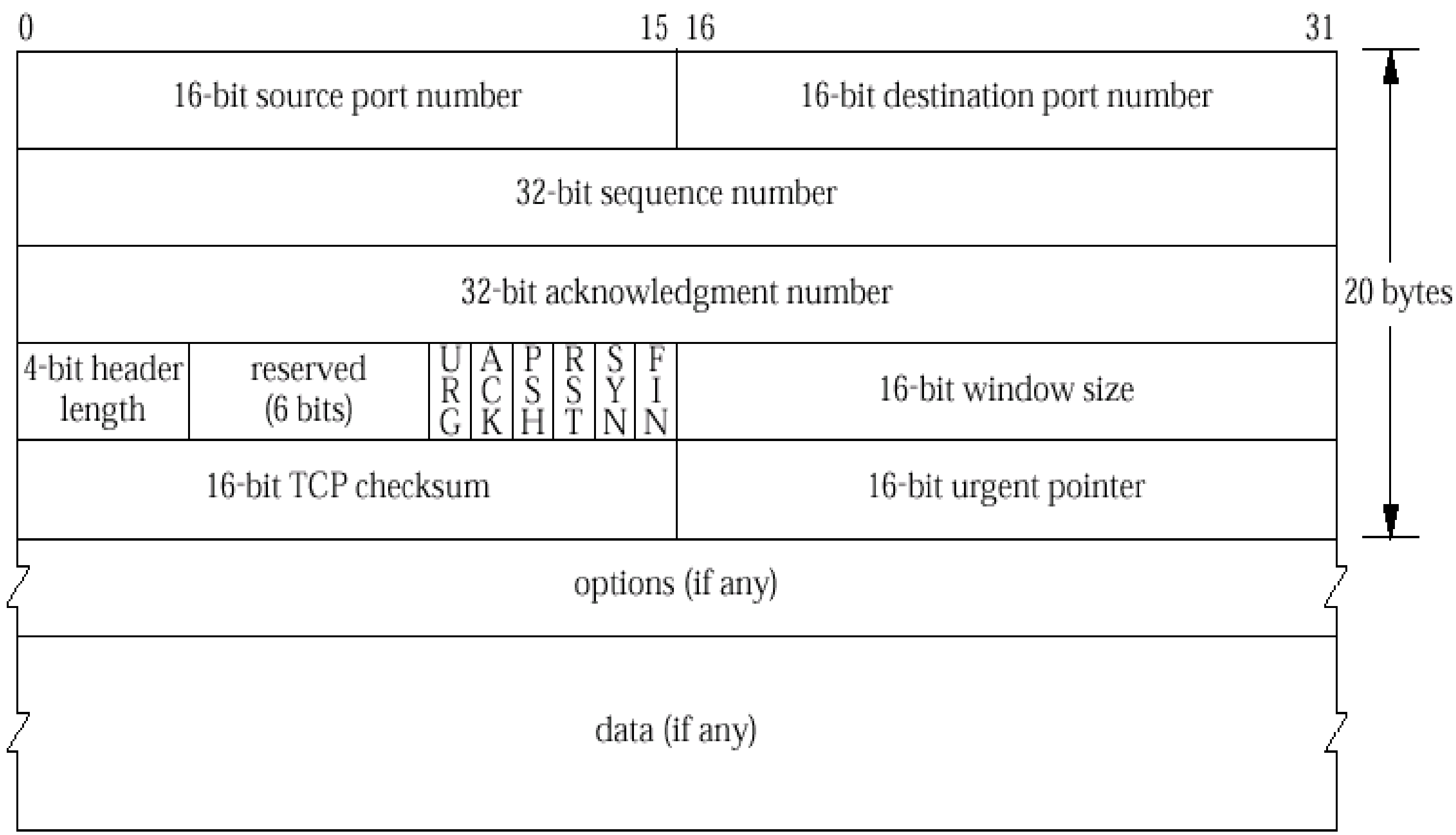
Send 1-segment request and receive 1-segment reply

TIME_WAIT State

- *The end that performs the active close goes through this state*
- Duration spent in this state is twice the *maximum segment life* (2 MSL)
  - MSL: maximum amount of time any given IP can live in the network
- Every TCP implementation must choose a value for MSL
  - Recommended value is 2 minutes (traditionally used 30 seconds)
- TIME_WAIT state motives
  - allow old duplicate segments to expire in the network (relate to *connection incarnation*)
    - ✓TCP will not initiate a new incarnation of a connection that is in TIME_WAIT state
  - Implement TCP's full-duplex connection termination reliably
    - ✓The end that performs the active close might have to resend the final ACK

TCP Segment Format

TCP Header



TCP Header Fields 1/2

- Source Port and Destination Port
  - Identify processes at ends of the connection
- Control bits
  - URG urgent (urgent data present)
  - ACK acknowledgment
  - PSH push request
    - ✓Inform receiver TCP to send data to application ASAP
  - RST reset the connection
  - SYN synchronize sequence numbers
  - FIN sender at end of byte stream

TCP Header Fields 2/2

- **Sequence Number**: position of the data in the sender's byte stream
- **Acknowledgment Number**: position of the byte that the source expects to receive next (valid if ACK bit set)
- **Header Length**: header size in 32-bit units. Value ranges from [5-15]
- **Window**: advertised window size in bytes
- **Urgent**
  - ✓defines end of urgent data (or "out-of-band") data and start of normal data
  - ✓Added to sequence number (valid only if URG bit is set)
- **Checksum**: 16-bit CRC (Cyclic Redundancy Check) over header and data
- **Options**: up to 40 bytes of options