Transport Layer (TCP)

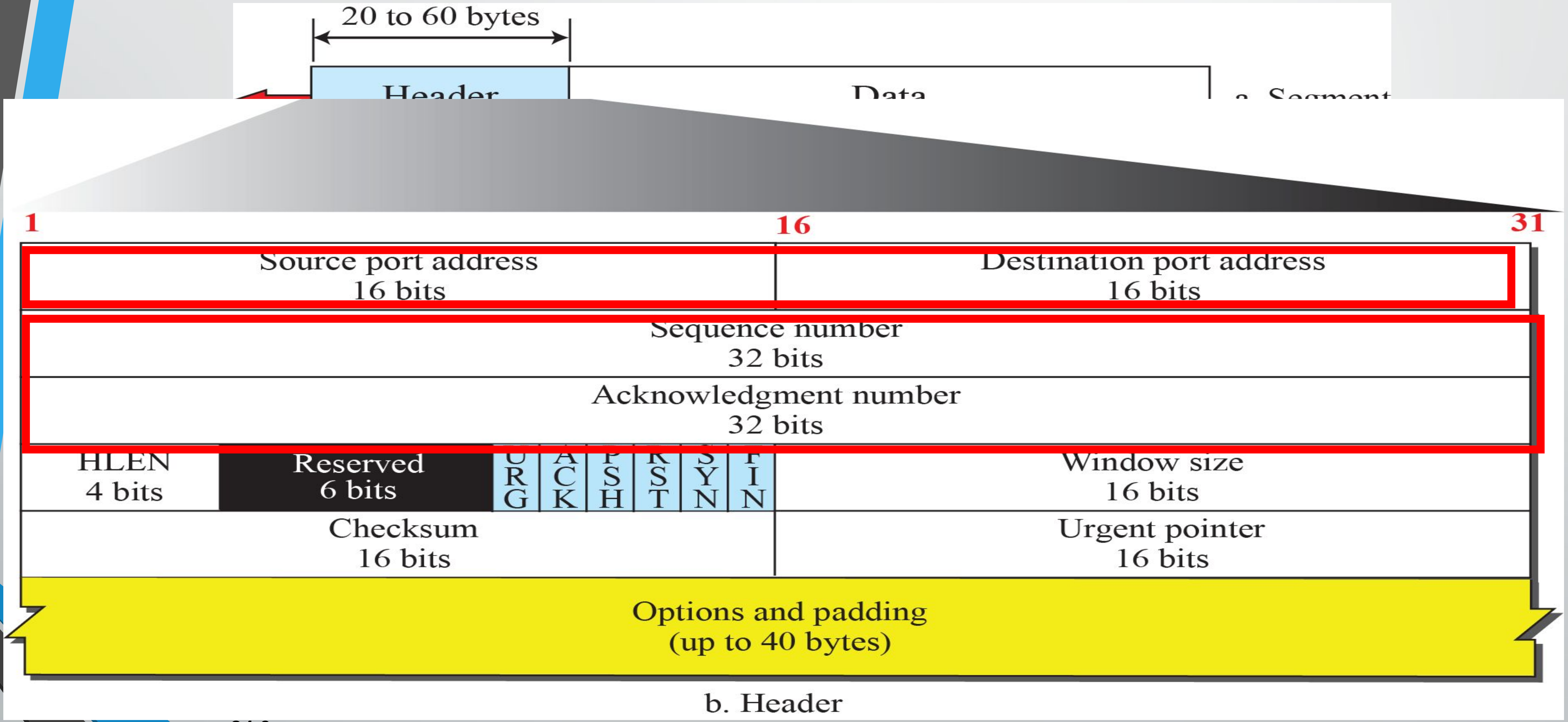
Lecture 5 | CSE421 – Computer Networks

Department of Computer Science and Engineering
School of Data & Science

Objectives

- TCP Header
- TCP Services

TCP Segment Header



Byte Number

- The bytes of data being transferred in each connection are numbered by TCP.
- The numbering starts with an arbitrarily generated number.
- An arbitrary number between **0 and $2^{32} - 1$** for the number of the first byte.

- For example if the number of the first byte happens to be **1067** and the total data to be sent is **3000 bytes** .
- What is the byte number for the first byte of data and last byte of data?

First Byte Number
1067

Last Byte Number
4066

Sequence Numbers

- The sequence number of the first segment is **the ISN (initial sequence number)**, which is a random number (byte number).

- The sequence number of any other segment is the sequence number of the previous segment plus the number of bytes **(real or imaginary)** carried by the previous segment.

- Suppose a TCP connection is transferring a file of 5,000 bytes. The first byte is numbered 10,001. What are the sequence numbers for each segment if data are sent in five segments, each carrying 1,000 bytes?

- **Solution:**

Segment 1	→	Sequence Number:	10001	**Range:**	10001	to	11000
Segment 2	→	Sequence Number:	11001	**Range:**	11001	to	12000
Segment 3	→	Sequence Number:	12001	**Range:**	12001	to	13000
Segment 4	→	Sequence Number:	13001	**Range:**	13001	to	14000
Segment 5	→	Sequence Number:	14001	**Range:**	14001	to	15000

Acknowledgement Number

- If receiving host TCP receives uncorrupted data, then…
- It is acknowledged using the acknowledgement number

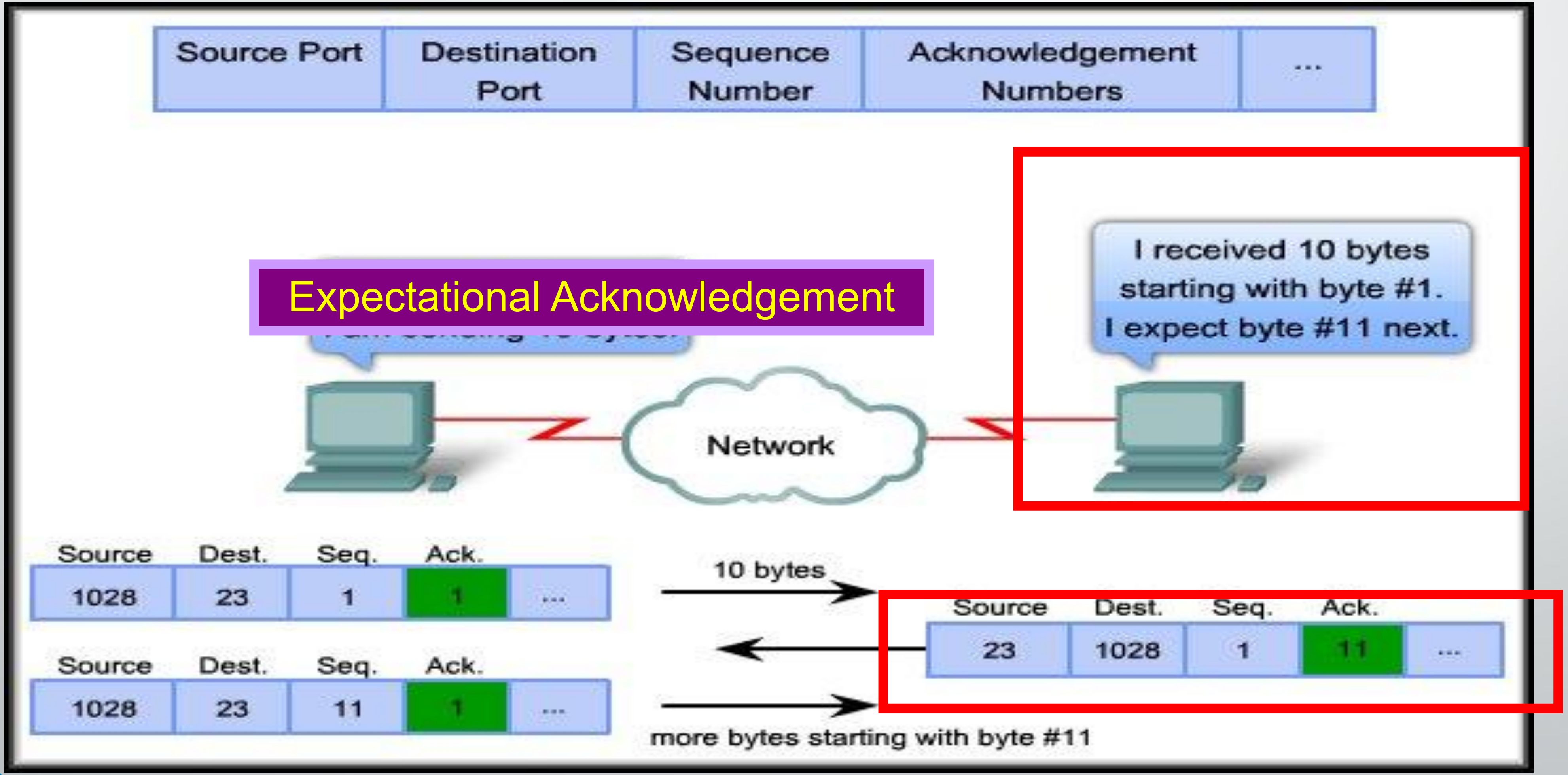
- The value of the acknowledgment field in a segment defines the **number of the next byte** the receiver expects to receive.

- For example if the sender receives **1001** as the acknowledgement number.
- What does it mean?

Received all data up to 1000, tells the sender that it ready to receive the next data from 1001 byte number.

Note :This does not indicate receiver has received 1000 bytes of data.

Acknowledgement Number



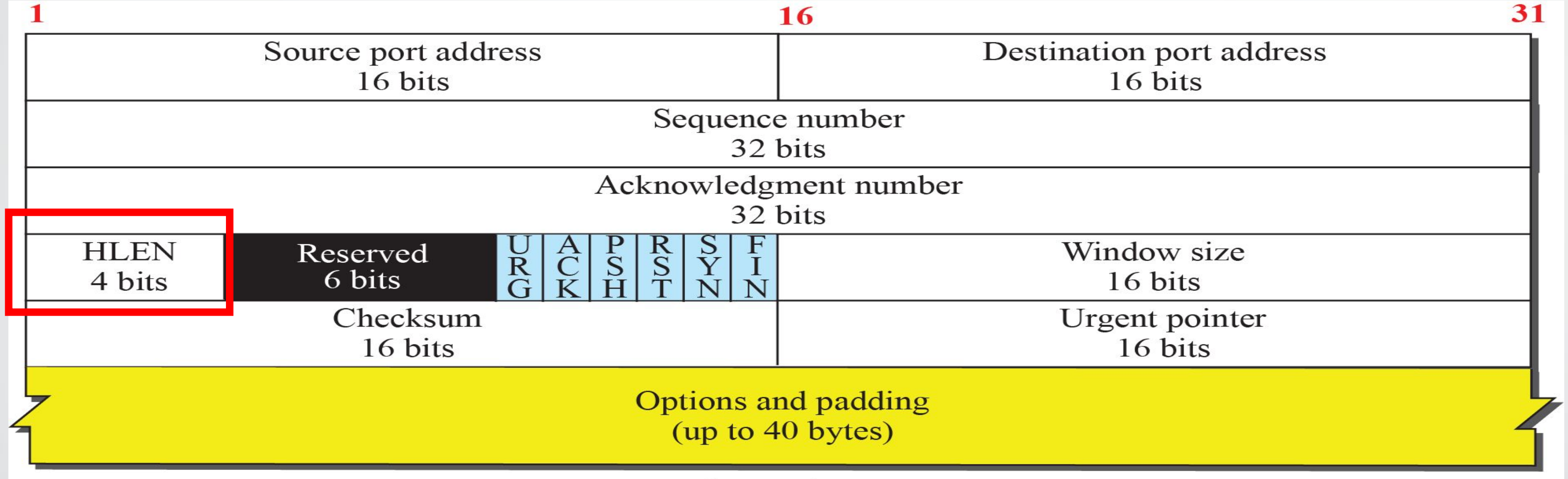
Acknowledgement Number

- The acknowledgment number is **cumulative**.
- Receiver acknowledges multiple data segments in one acknowledgement.

Sender

Receiver

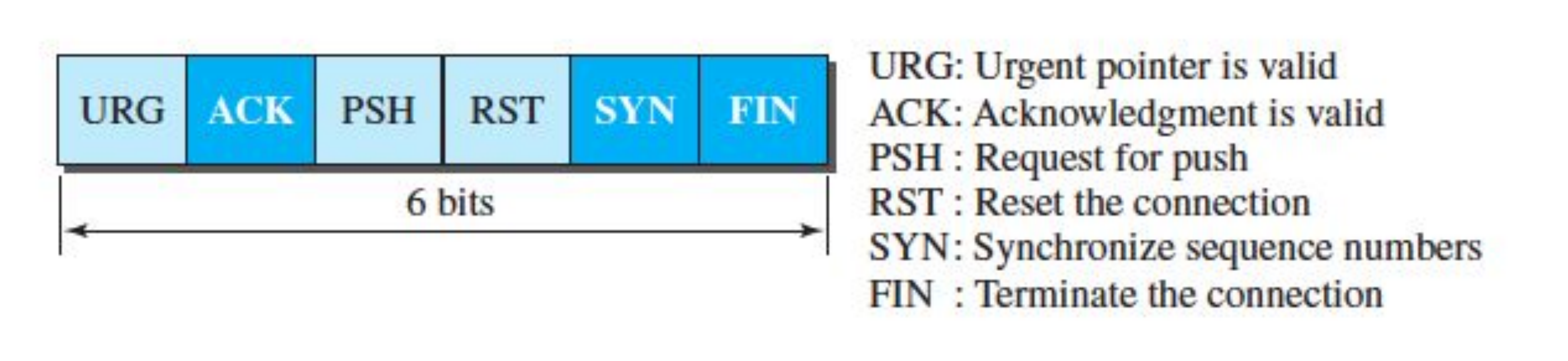
Header Length



b. Header

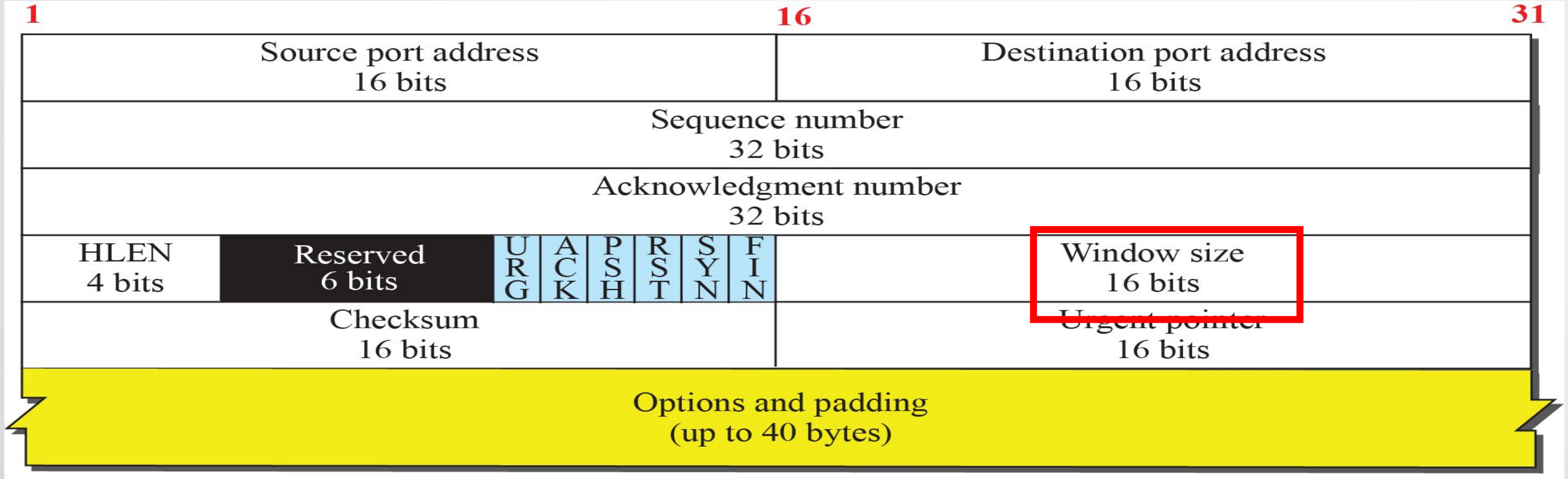
- Header Length :
  - Indicates the number of 4-byte words
  - The length of the header can be between 20 and 60 bytes

Control Bits



- Control Bits:
  - This field defines 6 different control bits or flags
  - One or more of these bits can be set at a time
  - These bits help indicate connection establishment and termination, flow control

Window Size



b. Header

- Window Size:
  - This field defines size of data in bytes of the sending TCP process
  - The maximum size of the window is 65,535 bytes
  - Normally referred to as the receiving window (rwnd)
  - The sender must obey the dictation of the receiver in this case

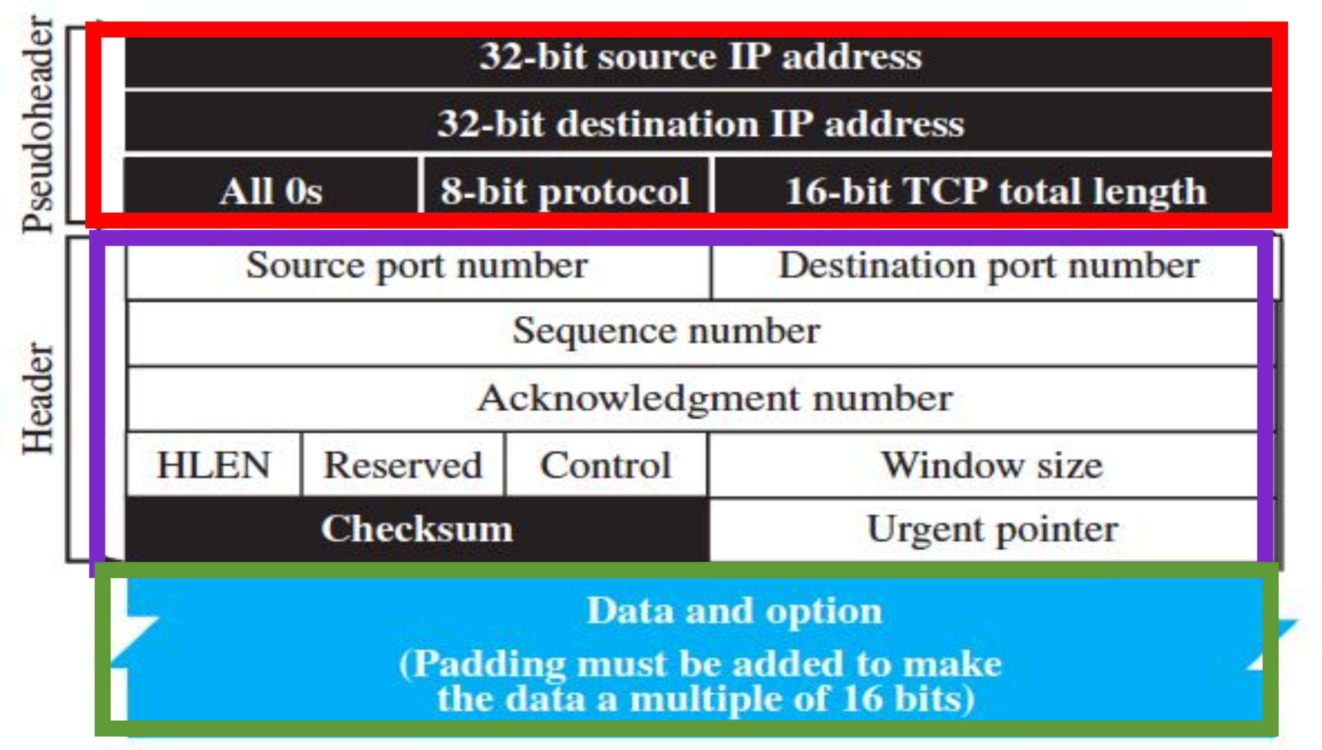
Checksum

- This 16 bits field is used to detect errors (*i.e.,* flipped bits) in the transmitted segment (intentionally or unintentionally) while traveling through the network.
- Also present in UDP header
- Mandatory in TCP but not in UDP
- Process is same for both protocols

UDP HEADER

Source port number 16 bits	Destination port number 16 bits
Total length 16 bits	Checksum 16 bits

- TCP/UDP Header
- TCP/UDP Body
- Pseudo IP Header



Checksum

	1st number	2nd number	sum
Transmitted:	5	6	11
Received:	4	6	11

receiver-computed checksum ≠ sender-computed checksum (as received)

Checksum Process

Goal: detect errors (*i.e.*, flipped bits) in transmitted segment

sender:

- treat contents of UDP segment (including UDP header fields and IP addresses) as sequence of 16-bit integers
- checksum: addition (one's complement sum) of segment content
- checksum value put into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - Not equal - error detected
  - Equal - no error detected. *But maybe errors nonetheless?* More later ....

Checksum: an example

example: add two 16-bit integers

		1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
		1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
wraparound	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
sum		1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0
checksum		0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1

Note: when adding numbers, a carryout from the most significant bit needs to be added to the result

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

Checksum: weak protection!

example: add two 16-bit integers

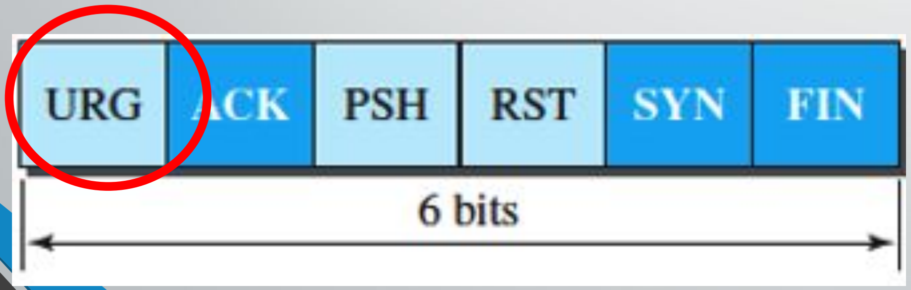
		1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
		1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
wraparound	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
sum		1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0
checksum		0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1

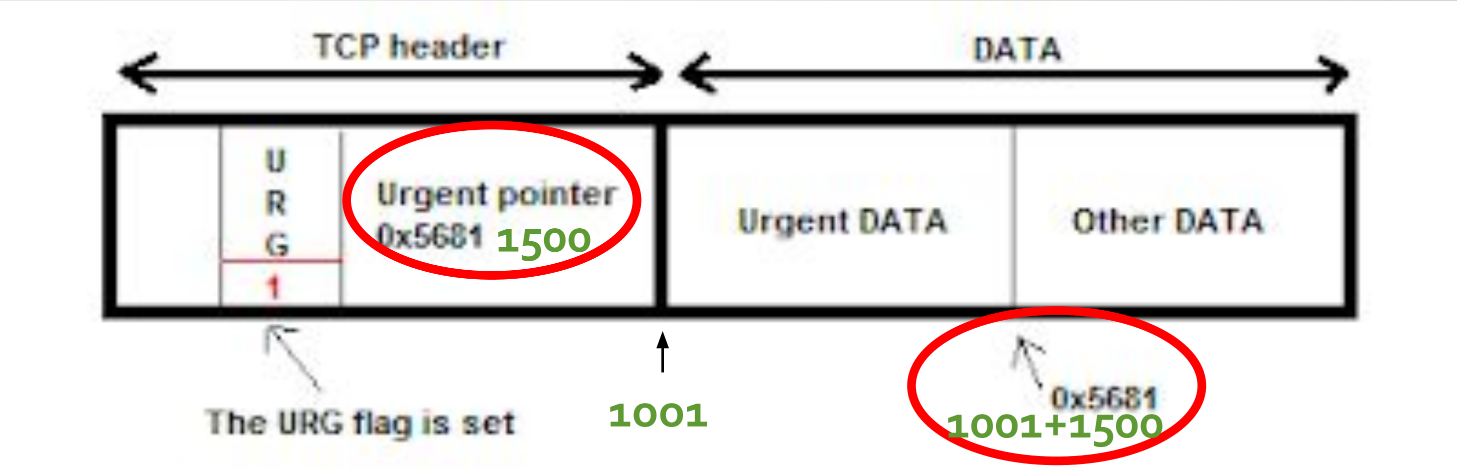
0 1
1 0

Even though numbers have changed (bit flips), *no* change in checksum!

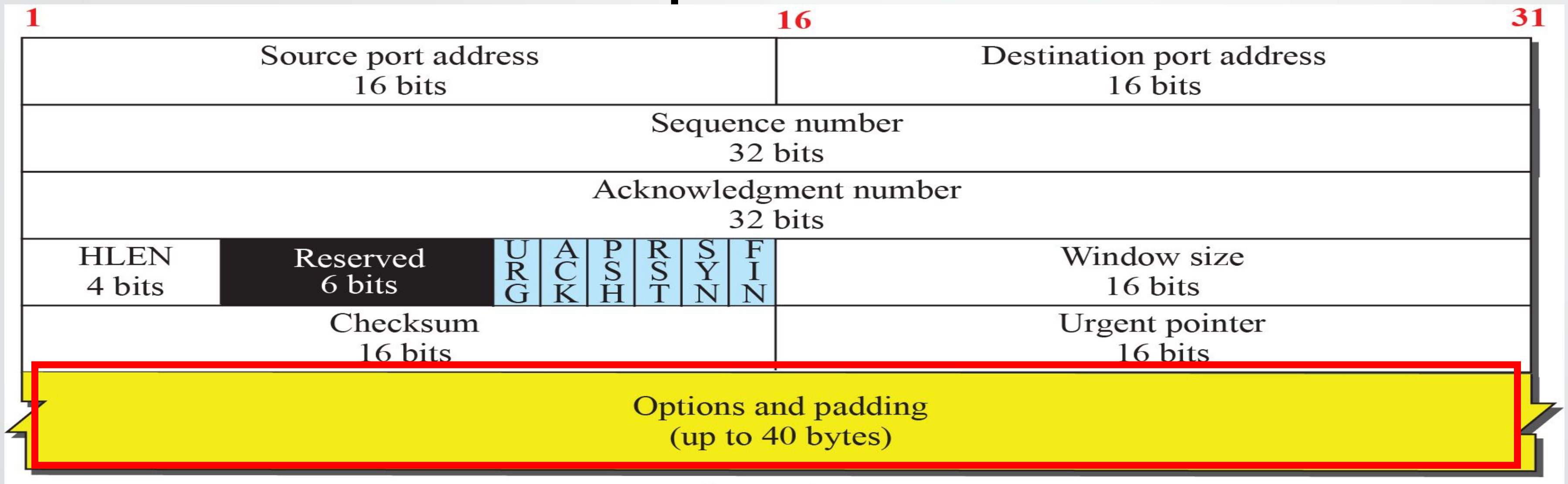
Urgent Pointer

- This 16-bit field, which is valid only if the urgent flag is set.
- Used when the segment contains urgent data.
- It defines a value that must be added to the sequence number to obtain the number of the last urgent byte in the data section of the segment.





Options



b. Header

- There can be up to 40 bytes of optional information in the TCP header
- Provides a way to deal with limitations of the original header
- For example :
  - MSS (Maximum Segment Size) is defined as the largest block of data that a sender using TCP will send to the receiver

Functions of the Transport Layer

- Primary responsibilities:

1. Segmenting the data and managing each piece.
2. Reassembling the segments into streams of application data.
3. Identifying the different applications.
4. Multiplexing

UDP &TCP

5. Establishing and terminating a connection.
6. Enabling error control and recovery.
7. Performing flow control between end users.

Only TCP

- Function 6
  Connection Establishment and Termination for Reliability

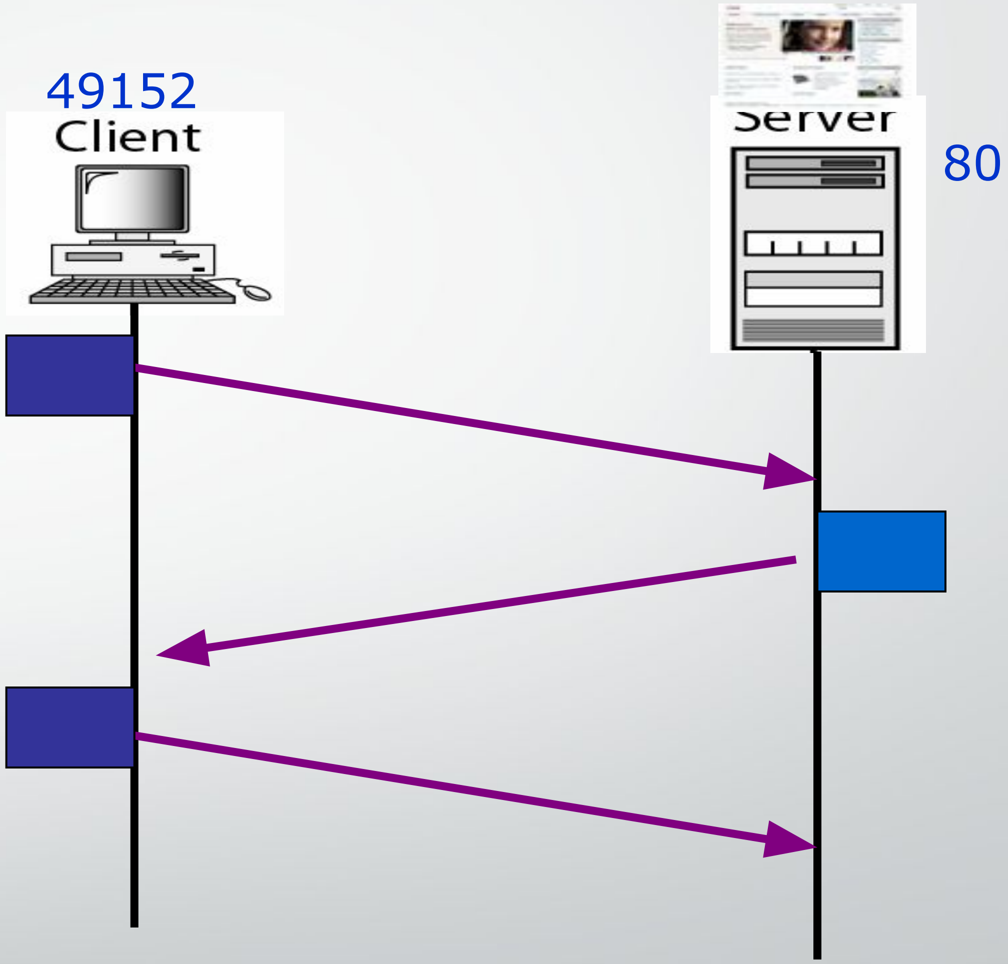
Connection Establishment

- TCP sets up a connection between end hosts before sending data
- This process is known as **"Three-way handshake"**
- After the connection is established the hosts can send data

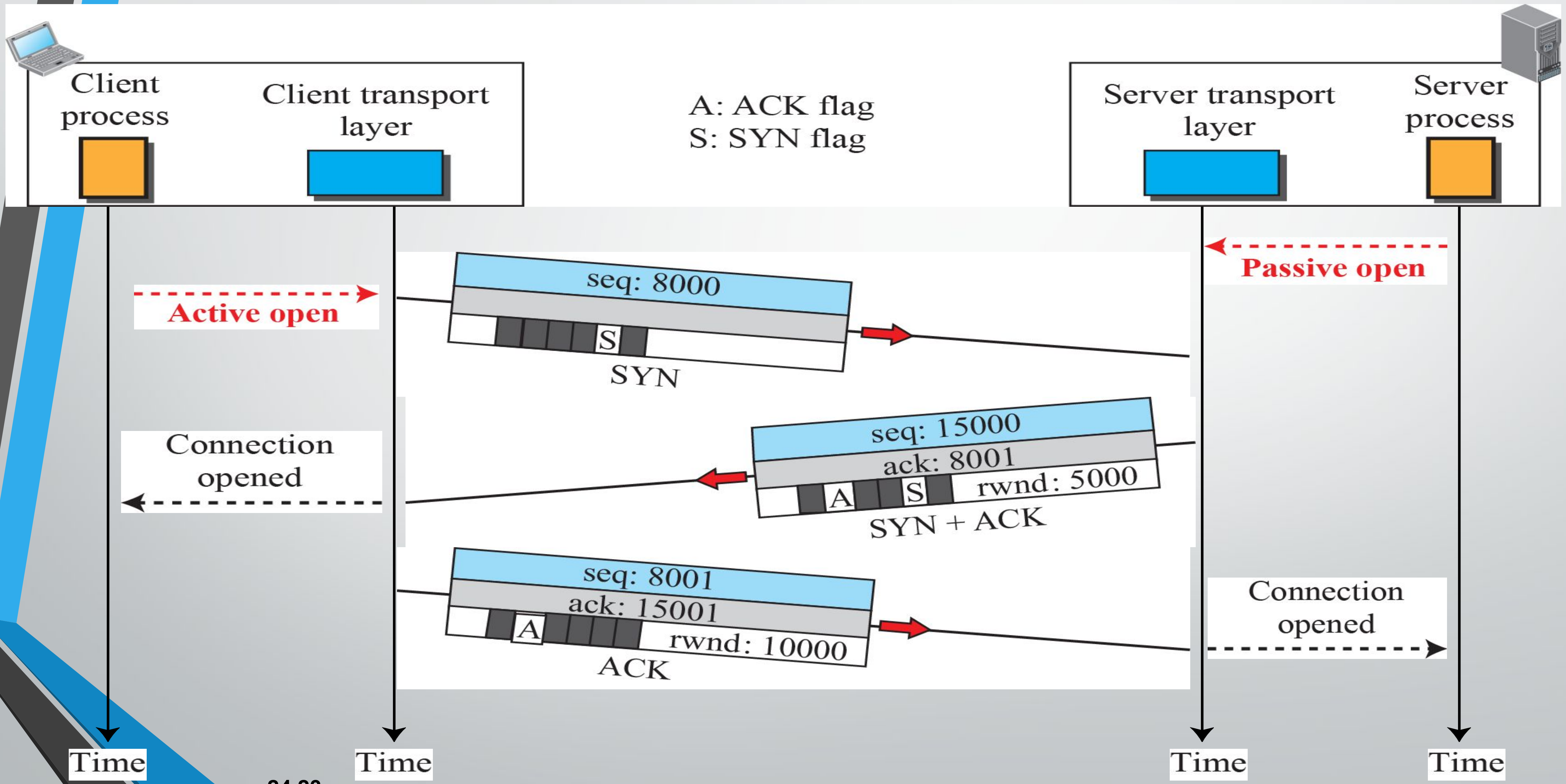
3 Way Handshake : Connection Establishment

Source Port No.					Destination Port No.		
Sequence No.							
Acknowledgement No.							
	U	A	P	R	S	F	Window Size
Others							

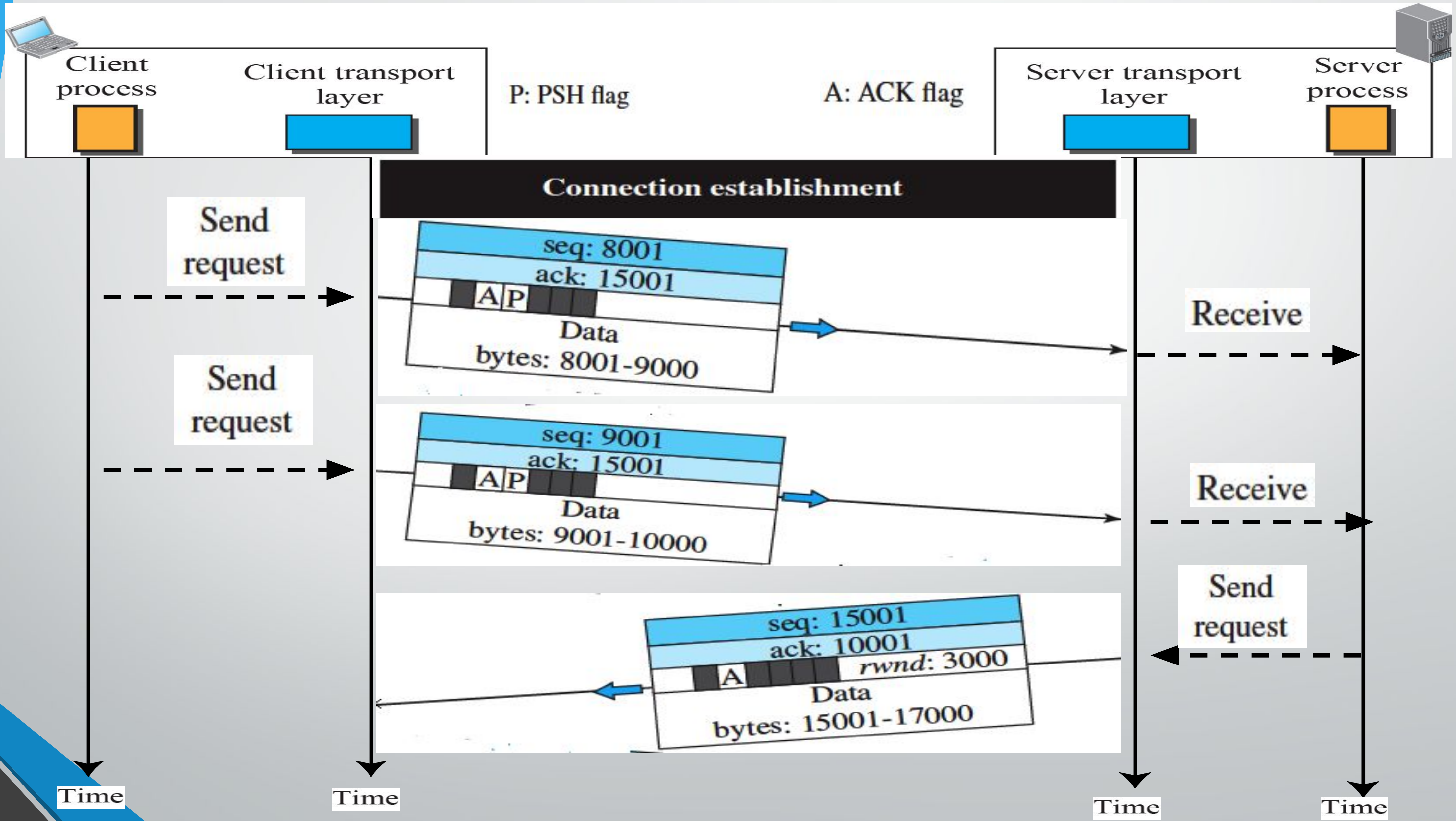
49152 80					80 49152 80		
100 0 101							
0 1011							
		A			S		4000 Bytes 8000 Bytes
Others							



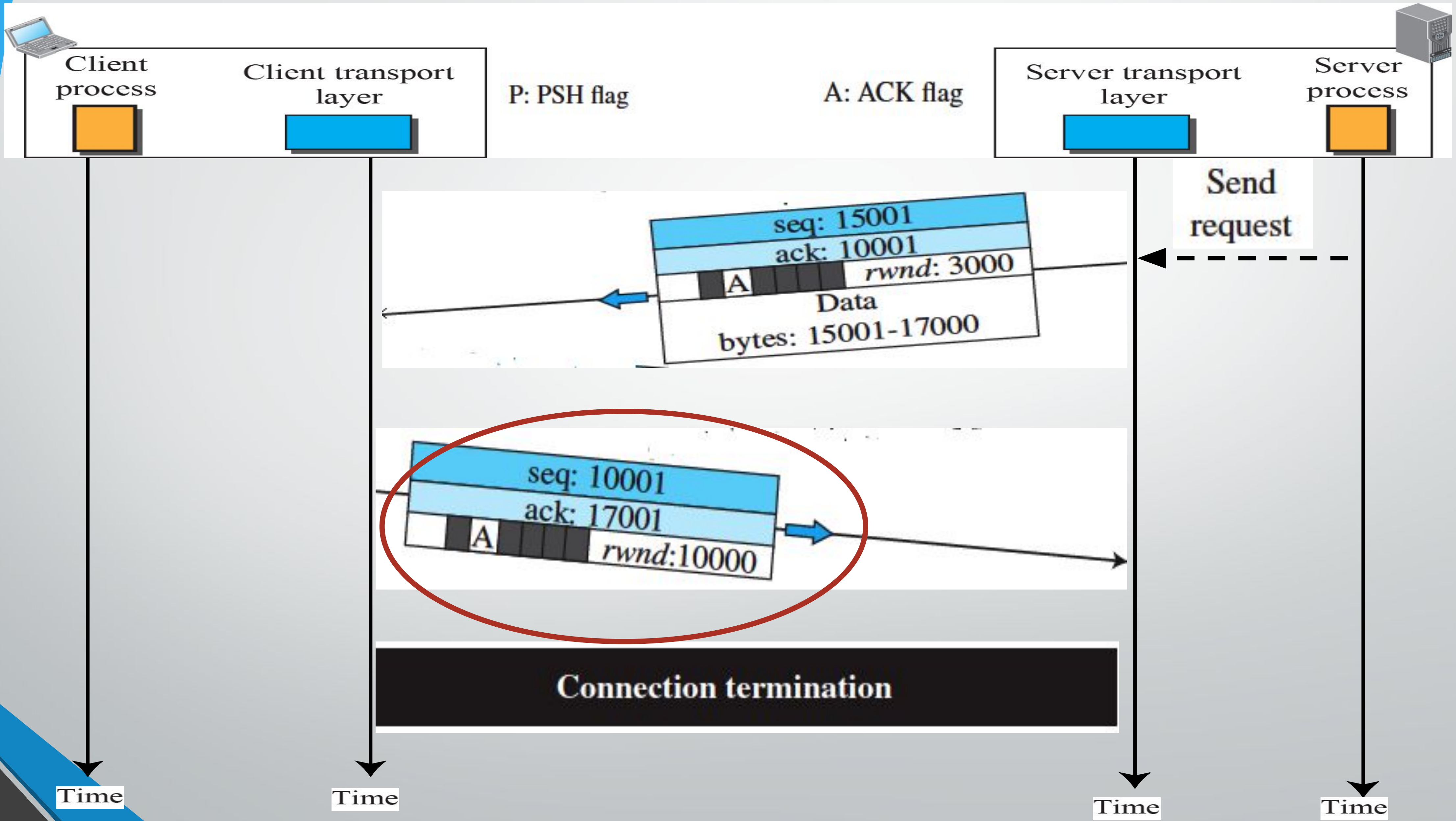
3 Way Handshake : Connection Establishment



Data Transfer



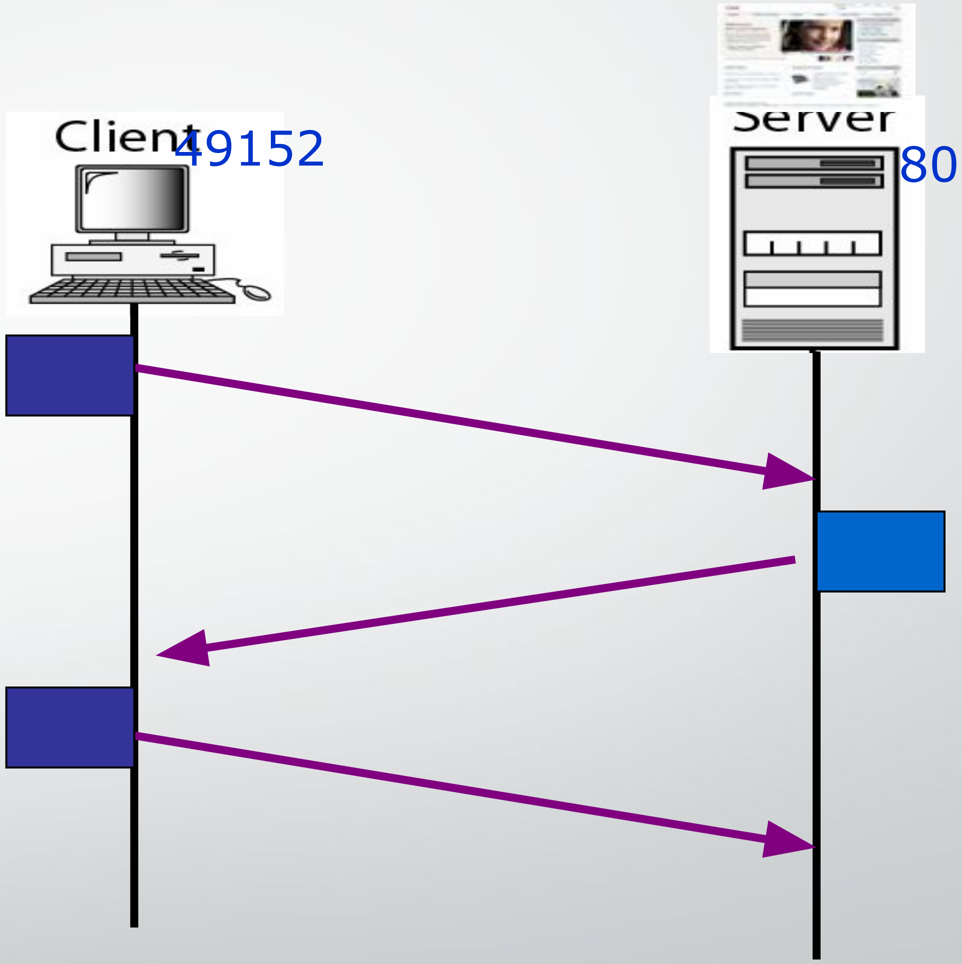
Data Transfer Continued..



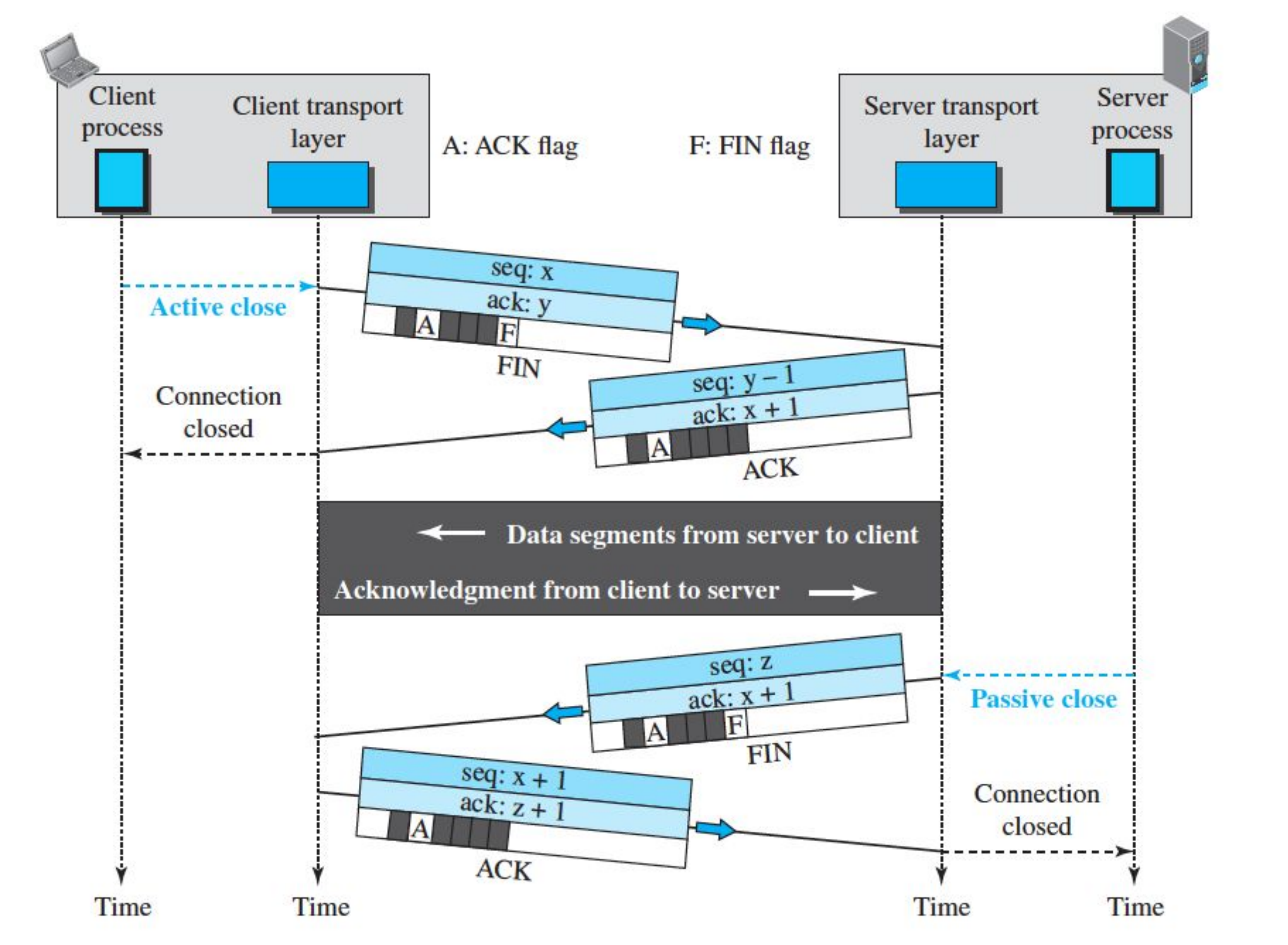
3 Way Handshake : Connection Termination

<table>
<tr><td colspan="7">Source Port No.</td><td colspan="2">Destination Port No.</td></tr>
<tr><td colspan="9">Sequence No.</td></tr>
<tr><td colspan="9">Acknowledgement No.</td></tr>
<tr><td></td><td>U</td><td>A</td><td>P</td><td>R</td><td>S</td><td>F</td><td colspan="2">Window Size</td></tr>
<tr><td colspan="9">Others</td></tr>
</table>

<table>
<tr><td colspan="7">49152 80</td><td colspan="2">80 49152</td></tr>
<tr><td colspan="9">10001 17001 10002</td></tr>
<tr><td colspan="9">17001 17002 10002</td></tr>
<tr><td></td><td></td><td>A</td><td></td><td></td><td></td><td>F</td><td colspan="2">4000 Bytes 8000 Bytes</td></tr>
<tr><td colspan="9">Others</td></tr>
</table>



Connection Termination :: Half Close



- Function 6
  Error Control and Recovery for Reliability

Reliability in TCP

- TCP provides **reliability** using **error control**
- Error control includes mechanisms for
  - detecting and resending corrupted segments
  - resending lost segments
  - storing out-of order segments until missing segments arrive
  - detecting and discarding duplicated segments.

- Error control in TCP is achieved through
  - **Checksum**
  - **Acknowledgment**
  - **Time-out and retransmission**

Error Control

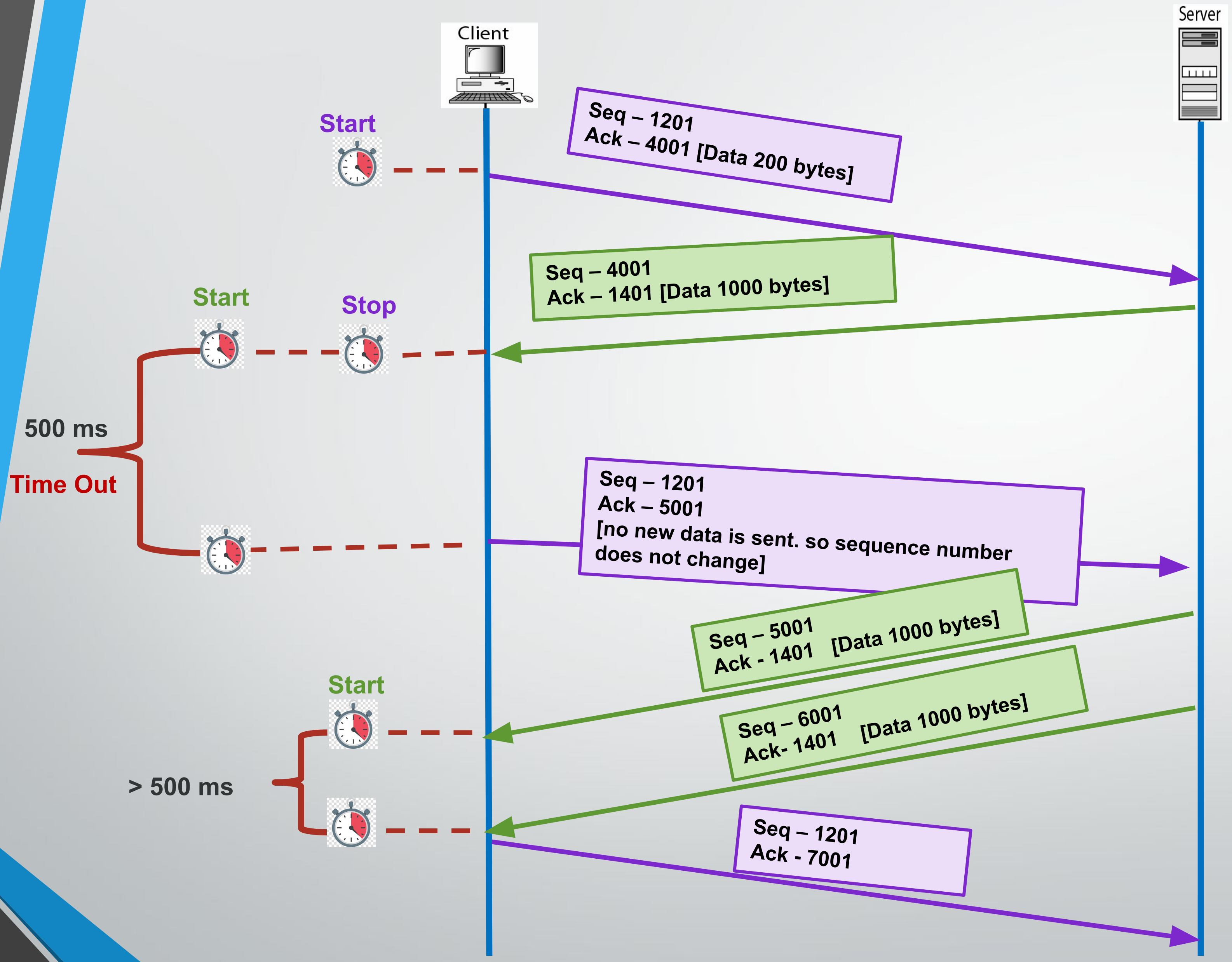
- **Checksum**
  - Each segment includes a checksum field, which is used to check for a corrupted segment
  - If a segment is corrupted, as detected by an invalid checksum, the segment is discarded

- **Acknowledgment**
  - Using Acknowledgement Number to confirm the receipt of data segments.
  - To confirm control segments that carry no data, but consume a sequence number
  - ACK segments do not consume sequence numbers and are not acknowledged.

Error Control

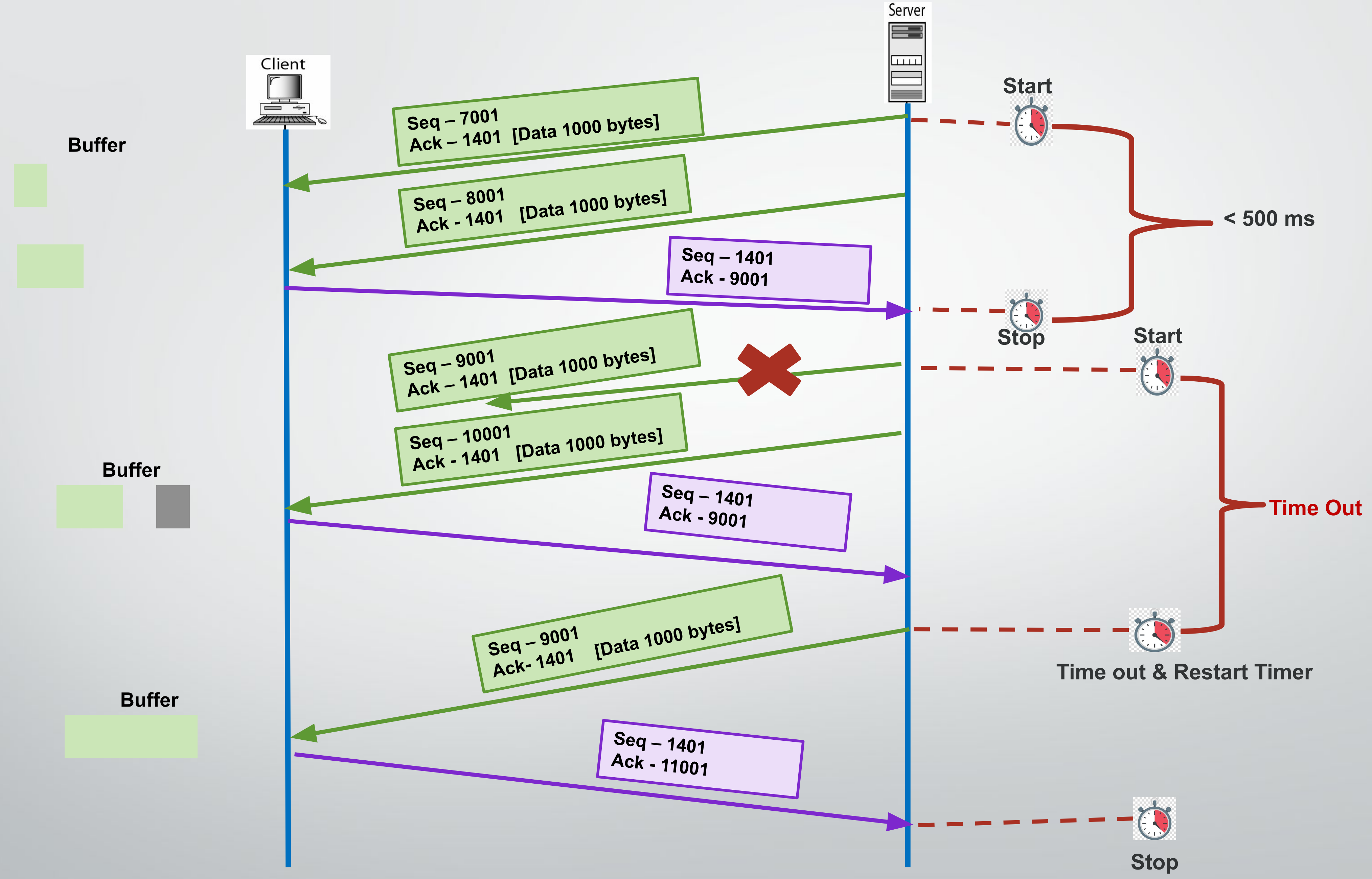
- **Retransmission**
- When a segment is sent, it is stored in a queue until it is acknowledged.
- Retransmission of segment will occur
- **After Retransmission Time Out**
  - The sending TCP maintains one retransmission time-out (RTO) timer for each connection.
  - When the timer matures TCP resends the segment in the front of the queue if the segment is not acknowledged
- **After Three Duplicate ACK Segments**
  - To be explained later

Normal Operation



Other Scenarios

- Segment Lost or Corrupted?
- Retransmission of segment ??
- How will the sender know ??
- What about the receiver, not aware of a packet sent?
- **RTO - Retransmission** after time out.

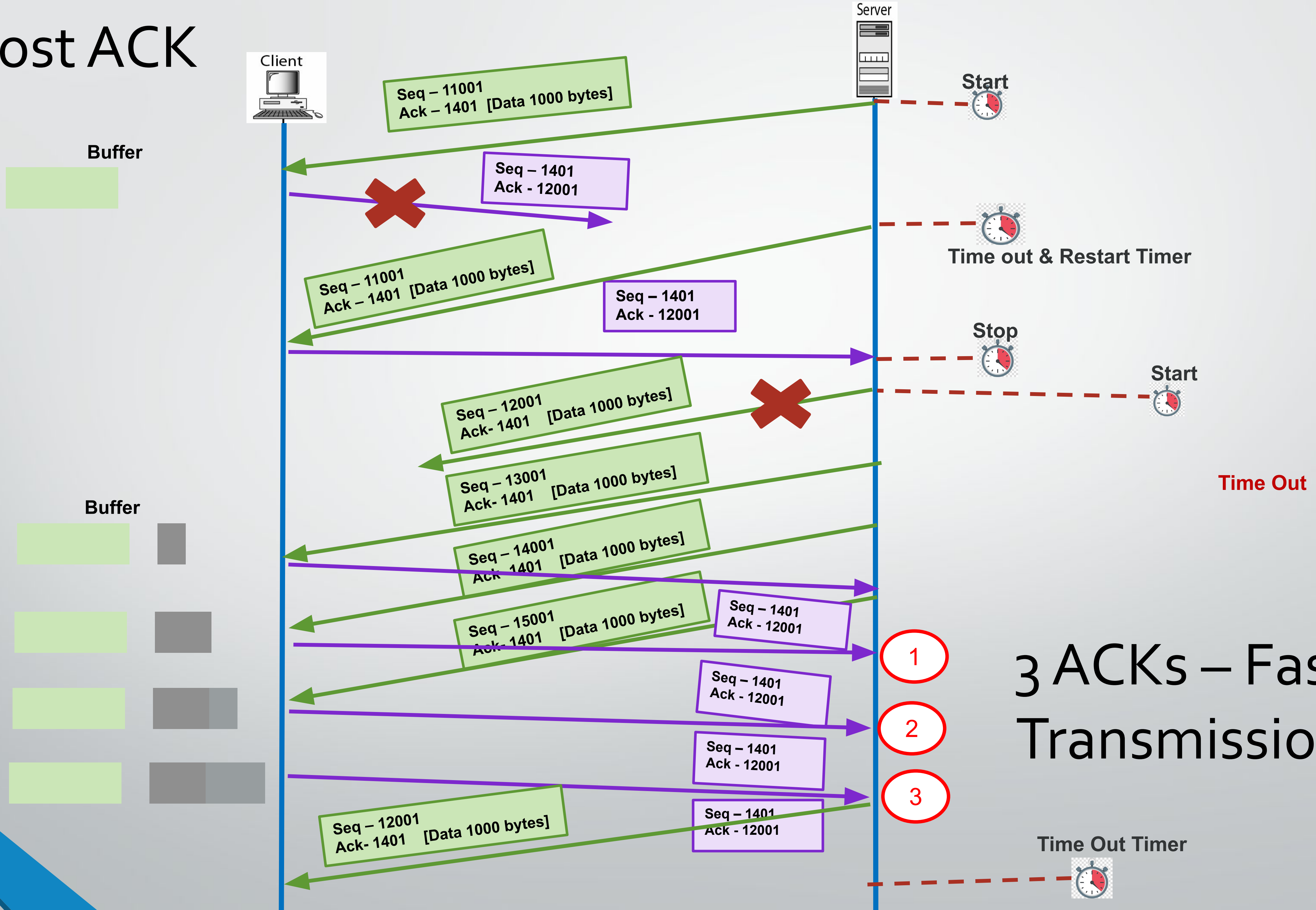


Lost Segment

Out of Order Segments

- TCP implementations today do not discard out-of-order segments.
- They store them temporarily .
- Flag them as out-of-order segments until the missing segments arrive.
- Out-of-order segments are never delivered to the process.
- TCP guarantees that data are delivered to the process in order.

Lost ACK



3 ACKs – Fast Transmission

- Function 7 :
  Flow Control and Recovery for Reliability

Flow Control

- Transmission Control Protocol (TCP) uses a ***sliding window*** for flow control.

- What is the "**Window** "?
  - Indicates the size of the device's receive buffer for the particular connection.
  - How much data a device can handle from its peer at one time before it is passed to the application process.
  - Set by receiver of data

  - **Example** : The server's window size was **360**. This means the receiver is willing to take **no more than 360 bytes** at a time from the sender.

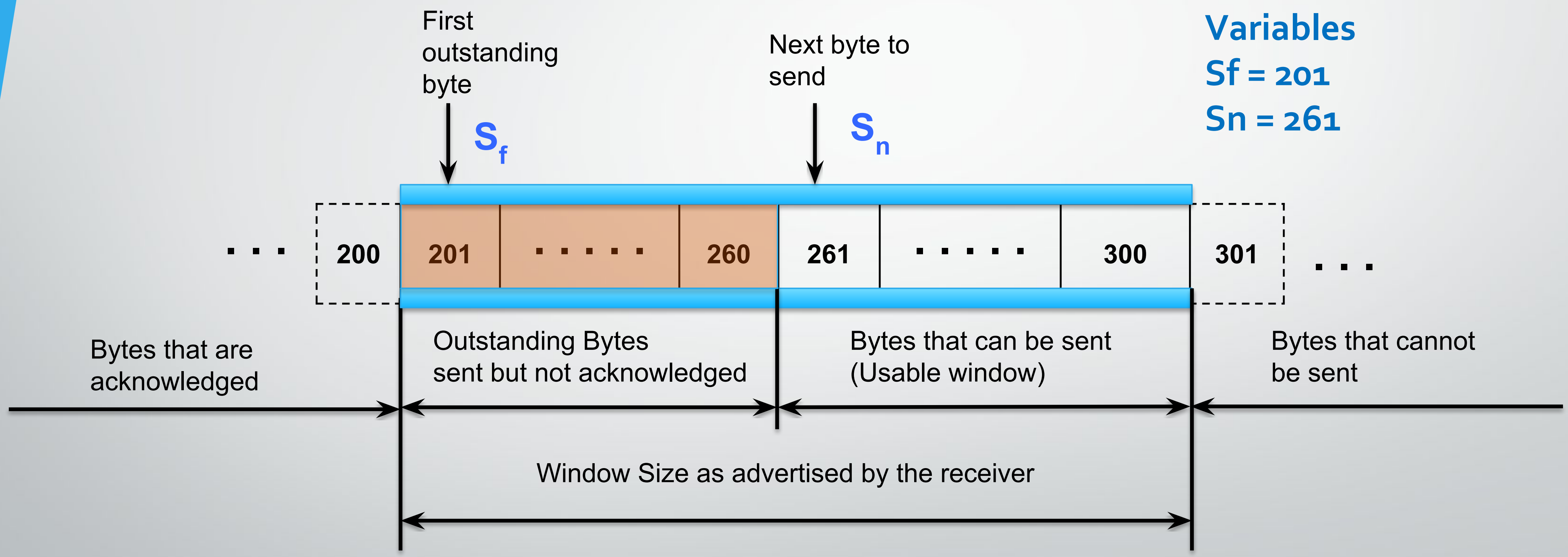
Sender Sliding Window

Window Size = 100 bytes

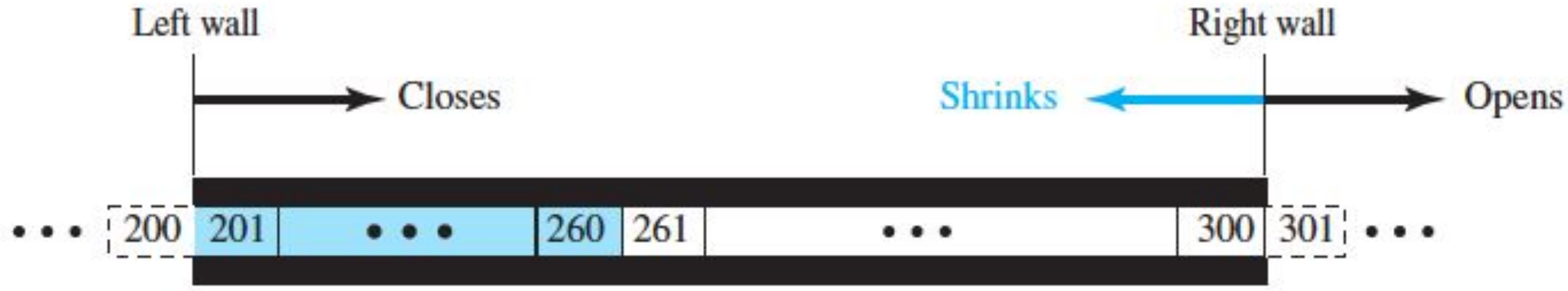
Variables

Sf = 201

Sn = 261



Sliding of Sender Window



b. Opening, closing, and shrinking send window

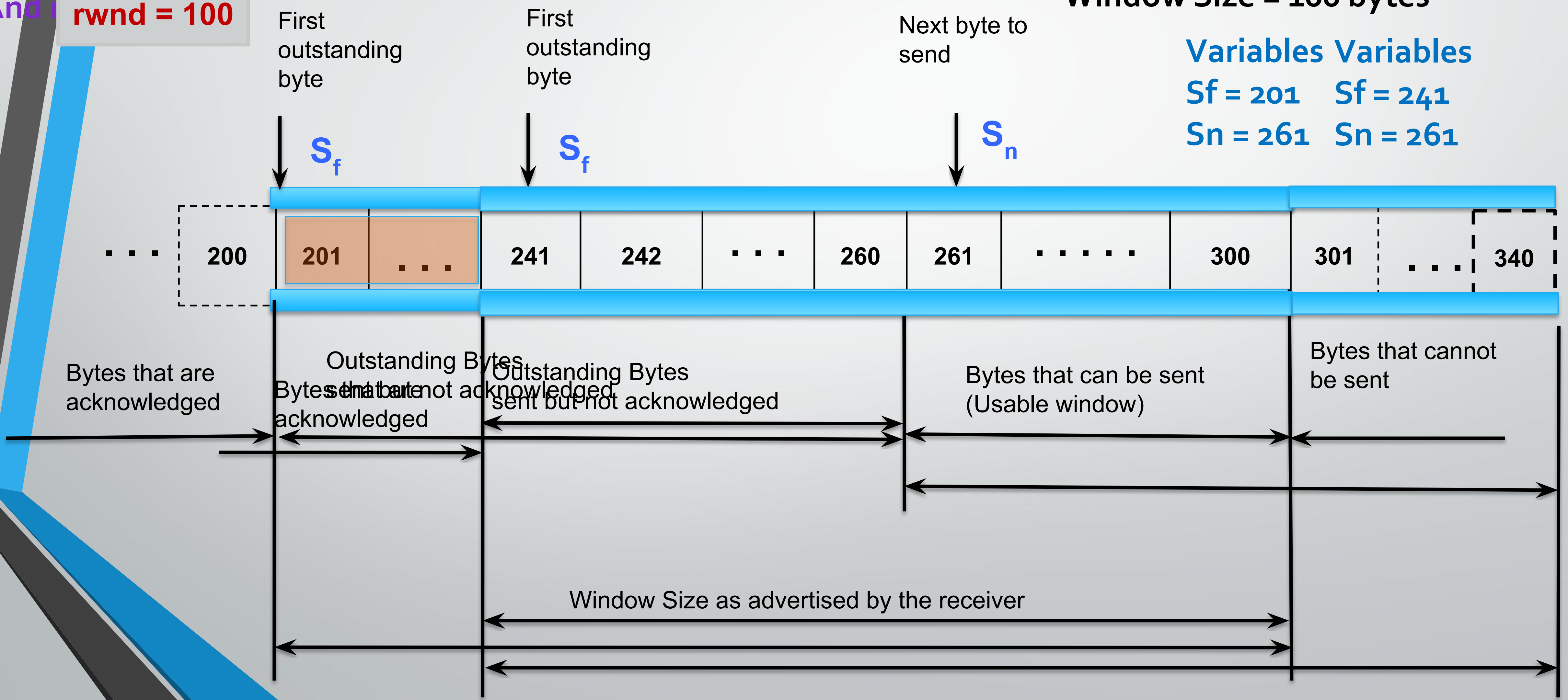
Sliding of Sender Window

#Sender receives a segment with ACK 241

And rwnd = 100

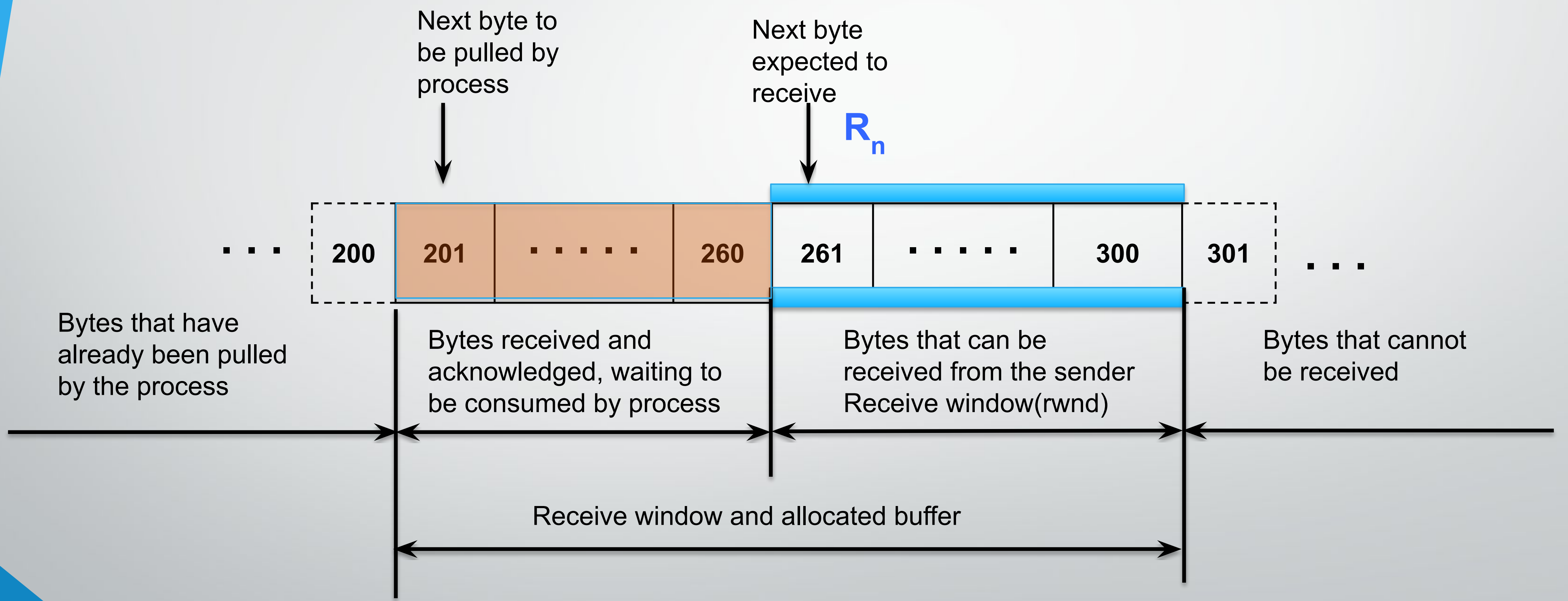
Window Size = 100 bytes

Variables	Variables
Sf = 201	Sf = 241
Sn = 261	Sn = 261



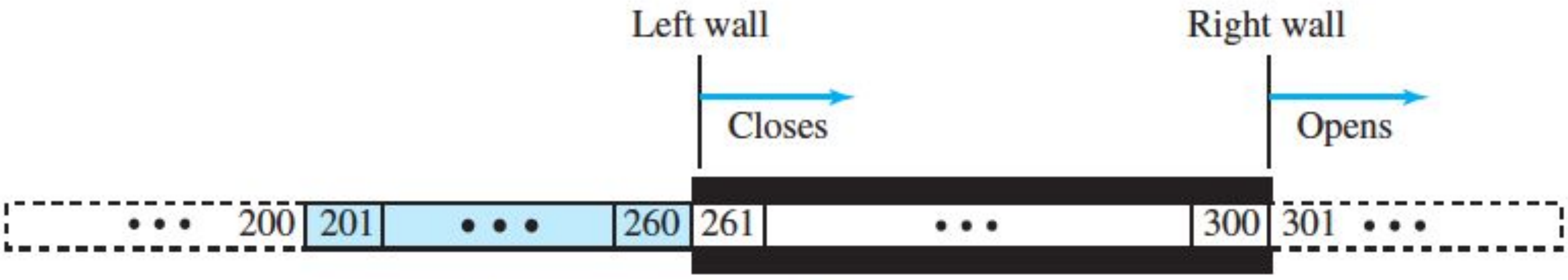
Receiver Sliding Window

Window Size = 100 bytes



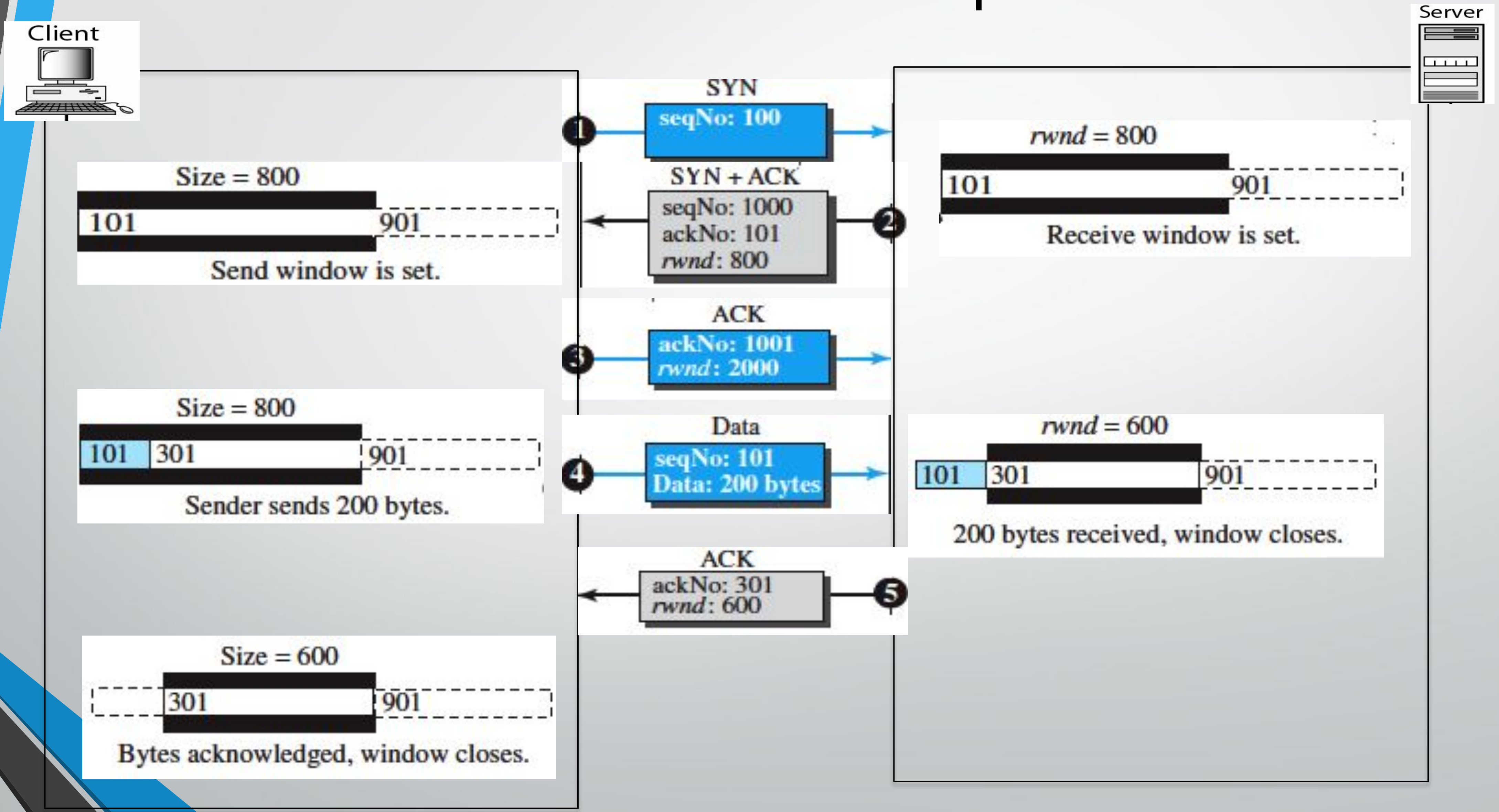
- **rwnd= buffer size – number of bytes to be pulled** **= 40 bytes**

Sliding of Receiver Window

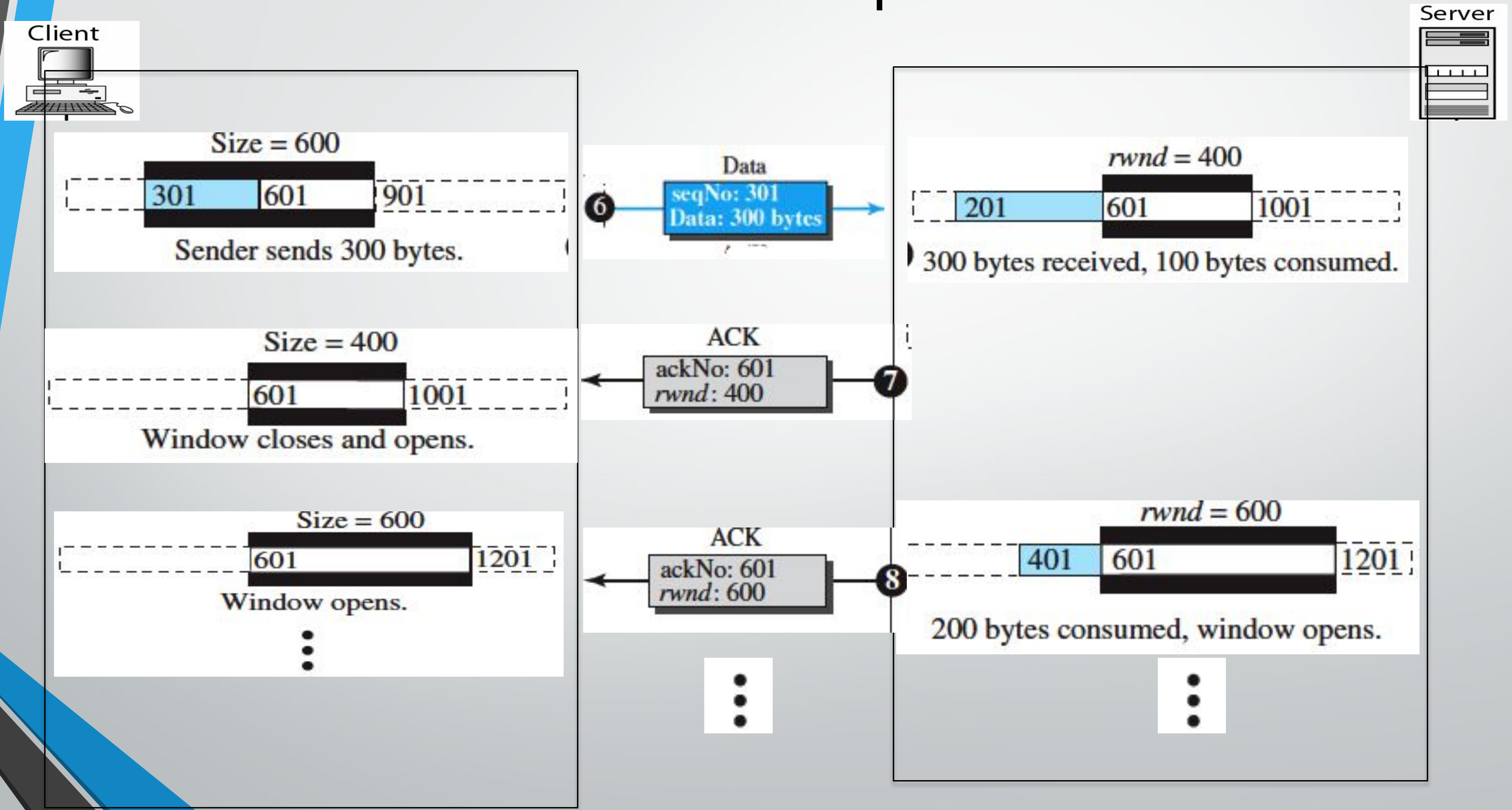


b. Opening and closing of receive window

Flow Control Example

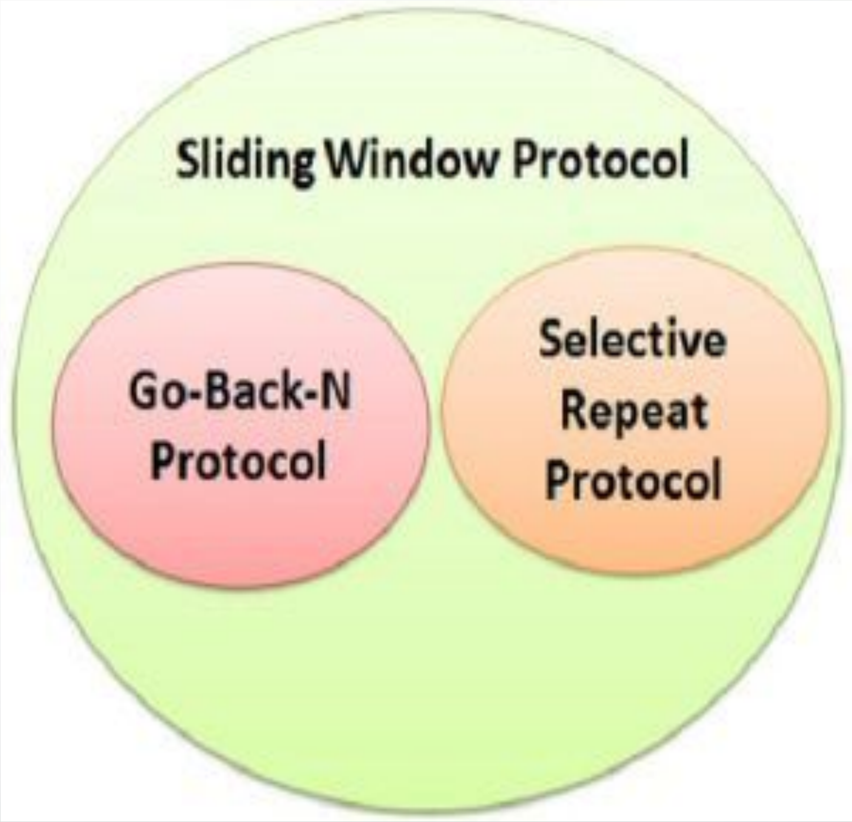


Flow Control Example Contd

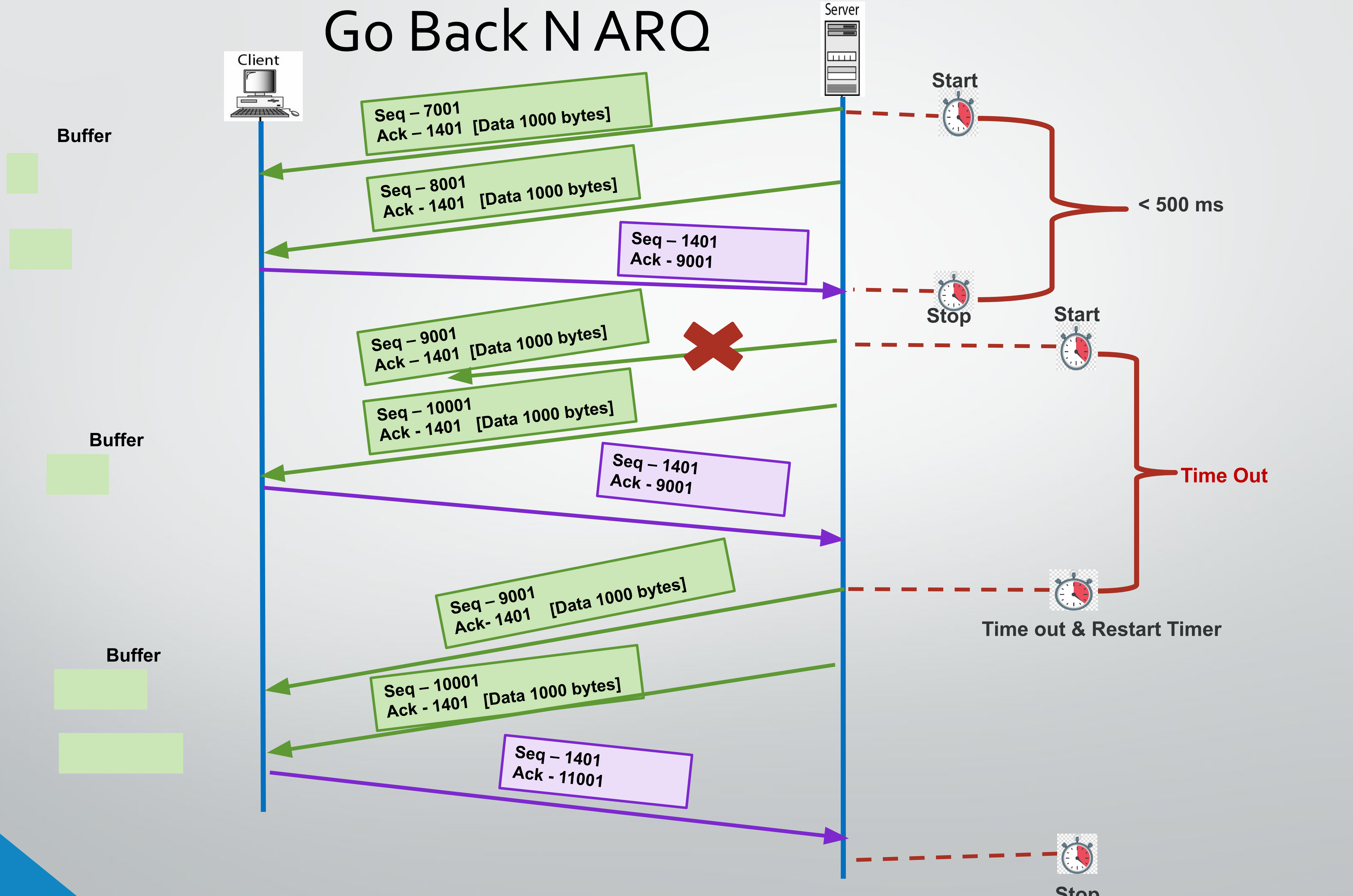


Different TCP Sliding Window Protocols

- **Selective Repeat Protocol**
  - Only those segments are re-transmitted which are found lost or corrupted
  - Keep track of out of order segments at the receiver side
  - More efficient for noisy channels
  - Widely used in TCP



Go Back N ARQ


Client
Server
Buffer
Seq – 7001
Ack – 1401 [Data 1000 bytes]
Start
Seq – 8001
Ack - 1401 [Data 1000 bytes]
< 500 ms
Seq – 1401
Ack - 9001
Stop
Start
Seq – 9001
Ack – 1401 [Data 1000 bytes]
Seq – 10001
Ack - 1401 [Data 1000 bytes]
Buffer
Seq – 1401
Ack - 9001
Time Out
Seq – 9001
Ack- 1401 [Data 1000 bytes]
Time out & Restart Timer
Buffer
Seq – 10001
Ack - 1401 [Data 1000 bytes]
Seq – 1401
Ack - 11001

Different TCP Sliding Window Protocols

- **Go Back N Protocol**
  - If the sent segment are are found corrupted or lost then all the segments are re-transmitted from the lost segment to the last segment transmitted
  - Do not keep track of out of order segments
  - Efficient for less noisy channel

Overall Flow control

- The initial window size is agreed during the **three-way handshake.**
- If this is too much for the receiver and it **loses data** (e.g. buffer overflow) then it can **decrease** the window size.
- If **all is well** then the receiver will **increase** the window size.

The End