Chapter 12

TCP

- TCP Services
- Segments and Options
- Flow Control and Error Control
- TCP Timers
- Connections
- State Transition Diagram
- Congestion Control
- TCP Operation and Design

Figure 12-1

Position of TCP in TCP/IP protocol suite

Application layer
SMTP FTP TFTP DNS SNMP ... BOOTP

Transport layer
TCP UDP

Network layer
IGMP ICMP IP

Data link layer
Underlying LAN or WAN technology

Physical layer

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Figure 12-2

TCP versus IP

Domain of IP protocol

Domain of TCP protocol

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Figure 12-3

Port numbers

TELNET (Client)

TELNET (Server)

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Figure 12-4

TCP segment format

Source port address
16 bits

Destination port address
16 bits

Sequence number
32 bits

Acknowledgment number
32 bits

Window size
16 bits

HLEN
4 bits

Reserved
6 bits

URG
1 bit

ACK
1 bit

PSH
1 bit

RST
1 bit

SYN
1 bit

FIN
1 bit

Checksum
16 bits

Urgent pointer
16 bits

Options & padding

Figure 12-5

Control field

URG: Urgent pointer is valid
ACK: Acknowledgment is valid
PSH: Request for push
RST: Reset the connection
SYN: Synchronize sequence numbers
FIN: Terminate the connection
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Figure 12-6

Options

- Single-byte
  - End of option
  - No operation
- Multiple-byte
  - Maximum segment size
  - Window scale factor
  - Timestamp

Figure 12-7

End of option

- Code: 0 00000000
  - a. End of option
  - b. Used for padding
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Figure 12-8

No operation option

- Code: 1
  00000001
  a. No operation option

  NO-OP
  An 11-byte option

  b. Used to align beginning of an option

  A 7-byte option
  NO-OP
  An 8-byte option

  c. Used to align the next option

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Figure 12-9

Maximum segment size option

- Code: 2
  00000010
  Length: 4
  00000100
  Maximum segment size

  1 byte 1 byte 2 bytes
Figure 12-10  
**Window scale factor option**

<table>
<thead>
<tr>
<th>Code: 3</th>
<th>Length: 3</th>
<th>Scale factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000011</td>
<td>00000011</td>
<td></td>
</tr>
</tbody>
</table>

1 byte 1 byte 1 byte

Figure 12-11  
**Timestamp option**

<table>
<thead>
<tr>
<th>Code: 8</th>
<th>Length: 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001000</td>
<td>00001010</td>
</tr>
</tbody>
</table>

Timestamp value

Timestamp echo reply
Figure 12-12

Pseudoheader added to the TCP segment

- 32-bit source IP address
- 32-bit destination IP address
- All 0s
- 8-bit protocol (6)
- 16-bit TCP total length
- Source port
- Destination port
- Sequence number
- Acknowledgment number
- HLEN
- Reserved
- Control
- Window size
- Checksum
- Urgent pointer

Data and Option
(Padding must be added to make the data a multiple of 16-bits)

Figure 12-13

Sliding window

a. Before sliding

b. After sliding
Figure 12-14  Sliding window with pointer

Sliding window

Acknowledged bytes

Bytes 4 to 7 have been sent
Bytes 8 to 13 can be sent
Bytes 14 to 16 cannot be sent

Figure 12-15  Increasing the window size

a. Window of size 7

b. 3 bytes acknowledged, window size increased to 10
Figure 12-16  Decreasing the window size

Sliding window

1 2 3 4 5 6 7 8 9 10 11 12 13 14

a. Window of size 7

Sliding window

1 2 3 4 5 6 7 8 9 10 11 12 13 14

b. 3 bytes acknowledged, window size decreased to 5

Figure 12-17  Window management

Sender
Segment 1
seq: 1001, 4000 bytes

Segment 2
seq: 5001, 1000 bytes

Receiver

ack: 5001  win:0

ack: 5001  win:1000

4000

Buffer

1000

3000

Buffer
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**Figure 12-18**

**Corrupted segment**

*Sender*

Segment 1
seq: 1201, 100 bytes

Segment 2
seq: 1401, 200 bytes

Segment 3
seq: 1601, 200 bytes

*Receiver*

Segment 3 corrupted

*Sender*

Segment 3, retransmitted
seq: 1601, 200 bytes

*Receiver*

Segment 3
seq: 1601, 200 bytes

ack: 1601

Time-out

*Sender*

Segment 3
seq: 1601, 200 bytes

*Receiver*

Segment 3
seq: 1601, 200 bytes

ack: 1601

**Figure 12-19**

**Lost segment**

*Sender*

Segment 1
seq: 1201, 100 bytes

Segment 2
seq: 1401, 200 bytes

Segment 3
seq: 1601, 200 bytes

*Receiver*

Segment 3 lost

*Sender*

Segment 3, retransmitted
seq: 1601, 200 bytes

*Receiver*

Segment 3
seq: 1601, 200 bytes

ack: 1601

Time-out

*Sender*

Segment 3
seq: 1601, 200 bytes

*Receiver*

Segment 3
seq: 1601, 200 bytes

ack: 1601
Lost acknowledgment

Sender

Receiver

Figure 12-20

Acknowledgment

lost

Figure 12-21

TCP Timers

Retransmission

Persistence

Keepalive

Time-waited
Three-Way Handshaking

Three-Way Handshaking:
- Segment 1: SYN
  seq: 1200, ack: ---
- Segment 2: SYN + ACK
  seq: 4800, ack: 1201
- Segment 3: ACK
  seq: 1201, ack: 4801

Four-way Handshaking

Four-way Handshaking:
- Segment 1: RST
  seq: 2500, ack: ---
- Segment 2: ACK
  seq: 7000, ack: 2501
- Segment 3: ACK
  seq: 7001, ack: 2501
- Segment 4: ACK
  seq: 2501, ack: 7002
Figure 12-24
State Transition Diagram

Figure 12-25
Window Size Increase Strategy

Transmission number

Congestion window size

Threshold

02 04 06 08 10 12 14 16 18 20 22 24 26

02 06 10 14 18 22 26

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Figure 12-26  
Encapsulation and Decapsulation

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Figure 12-27  
Queues in TCP

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**Figure 12-28**  
Multiplexing and demultiplexing

Application Programs  
TCP (Multiplexer)  
IP  
TCP (Demultiplexer)  
Application Programs

**Figure 12-29**  
TCP design

Application layer

Message from application

TCP segment  
TCP segment

Input processing module  
Main module  
Output processing module  
TCBs

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Figure 12-30  Transmission Control Blocks (TCBs)

<table>
<thead>
<tr>
<th>State</th>
<th>Process</th>
<th>Pointer</th>
<th>Buffers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

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