# CS4254

# Computer Network Architecture and Programming

Dr. Ayman A. Abdel-Hamid

Computer Science Department

Virginia Tech

## Transmission Control Protocol (TCP)

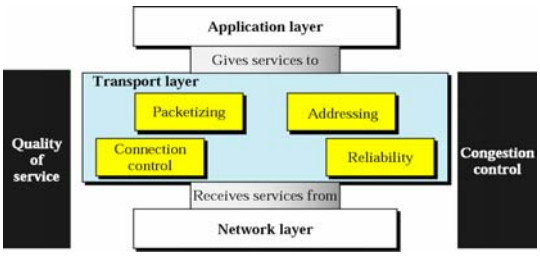


## Outline

- Transmission Control Protocol

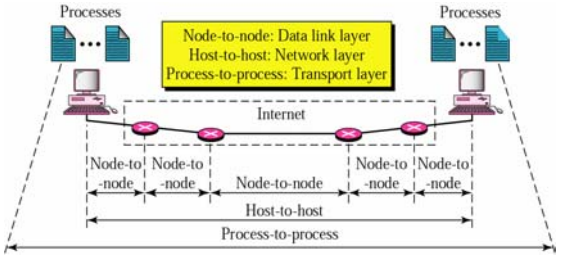


## Transport Layer 1/2






## Transport Layer 2/2



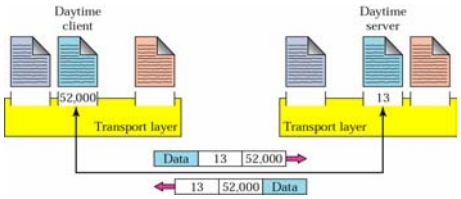

Process-to-process delivery



## 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



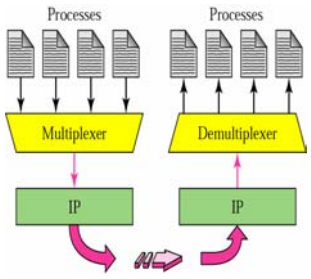
## Multiplexing and Demultiplexing

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 1/10

- 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 2/10

- 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 = $\alpha$ * old RTT + (1- $\alpha$)* new RTT where $\alpha$ usually 90%
  - Most common, Retransmission time = 2* RTT
  - Acknowledgments can be "piggy-backed" on reverse direction data packets or sent as separate packets



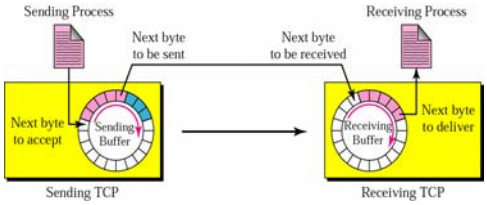
## Transmission Control Protocol 3/10

- 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



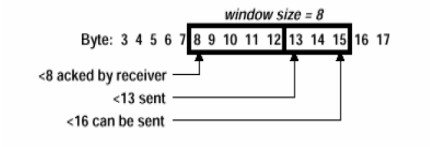
## Transmission Control Protocol 4/10

- 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 5/10

- 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 6/10

- 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 7/10

- 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)



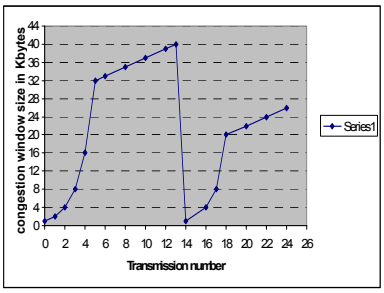
## Transmission Control Protocol 8/10

- 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



## Transmission Control Protocol 9/10

- Congestion Control






## Transmission Control Protocol 10/10

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

# TCP Connection Establishment

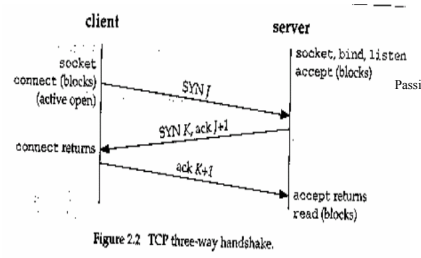


Figure 2.2 TCP three-way handshake.

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

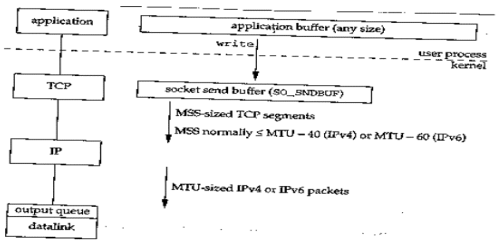


Figure 2.11 Steps and buffers involved when application writes to a TCP socket.



# TCP Connection Termination

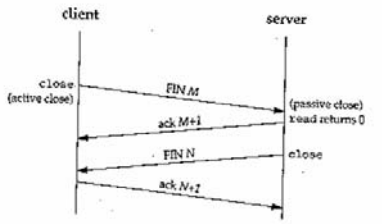


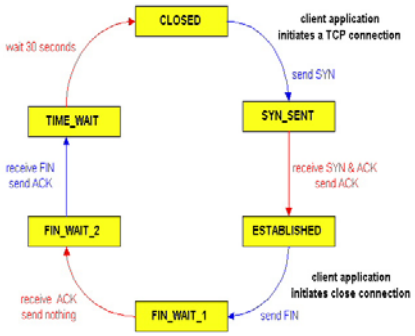
Figure 2.3 Packets exchanged when a TCP connection is closed.

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



# State Transition Diagram 1/4

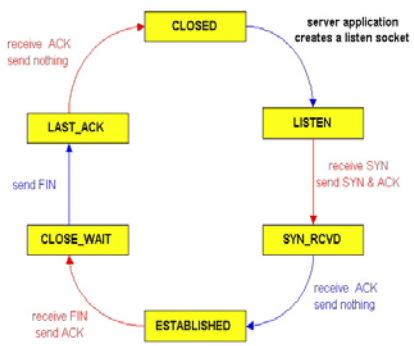
Typical TCP states visited by a TCP client






# State Transition Diagram 2/4

Typical TCP states visited by a TCP server



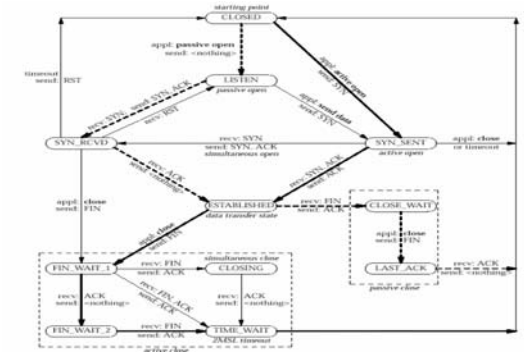
# State Transition Diagram 3/4

| 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

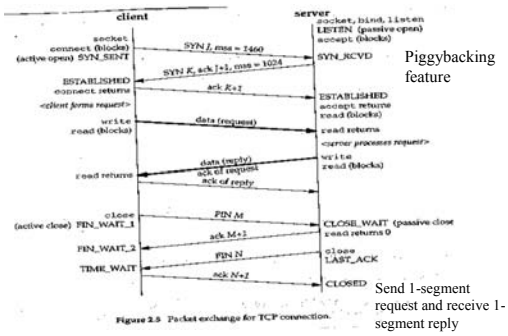



Figure 2.5 Packet exchange for TCP connection.

Piggybacking feature

Send 1-segment request and receive 1-segment reply

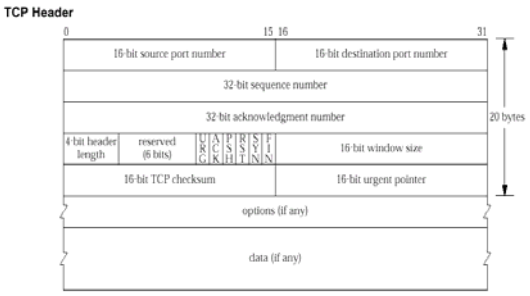


# TIME_WAIT State

- *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 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