TCP/IP Overview

Helpful References

- Forouzan, Data Communications and Networking, 5ed

- http://tcpipguide.com/free/t_toc.htm

- https://www.geeksforgeeks.org/services-and-segment-structure-in-tcp/

Network Review

- When it comes to designing, implementing, debugging, and testing networking software, we must be aware of

    - Network layers

    - Network headers

    - Network protocol flow

Network Layer Review

- Physical Layer:

  - Responsible for physical links between adjacent devices

  - Determines how to represent data in electromagnetic form

- Data Link Layer:

  - Responsible for getting data from one device to a neighbouring device in the current network

  - Breaks up data into individual frames

  - Handles error detection and correction as required

- Ethernet encompasses physical and data link layers

Network Layer Review

- Network Layer:

  - Responsible for determining network routes

  - Gets a packet from a source network to a destination network

  - IP

- Transport Layer:

  - Deals with sender and receiver issues: (De)multiplexing, packet ordering, flow control, etc.

  - TCP (reliable but slower), UDP (unreliable but faster)

IPv4 Header Review

Version	Header Length	DSCP	ECN	Header + Data Length	ID	Flags	Offset	TTL	Proto	Header Check sum	Src IP	Dst IP	Opts

- Differentiated Services Code Point (DSCP) can be used to describe the payload (e.g., Voice over IP), allowing the router to make smarter choices

- Explicit Congestion Notification (ECN) can be used to alert the destination of impending congestion, which can then alert the source

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IPv4 Header Review

Version	Header Length	DSCP	ECN	Header + Data Length	ID	Flags	Offset	TTL	Proto	Header Check sum	Src IP	Dst IP	Opts

- ID + Flags + Offset used to enable/identify fragments

- Time To Live (TTL); usu. a per-router hop count; at 0, packet is discarded and an *ICMP Time Exceeded* error is transmitted to the sender
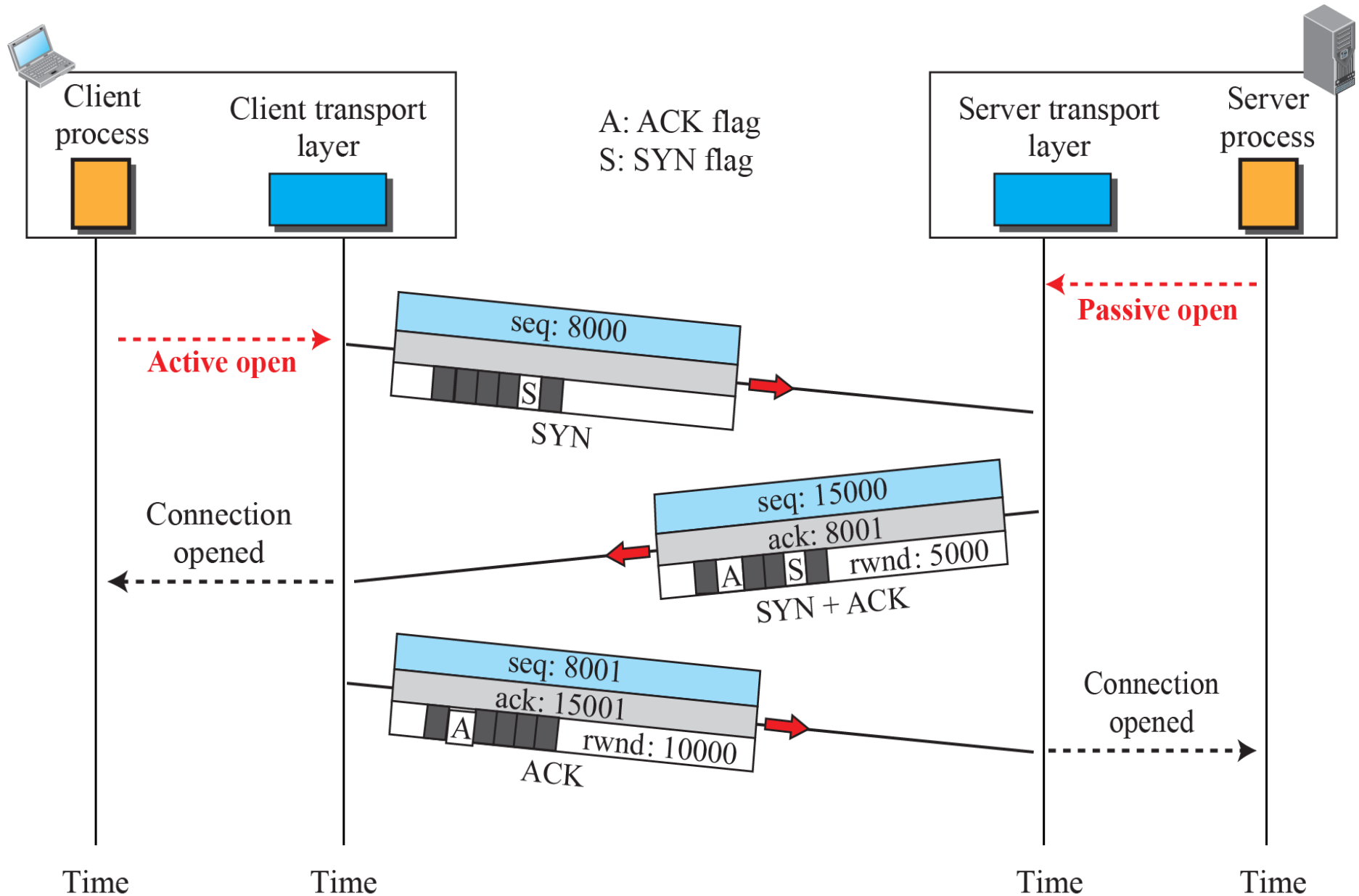
- Proto identifies the payload type

TCP Header Review

Src Port	Dst Port	Sequence Number	Ack. Number	Header Length	0	Flags	Window Size	Chksum	Urgent Pointer	Opts

- Urgent Pointer points to the location of the urgent data in the payload section (if URG flag set)

UDP Header Review

Source Port	Destination Port	Header + Data Length	Checksum (Optional if used with IPv4)

TCP Connection (3-way Handshake) Review

A: ACK flag
S: SYN flag

Client process

Client transport layer

Server transport layer

Server process

Active open

Passive open

seq: 8000

S

SYN

Connection opened

seq: 15000
ack: 8001

A S rwnd: 5000

SYN + ACK

seq: 8001
ack: 15001

A rwnd: 10000

ACK

Connection opened

Time   Time   Time   Time

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Connection Establishment Notes

- ACK = Acknowledgement

- rwnd = Receive window (used for flow control)

- SYN = Synchronize sequence numbers

- SYN and SYN/ACK segments do not carry data

- An ACK **without** data does not consume a sequence number

- Full duplex requires two receive windows

Sequence Numbers

- Initial number is random (Wireshark obscures this by default to make analysis easier)

- Subsequent numbers depend on number of bytes transmitted

  - e.g., assume first number is 10001

  - If 1000 bytes are transmitted, the sequence number range will be 10001 to 11000
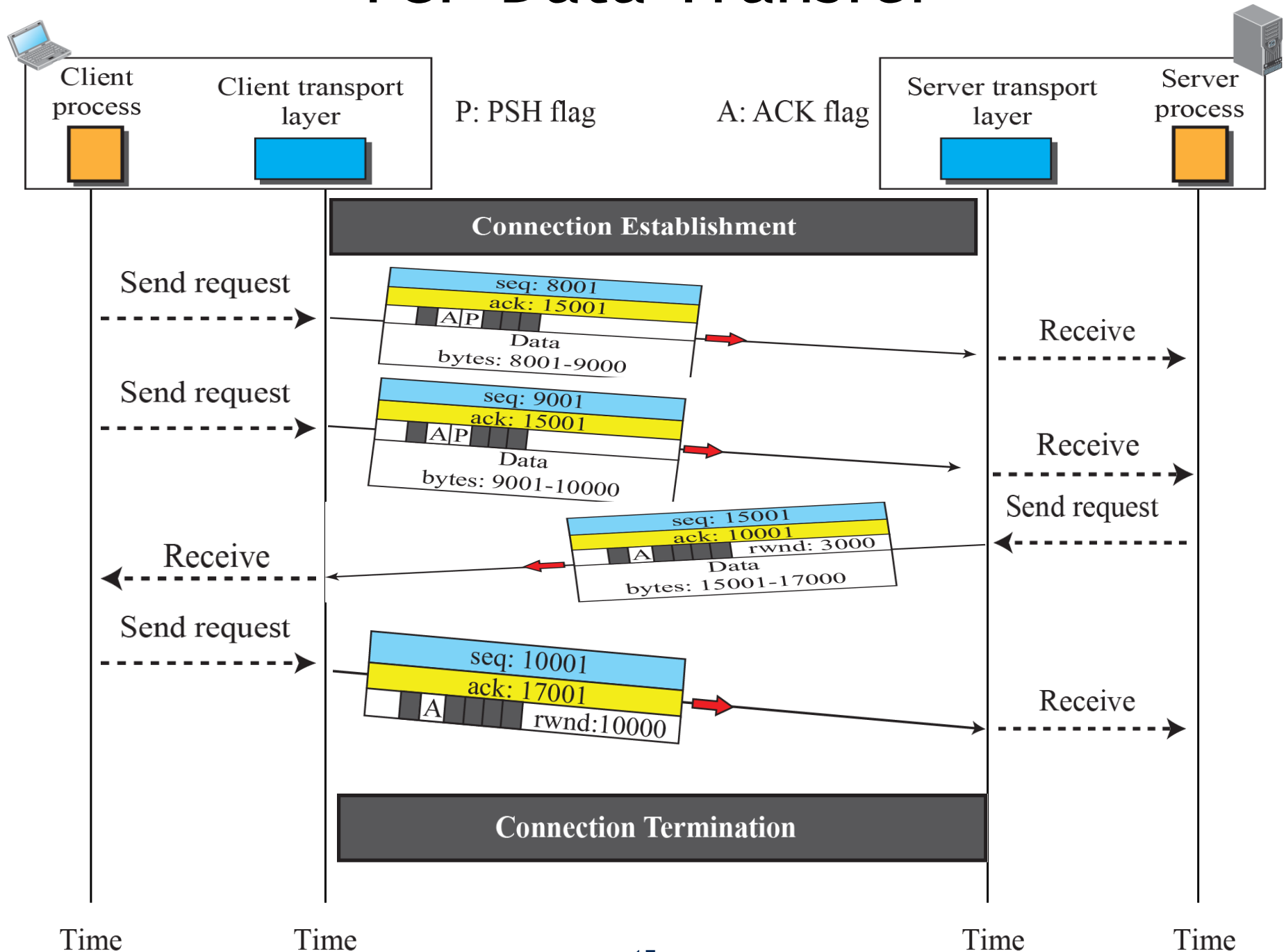
  - The next segment would start at 11001

Exercises

- A TCP connection is established using a _____

Exercises

- During TCP connection establishment, if the server receives a packet with the SYN flag set and a sequence number set to 18573, it must reply with the _____ flag(s) set and the sequence number set to _____ and the acknowledgement number set to _____

TCP Data Transfer

Client process

Client transport layer

P: PSH flag

A: ACK flag

Server transport layer

Server process

Connection Establishment

Send request

seq: 8001
ack: 15001
A P
Data
bytes: 8001-9000

Receive

Send request

seq: 9001
ack: 15001
A P
Data
bytes: 9001-10000

Receive

Send request

Receive

seq: 15001
ack: 10001
A   rwnd: 3000
Data
bytes: 15001-17000

Send request

seq: 10001
ack: 17001
A
rwnd:10000

Receive

Connection Termination

Time   Time   Time   Time

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Data Transfer Notes

- The sequence number is referring to the first byte in the segment

- Note the window size update and the ACK number

- The push flag indicates to the destination that buffered data should be made available to the application right away, rather than delay for more data to accumulate

- Can emphasize urgency even more by setting the URG flag; points to urgent data in the data stream and causes a signal to be sent to the listening application

Exercises

- If the TCP segment sequence number is 58293 and 100 bytes are sent, the acknowledgement number must be _____
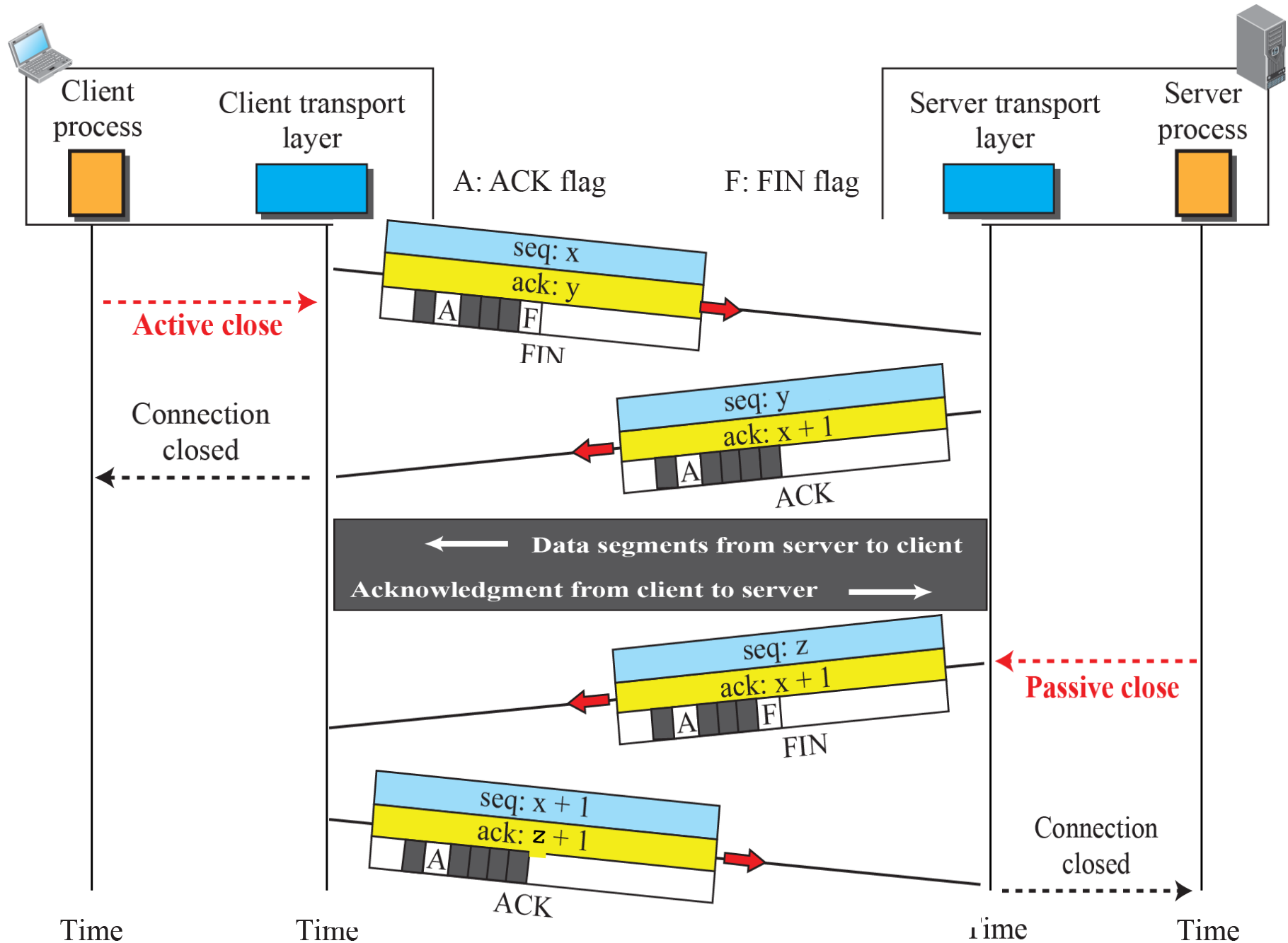
TCP Connection Termination
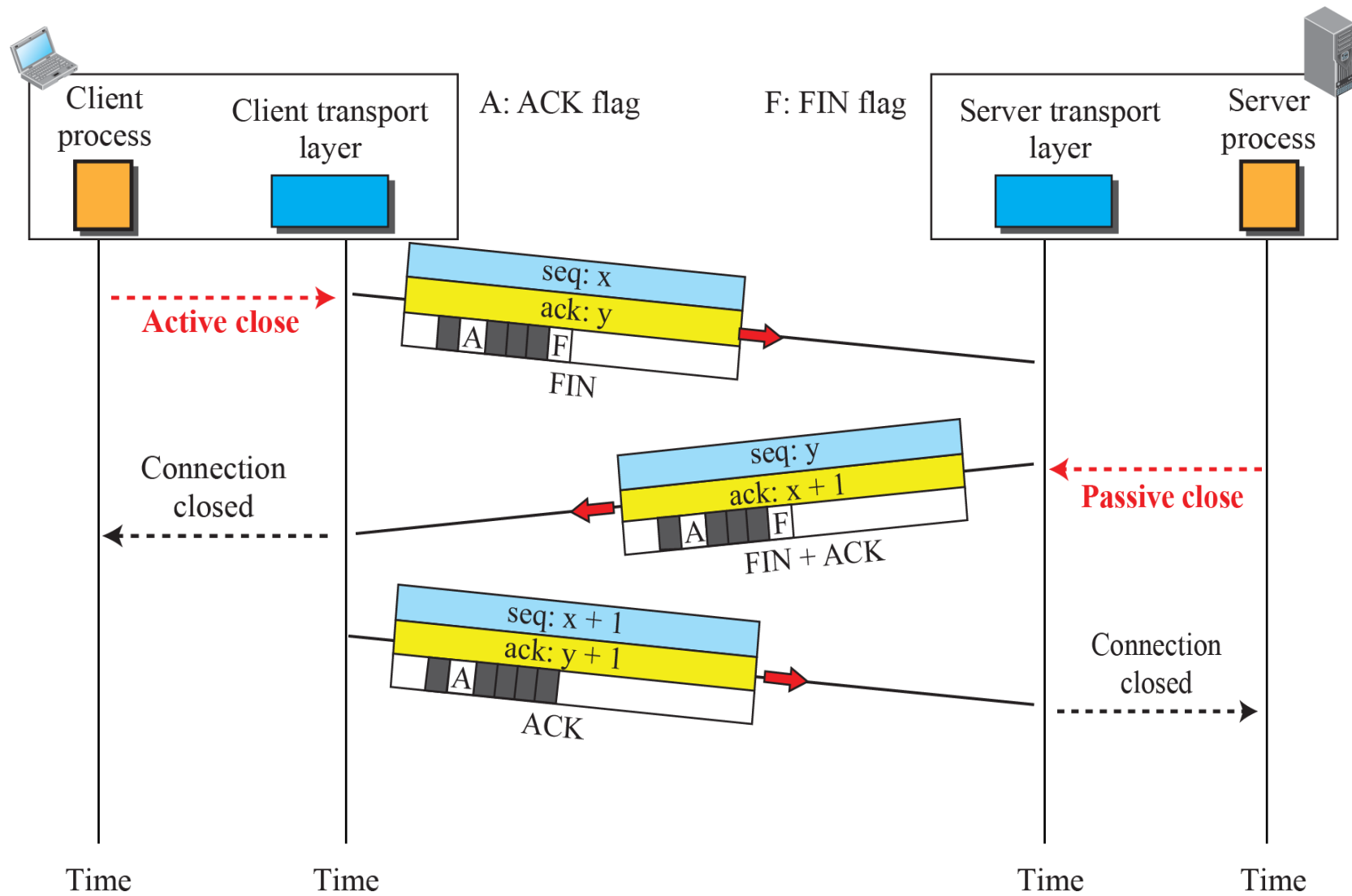
Connection Termination Notes

- FIN/FIN+ACK consumes 1 sequence number even if it contains no data

- Last ACK contains no data

- But what if more data must be sent? (e.g., a database query takes time to retrieve?)

TCP Half Close

Client process | Client transport layer

A: ACK flag

F: FIN flag

Server transport layer | Server process

Active close

seq: x
ack: y

A | F

FIN

Connection closed

seq: y
ack: x + 1

A

ACK

◄─── **Data segments from server to client**

Acknowledgment from client to server ───►

seq: z
ack: x + 1

A | F

FIN

Passive close

seq: x + 1
ack: z + 1

A

ACK

Connection closed

Time | Time | Time | Time

Two Army Problem

- Assume the final ACK gets lost

- How do we know that the left hand side won't wait forever for a FIN?

- Problem: Do we ACK the ACK?
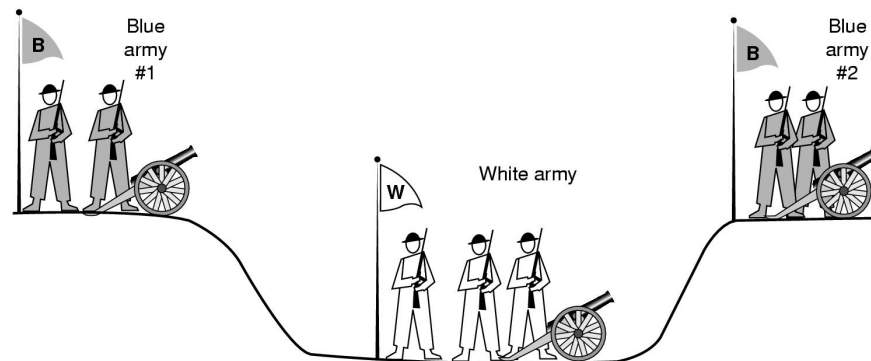
Source: Andy Tanenbaum, Computer Networks, 4th ed., Prentice-Hall

Two Army Problem

- TCP "solution" to this problem uses timeouts

- Usually works in practice

TCP Error Control

- To handle lost or damaged segments, timers are set by both sides to determine whether or not to retransmit data or ACKs

- Rule 1: When there is data to be sent, the sender must include an ACK, with the acknowledgement number set to the next sequence number it expects to receive from the receiver

- Rule 2: When the recipient has received a valid segment from the sender, and the recipient has no data to send in return, it must set a timeout after which an ACK must be returned to the sender, with the acknowledgement number set to the next expected sequence number

- Rule 3: When a second unacknowledged segment arrives, the recipient must return an ACK to the sender, with the acknowledgement number set to the next expected sequence number
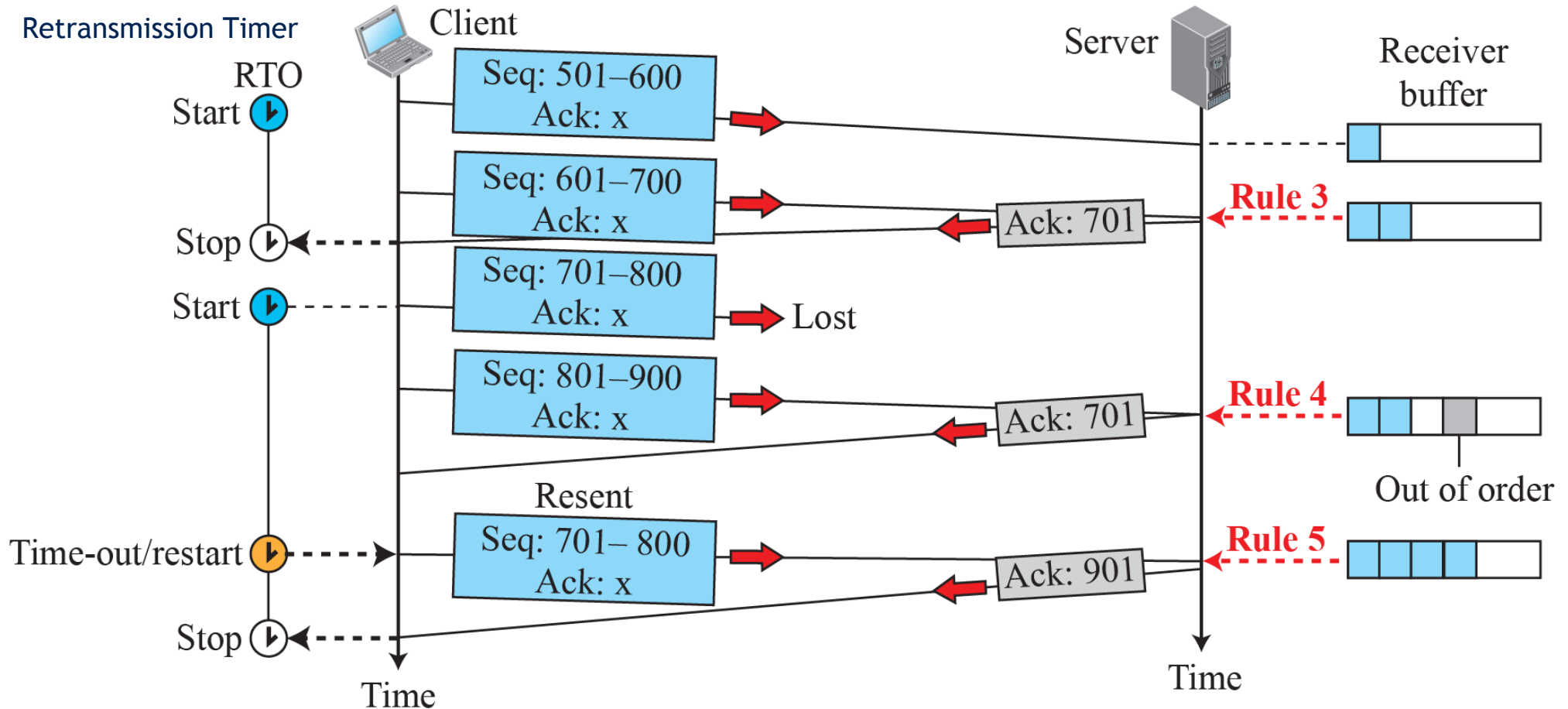
TCP Error Control

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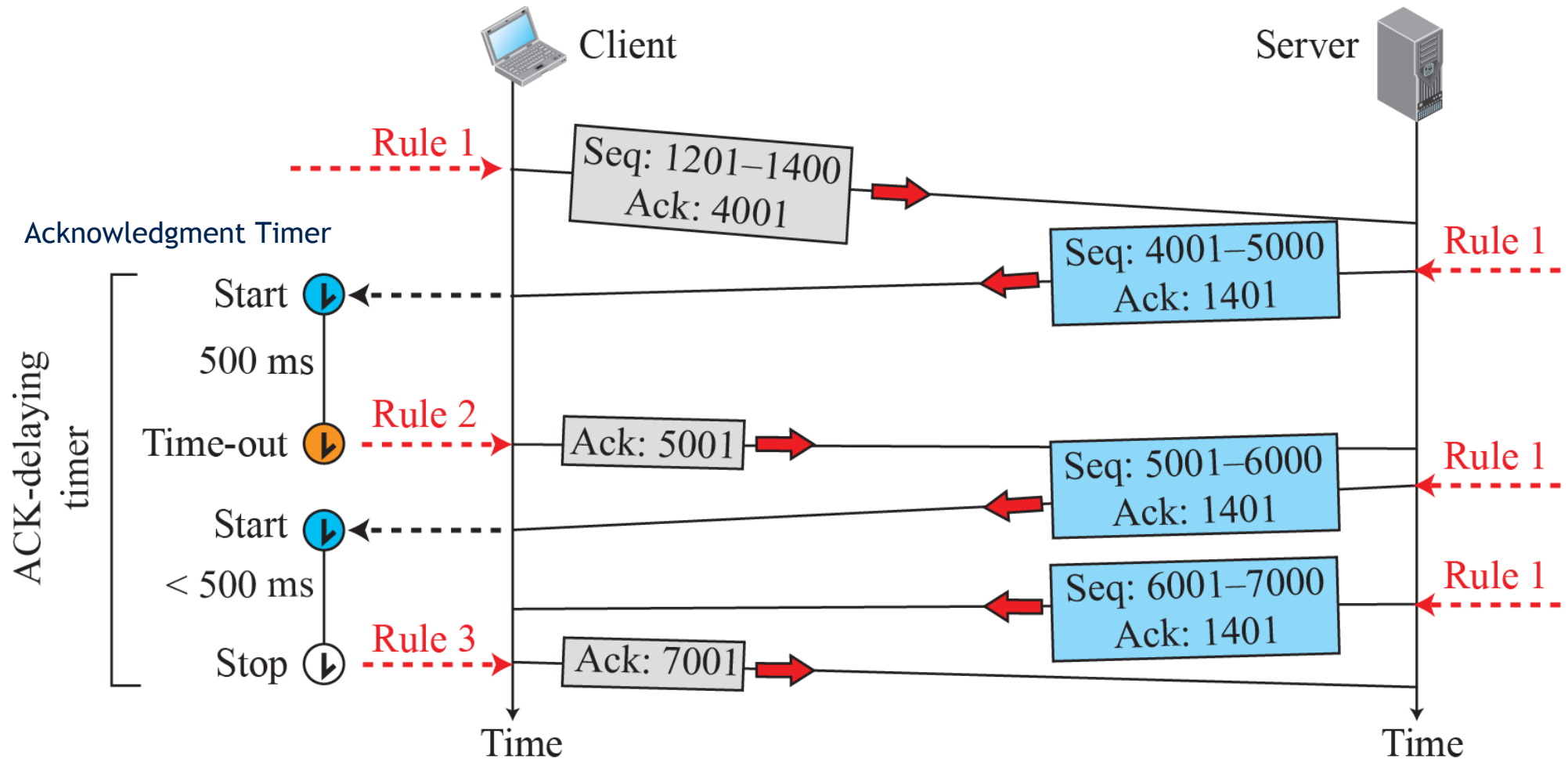
TCP Error Control

- Rule 4: When an out-of-order sequence number arrives, the segment is buffered and an ACK is returned to the sender, with the acknowledgement number set to the next expected sequence number

- Rule 5: When a missing segment arrives, the recipient returns an ACK to the sender, with the acknowledgement number set to the next expected sequence number
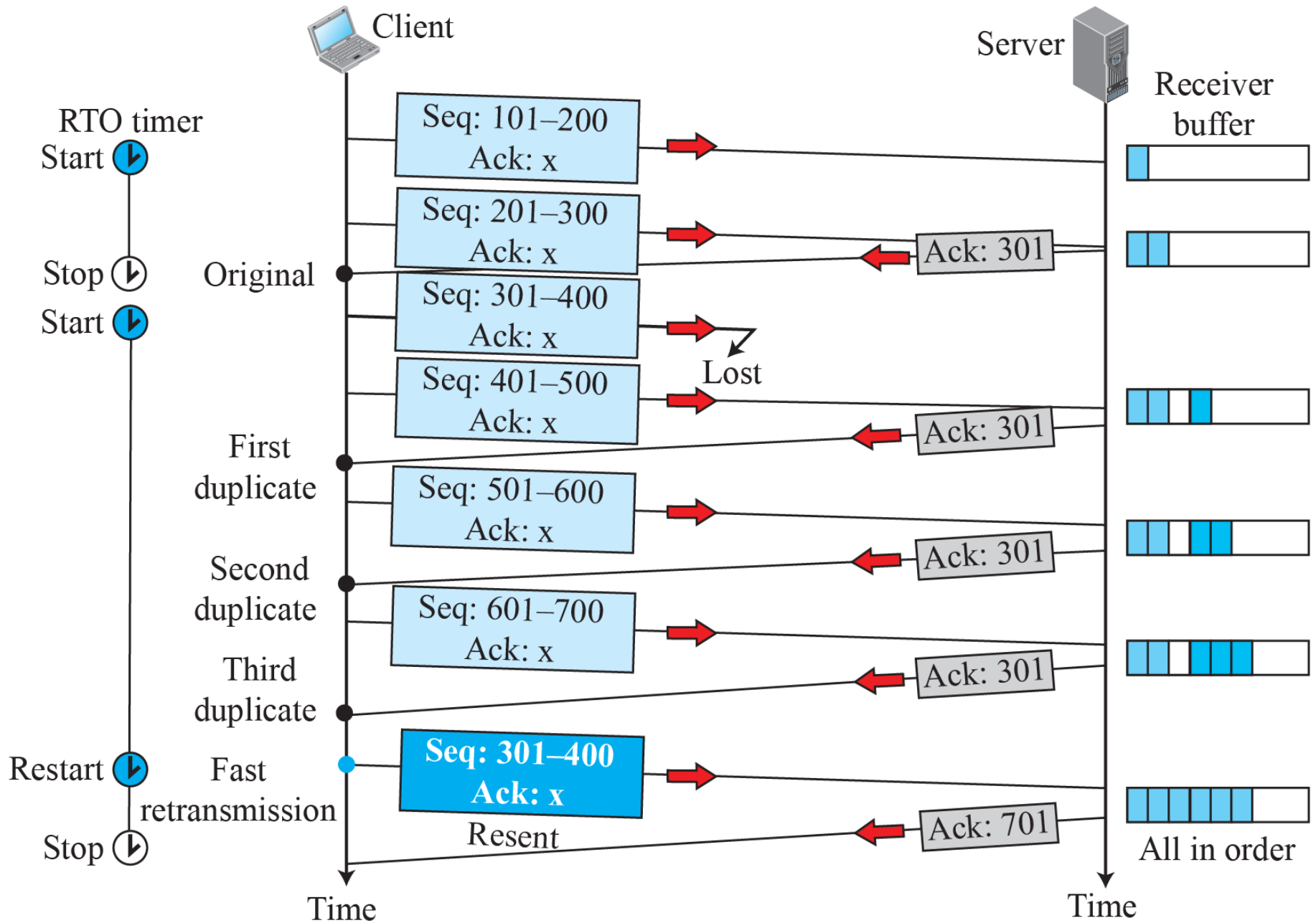
TCP Error Control

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TCP Error Control

- Fast Retransmission Rule: If a 3rd duplicate ACK arrives, the subsequent segment is deemed lost, its retransmit timer is restarted, and the segment is retransmitted
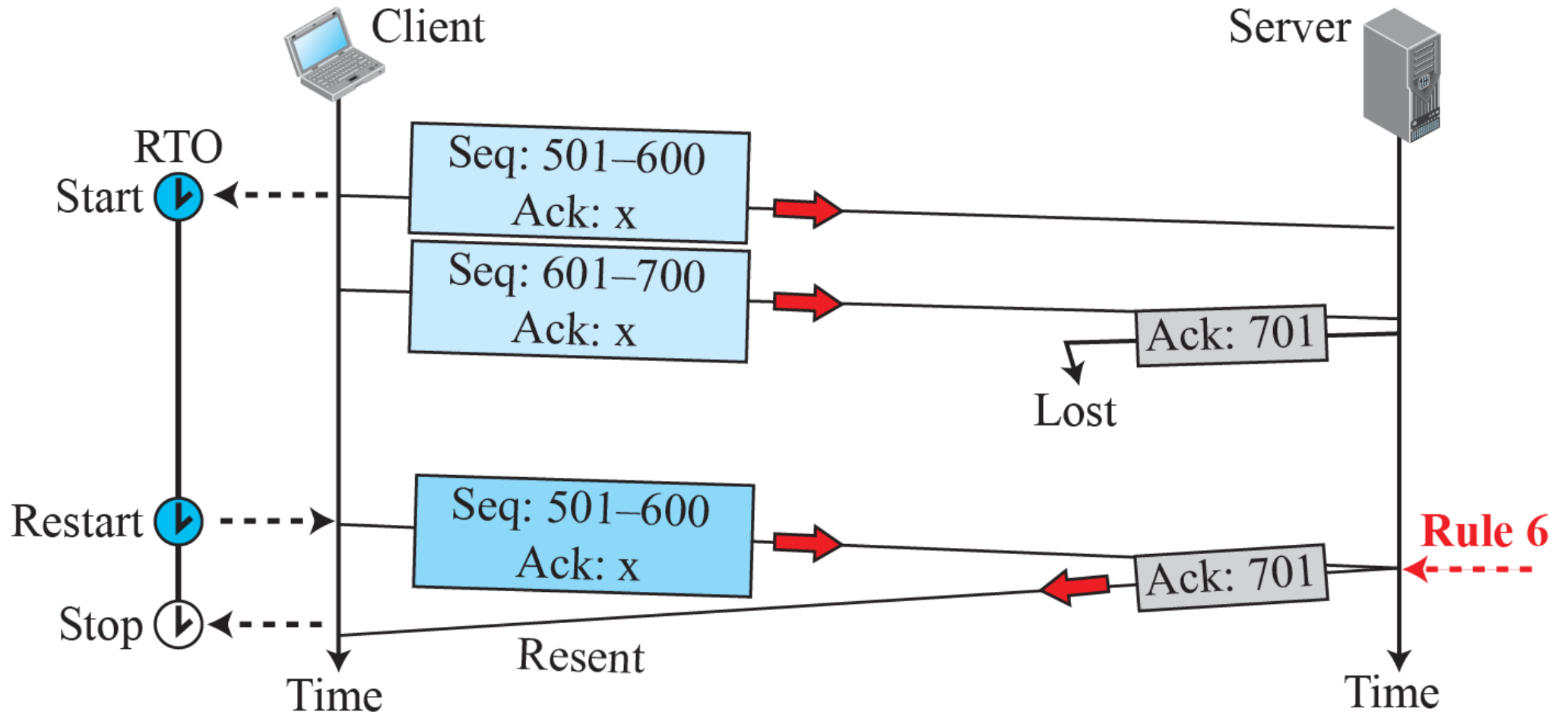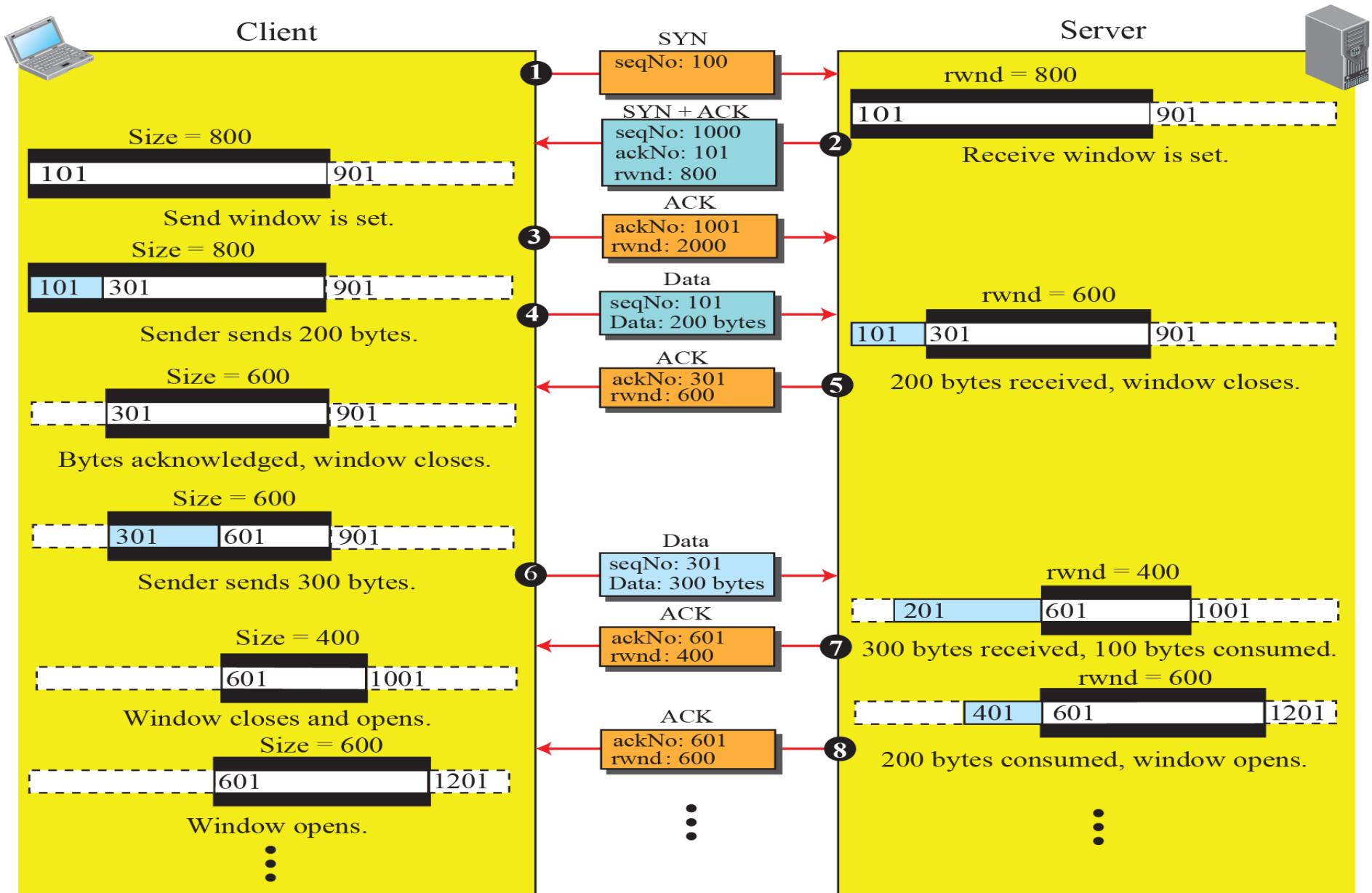
Fast Retransmission

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TCP Error Control

- Rule 6: When a duplicate segment is received, it is discarded, but the recipient returns an ACK to the sender, with the acknowledgement number set to the next expected sequence number

Lost ACK

TCP Flow Control

Note: We assume only unidirectional communication from client to server. Therefore, only one window at each side is shown.

Client

Server

SYN
seqNo: 100
1

rwnd = 800
101 | 901

Size = 800
101 | 901

SYN + ACK
seqNo: 1000
ackNo: 101
rwnd: 800
2

Receive window is set.

Send window is set.

Size = 800
101 | 301 | 901

ACK
ackNo: 1001
rwnd: 2000
3

Sender sends 200 bytes.

Data
seqNo: 101
Data: 200 bytes
4

rwnd = 600
101 | 301 | 901

Size = 600
301 | 901

ACK
ackNo: 301
rwnd: 600
5

200 bytes received, window closes.

Bytes acknowledged, window closes.

Size = 600
301 | 601 | 901

Sender sends 300 bytes.

Data
seqNo: 301
Data: 300 bytes
6

rwnd = 400
201 | 601 | 1001

Size = 400
601 | 1001

ACK
ackNo: 601
rwnd: 400
7

300 bytes received, 100 bytes consumed.

Window closes and opens.

rwnd = 600
401 | 601 | 1201

Size = 600
601 | 1201

ACK
ackNo: 601
rwnd: 600
8

200 bytes consumed, window opens.

Window opens.

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Exercises

- If a valid TCP segment is received from a sender, the recipient must _____ and _____, assuming the recipient has no valid data to send

Exercises

- If a duplicate TCP segment is received from the sender, the recipient must _____, _____ and set the acknowledgement number to _____

Exercises

- Assuming the receive buffer already contains bytes 1000 - 1200 and a TCP segment arrives with sequence number 1400 and length 100, the recipient must _____ and set the acknowledgement number to _____ and save bytes _____

Key Skills

- Explain TCP connection establishment, data transmission, error control, flow control, and connection termination