TCP Protocol and Its Attacks

Lecture 05

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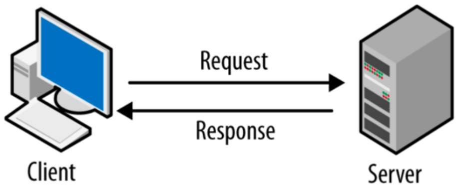
Introduction

- ***Transmission Control Protocol*** (***TCP***)
  - core protocol of Internet Protocol suite
  - sits on top of Internet Protocol (IP) layer
  - provides *reliable* and *ordered* communication channel between apps. (e.g., browser, email, etc) running on network computers
- *Transport layer*: TCP and UDP (User Datagram Protocol)
  - UDP ***does not*** provide *reliable* or *ordered* communication
    - lightweight, low overhead, and ***good*** for applications that do not require *reliability* or *order*
  - TCP provides host-to-host communication services for applications
    - requires both ends to maintain a *connection* (logical)
    - ***no security mechanism*** was built into it when developed
      - eavesdropping, injection, hijacking, disconnection attacks

How TCP Protocol Works

- TCP is quite complicated, with a lot of details
  - cover enough details to understand its *security aspects*
- A pair of simple TCP programs, *client* and *server*, is used to *illustrate how TCP works*



- TCP client program:
  - sending a simple hello message to the server
- TCP server program:
  - use an existing utility to serve as the server
  - command:

    $ nc –nv -l 9090

    - start a TCP server
    - wait on port 9090
    - display whatever is sent from the client

How TCP Protocol Works: Client Program

- TCP client program:

Create a socket
Specify the type of communication
- TCP uses SOCK_STREAM
- UDP uses SOCK_DGRAM

Server info: IP addr. and Port #

Initiate the TCP connection
- connection-oriented protocol
- 3-way handshake
- uniquely identified: src. IP, src. port #, des. IP, des. port #

Do Not Forget to Close the Connection!

Send data

bonus functions for retrieving data:
read(); recv(); recvfrom(); recvmsg()

```
// Step 1: Create a socket
int sockfd = socket(AF_INET, SOCK_STREAM, 0);

// Step 2: Set the destination information
struct sockaddr_in dest;
memset(&dest, 0, sizeof(struct sockaddr_in));
dest.sin_family = AF_INET;
dest.sin_addr.s_addr = inet_addr("10.0.2.17");
dest.sin_port = htons(9090);

// Step 3: Connect to the server
connect(sockfd, (struct sockaddr *)&dest,
        sizeof(struct sockaddr_in));

// Step 4: Send data to the server
char *buffer1 = "Hello Server!\n";
char *buffer2 = "Hello Again!\n";
write(sockfd, buffer1, strlen(buffer1));

write(sockfd, buffer2, strlen(buffer2));
```

write(); send(); sendto(); sendmsg()

How TCP Protocol Works: Server Program

- TCP server program:

Create a socket (same as the client prog.)

```
// Step 1: Create a socket
sockfd = socket(AF_INET, SOCK_STREAM, 0);

// Step 2: Bind to a port number
memset(&my_addr, 0, sizeof(struct sockaddr_in));
my_addr.sin_family = AF_INET;
my_addr.sin_port = htons(9090);
bind(sockfd, (struct sockaddr *)&my_addr, sizeof(struct
  sockaddr_in));
```

Bind to a port #

- an app. that connects with others needs to register a port # on the host computer
- when packets arrive, the OS knows which app. is the intended receiver
- *bind()*
- the server uses port 9090

- Popular servers use specific port #s which are well known
  - e.g., web server: 80 and 443
    SSH server: 22
- Client also needs to register a port #
  - no need to use specific port #
  - do not call bind() to register
    - leave it to OS who will assign

How TCP Protocol Works: Server Program

- TCP server program:

Listen for connections

```
// Step 3: Listen for connections
listen(sockfd, 5);
```

The limit of the queue (how many pending connections can be stored in the queue)

- if full, further connection requests will be dropped

- Once the socket is set up, the server call *listen()* to wait for connections
  - telling OS the app. is ready for receiving connection requests
- Once a connection request is received, the OS will go through TCP 3-way handshake protocol with the client to establish a connection
  - an established connection is placed in the queue, waiting for app. to take over the connection

How TCP Protocol Works: Server Program

- TCP server program:

Accept a connection request

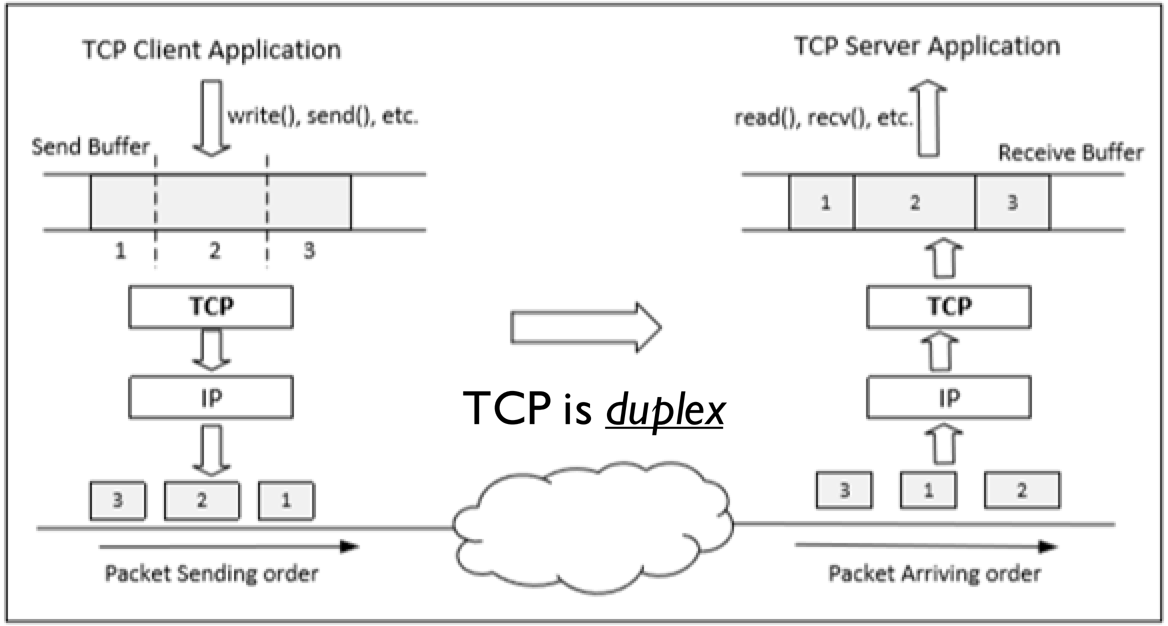
```
// Step 4: Accept a connection request
int client_len = sizeof(client_addr);
newsockfd = accept(sockfd, (struct sockaddr *)&client_addr,
  &client_len);
```

- the app. needs to specifically "accept" the connection before accessing it
  - *accept()*
    - extract the *first* connection request from the *queue*
    - ***create a new socket***
    - ***return a new file descriptor to that socket***
- the socket created before (at the beginning of the program) is only used for listening
  - not associated with any connection
  - a new socket is created when a connection is accepted
  - the app. access the connection via the new socket
  - send and receive data

Data Transmission: Under the Surface

- How TCP data are transmitted

- Once a connection is established, OS allocates *two buffers* for each end,
  - *one for sending data* (send buffer)
  - *one for receiving buffer* (receive buffer)
- When an application needs to send data out, it places data into the TCP *send buffer*.
  - the TCP code in OS decides when to send data
  - TCP usually waits until the data are enough for one packet



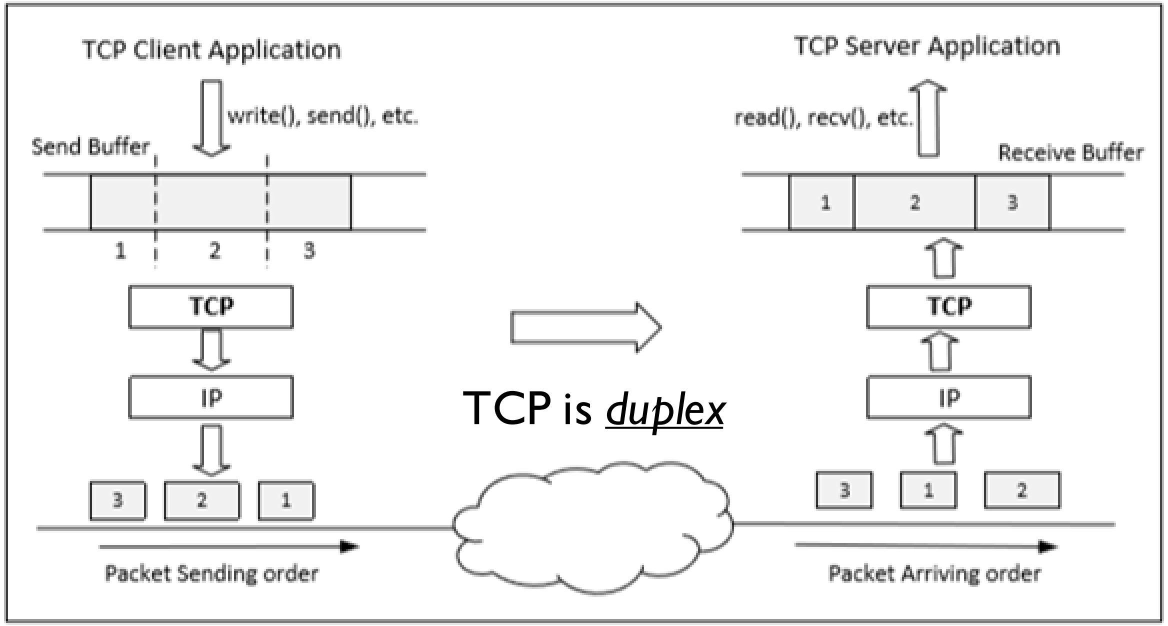
- Each ***byte*** in *send buffer* has a ***seq. #*** associated with it
  - stored in the TCP header (***seq. # field***)
- Client use the seq. # to place data in right position inside the receive buffer

Data Transmission: Under the Surface

- How TCP data are transmitted

- Once data are placed in the receive buffer, they are merged into a single data stream
  - regardless of whether they come from the same packet or different ones

- When the receive buffer gets enough data, TCP will make data available to the app.

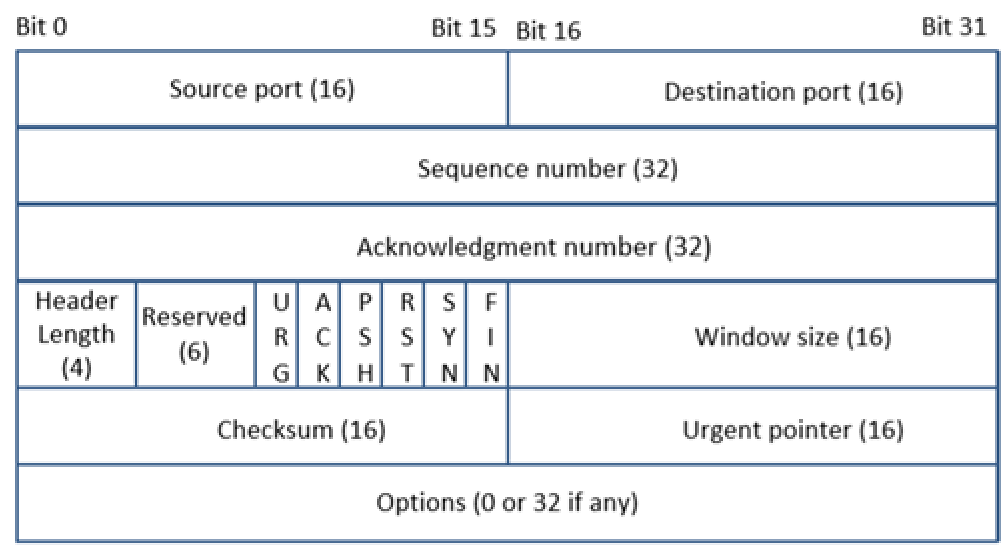


- The receiver must inform the sender that data have been received
  - send out ***acknowledgement packets (ack packets)***
  - for *performance reason*, does not acknowledge each packet that is has received
    - it tell the sender the ***next seq. #*** that it ***expects to receive*** from the sender

TCP Header (cont.)

- The TCP part of an IP packet is called TCP *segment*, which starts with a ***TCP header***, followed by a ***payload***.

The format of TCP header



- Source and Destination port (16 bits each): Specify port numbers of the sender and the receiver.
- Sequence number (32 bits): Specifies the sequence number of the ***first byte*** in the TCP segment. If SYN bit is set, it is the initial sequence number.
- Acknowledgement number (32 bits): Contains the value of the ***next sequence number expected*** by the sender of this segment. Valid only if ACK bit is set.

TCP Header (cont.)

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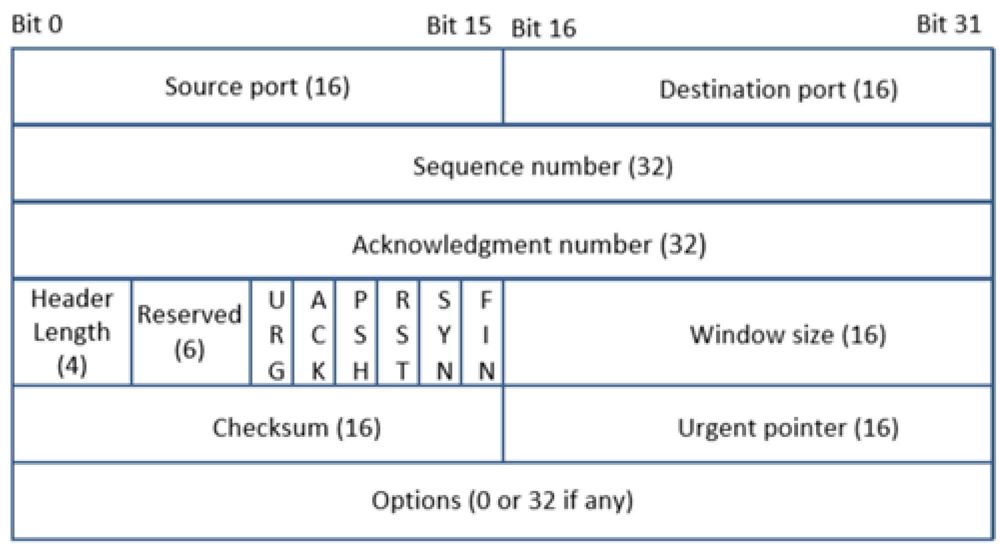


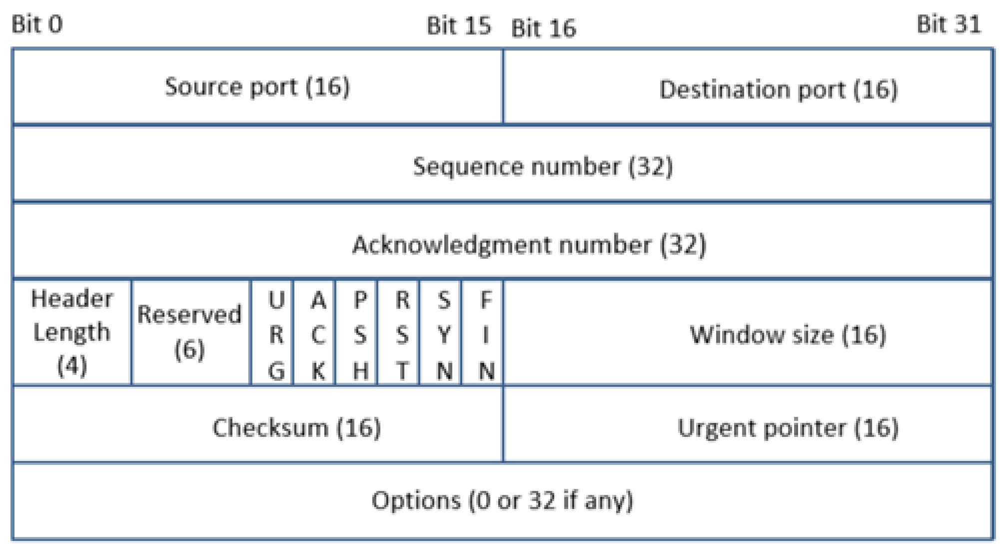
- Header length (4 bits): Length of TCP header is measured by the number of 32-bit words in the header, so we multiply by 4 to get number of bytes in the header.
- Reserved (6 bits): This field is ***<u>not used</u>***.
- Code bits (6 bits): There are six code bits, including SYN,FIN,ACK,RST,PSH and URG.
- Window (16 bits): Window advertisement to specify *<u>the number of bytes</u>* that the sender of this TCP segment is *<u>willing to accept</u>*. The purpose of this field is for flow control.

TCP Header (cont.)

- The TCP part of an IP packet is called TCP *segment*, which starts with a ***<u>TCP header</u>***, followed by a ***<u>payload</u>***.

- Checksum (16 bits): The checksum is calculated using part of IP header, TCP header and TCP data.
- Urgent Pointer (16 bits): If the URG code bit is set, the first part of the data contains urgent data (do not consume sequence numbers).
  - The urgent pointer specifies where the urgent data ends and the normal TCP data starts.
  - Urgent data is for priority purposes as they do not wait in line in the receive buffer and will be delivered to the applications immediately.

The format of TCP header

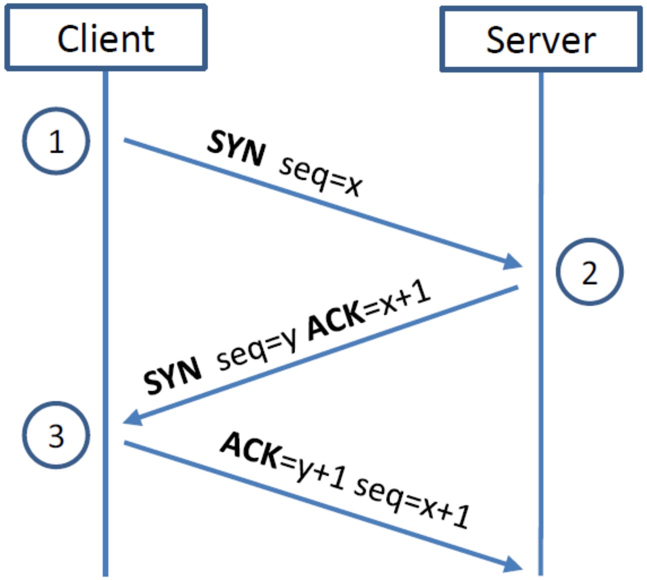


- Options (0-320 bits): TCP segments can carry a variable length of options which provide a way to deal with the limitations of the original header.

TCP 3-Way Handshake Protocol

- In TCP protocol, client and server need to establish a TCP connection *before* taking to each other
  - server needs to make itself ready for such connection by entering LISTEN state (invoking *listen()*)
  - client needs to initiate the connection via ***3-way handshake***

1. ***SYN Packet***: The client sends a special packet called ***SYN packet*** to the server using a *randomly generated number x* as its sequence number.
2. ***SYN-ACK Packet***: On receiving it, the server sends a reply packet (***SYN-ACK packet***) using its own *randomly generated number y* as its sequence number.
3. ***ACK Packet***: Client sends out ***ACK packet*** to conclude the handshake



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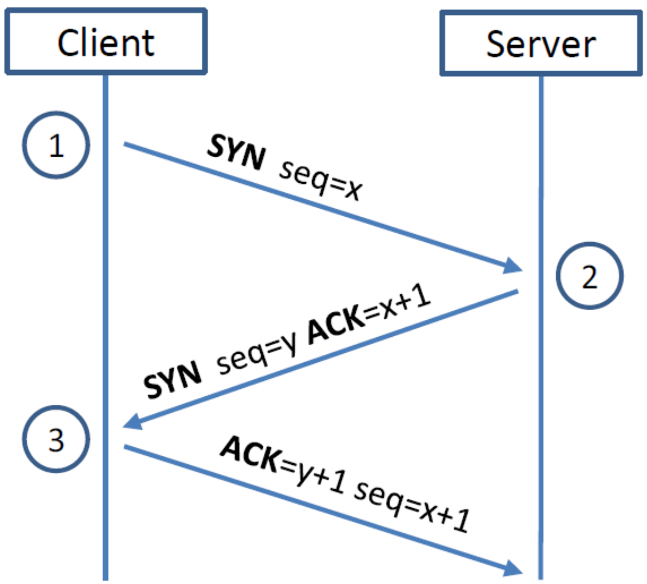
- When the server receives the initial SYN packet, it uses TCB (Transmission Control Block) to store the information about the connection.
  - At this step, the connection is not fully established yet.
    - called half-open connection as only client-to-server connection is confirmed.
  - The server stores the TCB in a queue and take it out of the queue after receiving ACK packet from the client.



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- If ACK doesn't arrive, the server will resend SYN+ACK packet.
- The TCB will eventually be discarded after a certain time period or if ACK packet never comes