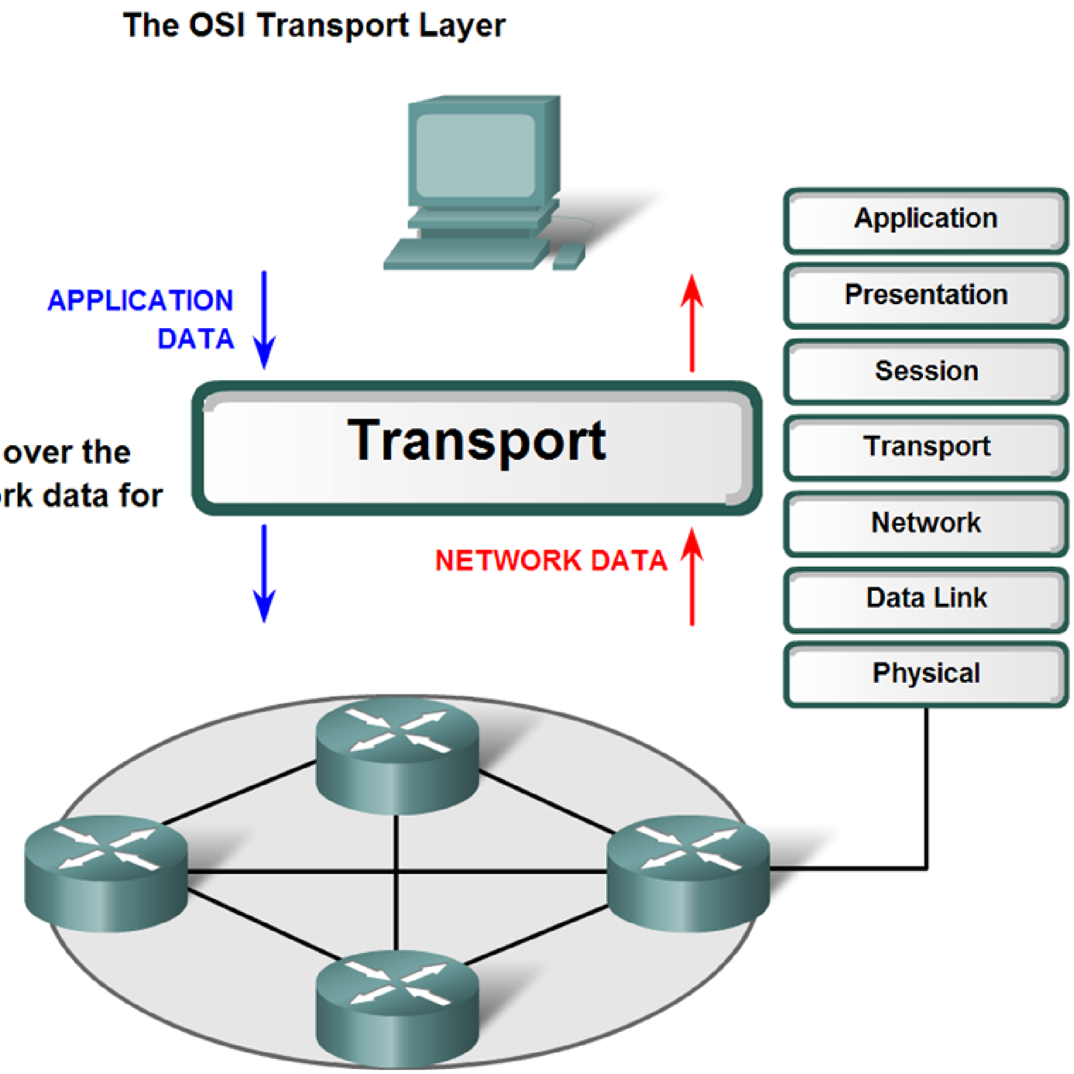
Transport Layer Protocols

TCP/UDP

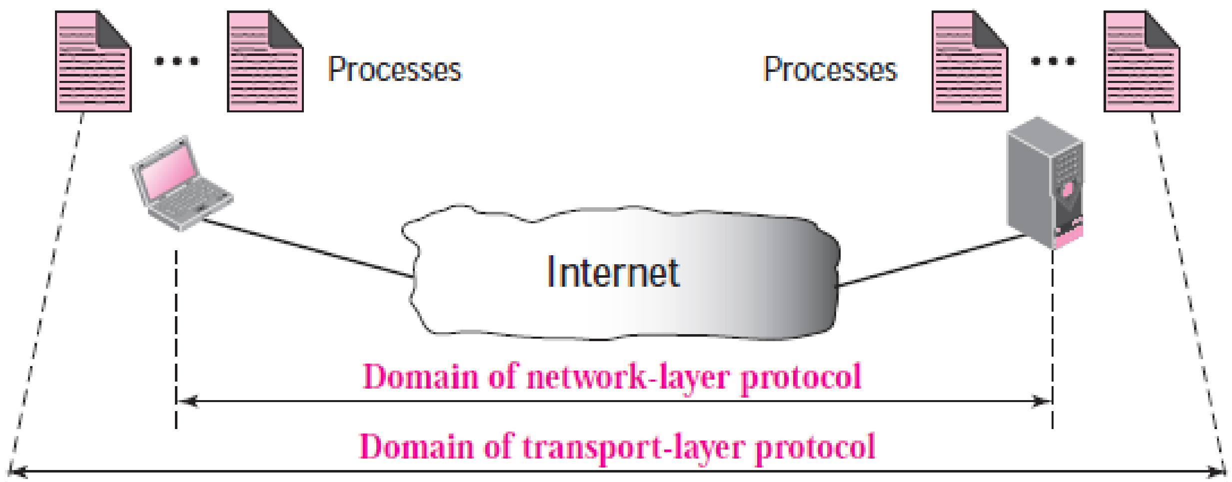
Overview



The Transport layer prepares application data for transport over the network and processes network data for use by applications.

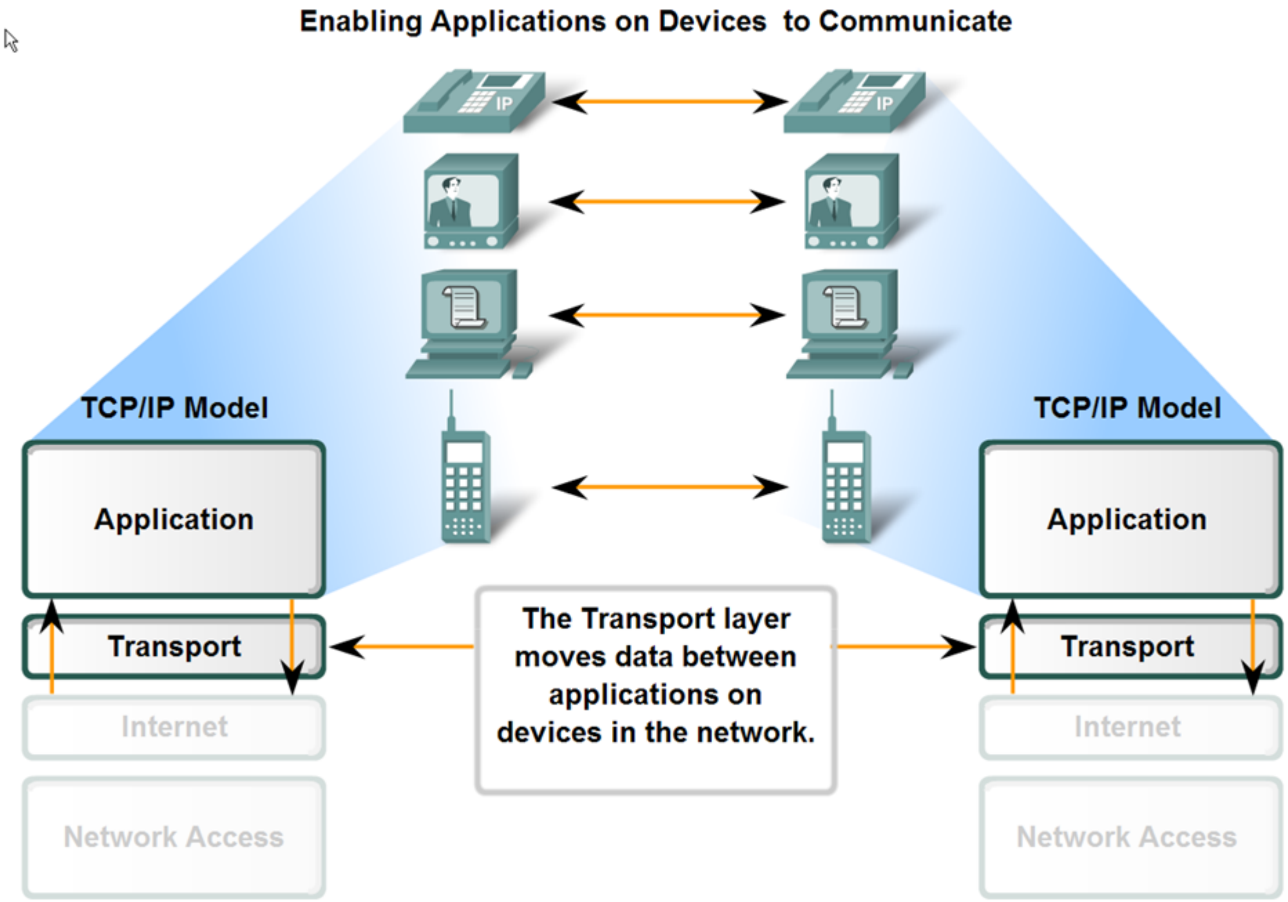
Process-to-Process Communication

- Transport-layer protocol provides **process-to-process communication.**
- A process is an application-layer entity (**running program**) that uses the services of the transport layer.
- Host-to-host communication vs. process-to-process communication

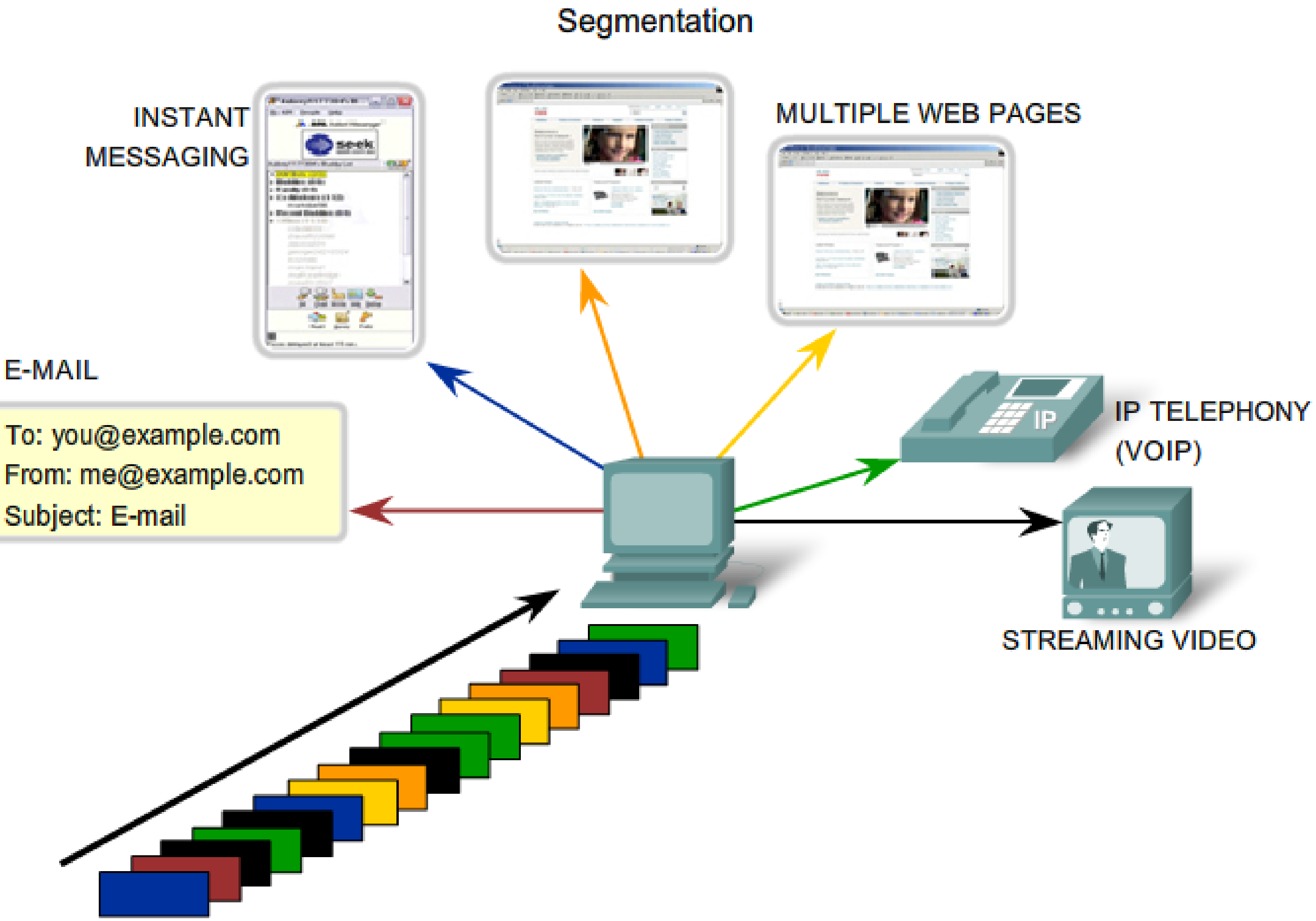


Transport Layer Role and Services

- Major functions of the transport layer and the role it plays in data networks

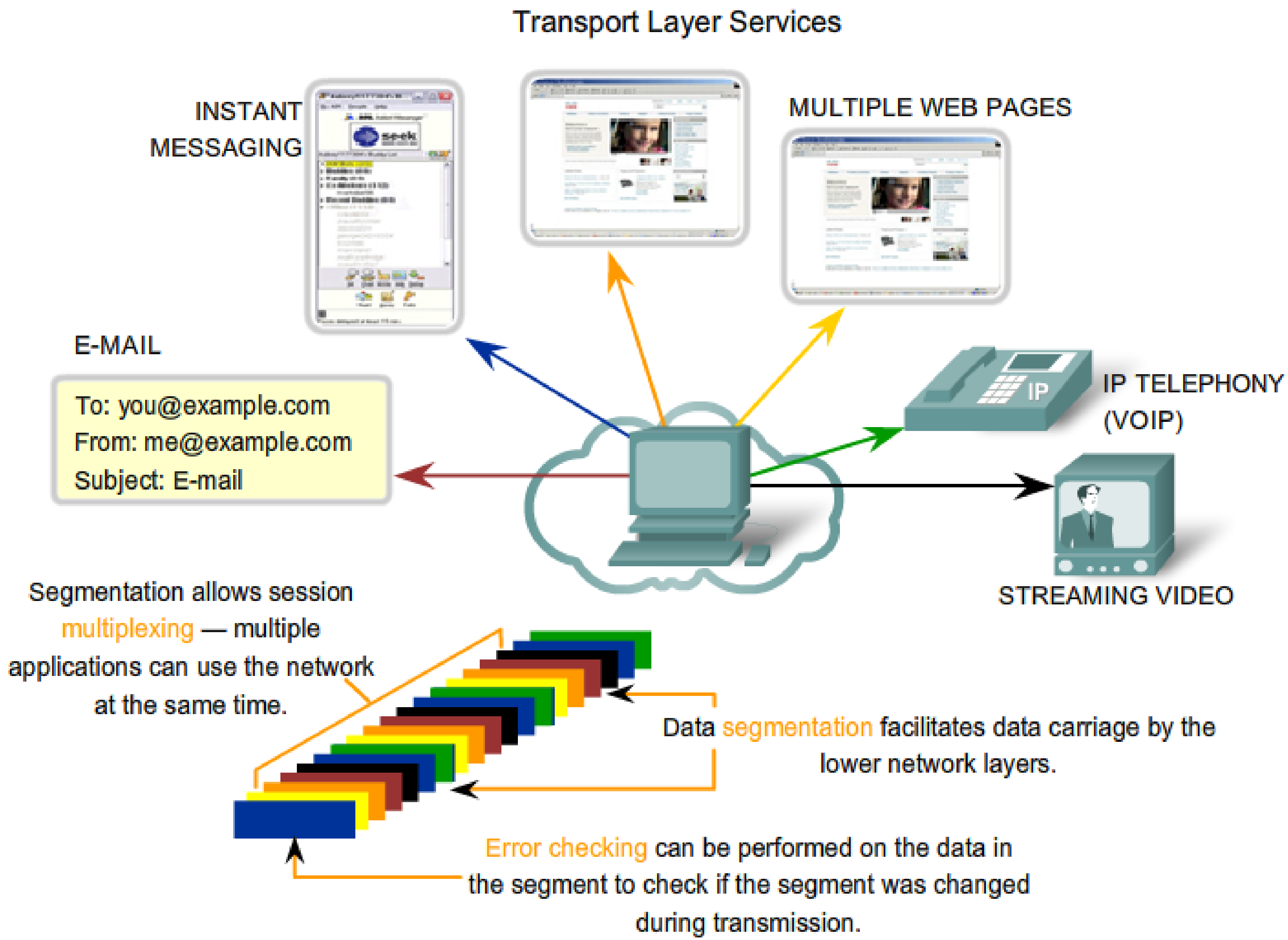


Transport Layer Role and Services



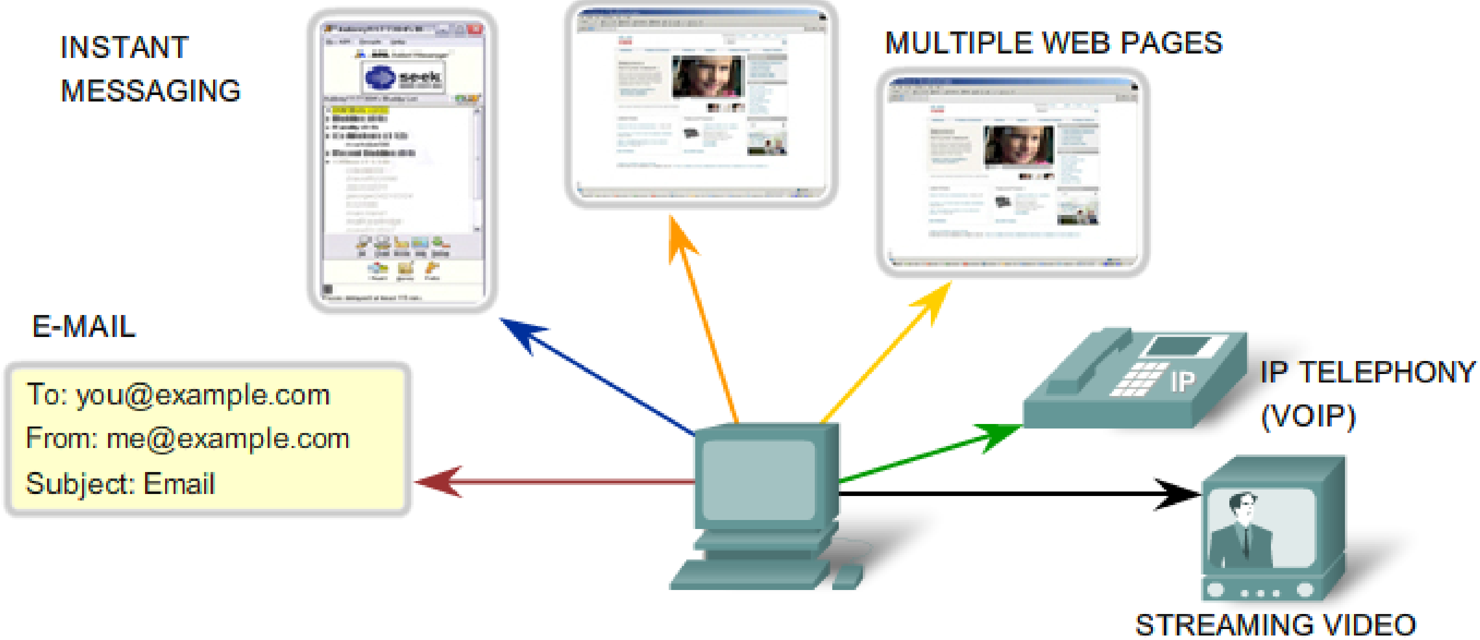
The Transport layer divides the data into segments that are easier to manage and transport.

Transport Layer Role and Services



Summary

Transport Layer Services



Establishing a Session ensures the application is ready to receive the data.

Reliable delivery means lost segments are resent so the data is received complete.

Same order delivery ensures data is delivered sequentially as it was sent.

Flow Control manages data delivery if there is congestion on the host.

Sample Question

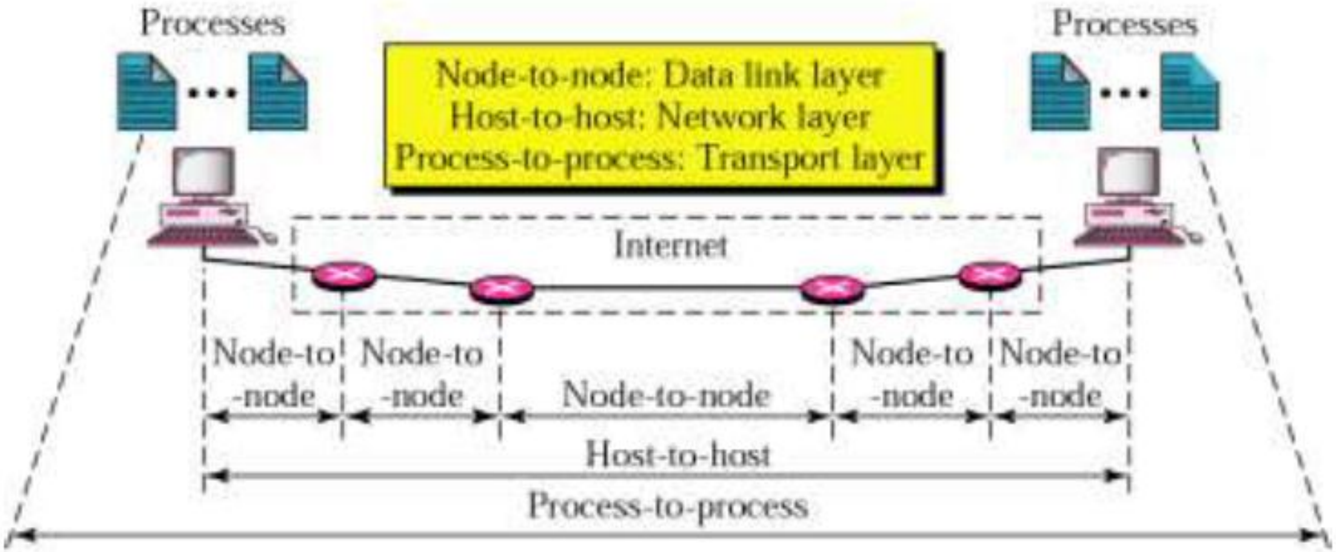
- One of the responsibilities of the transport layer protocol is to create a _______ communication.

A) host-to-host

B) process-to-process

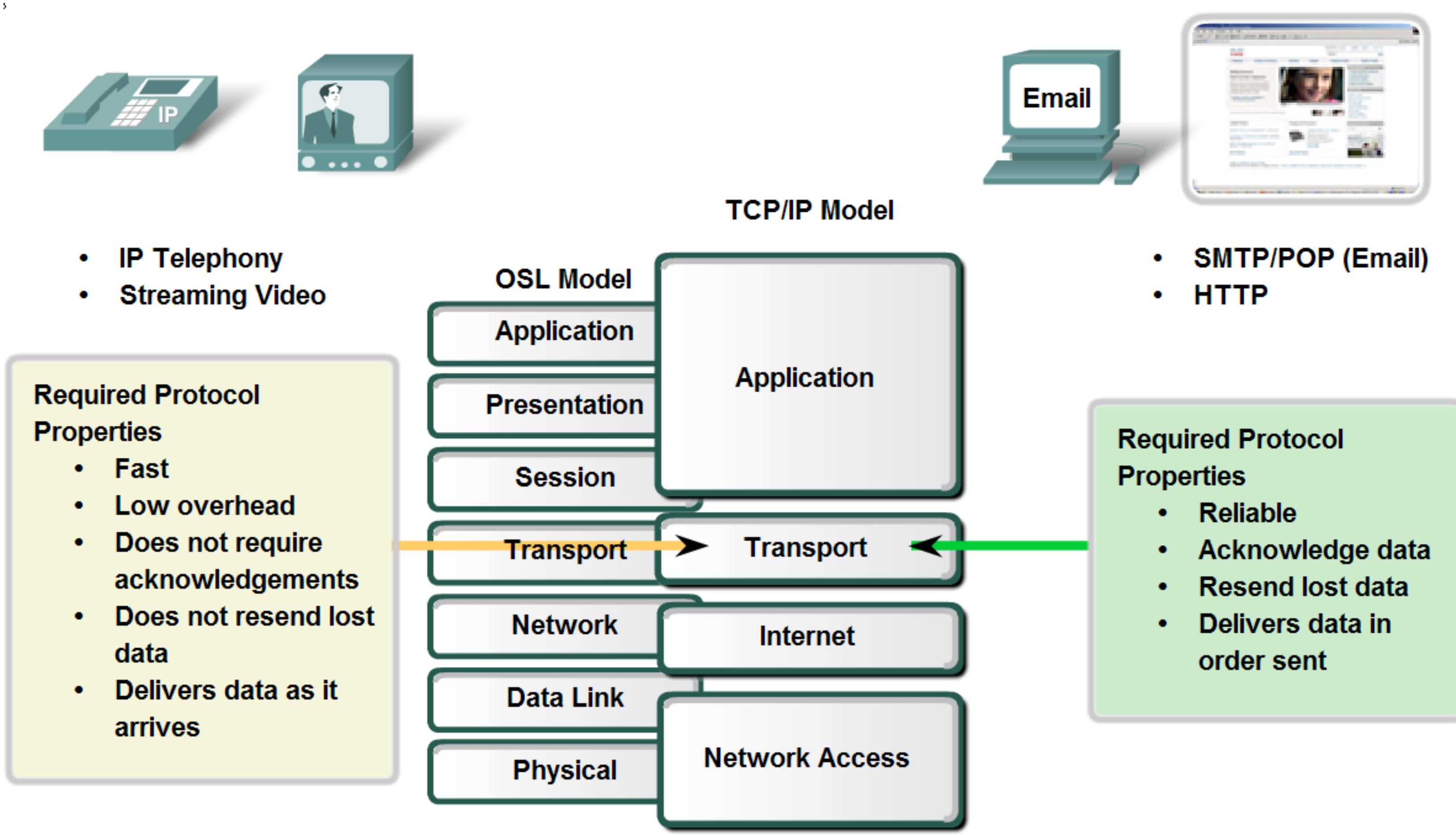
C) node-to-node

D) none of the above



Transport Layer Requirements

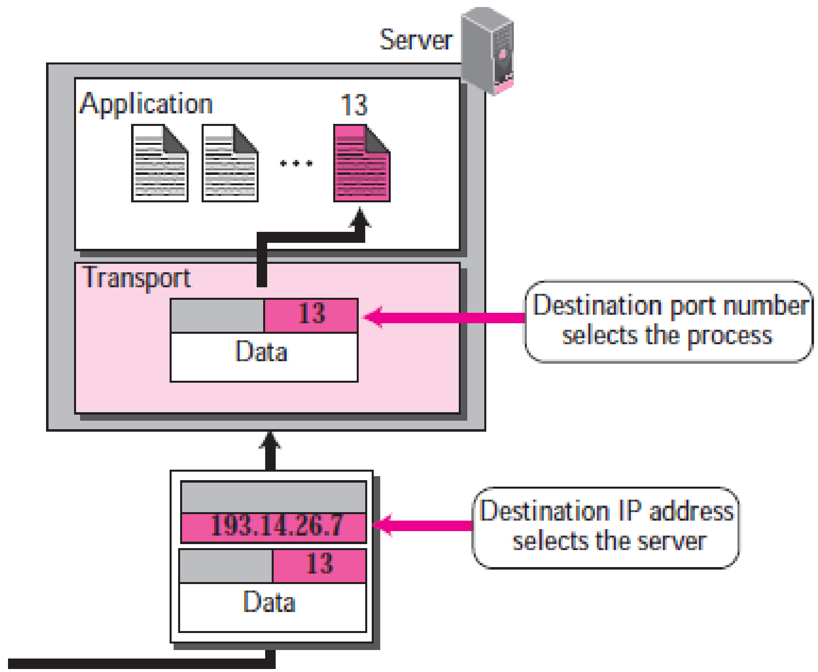
Transport Layer Protocols



Application developers choose the appropriate Transport Layer protocol based on the nature of the application.

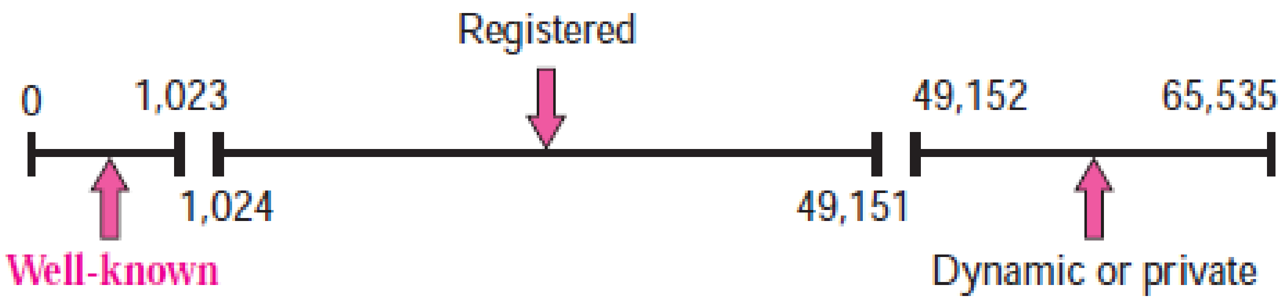
Addressing: Port Numbers

- **Port address/number -** in TCP/IP protocol, an integer identifying a process; Port numbers are integers between 0 and 65,535.
- TCP/IP has decided to use universal port numbers for servers; called **well-known port numbers.**

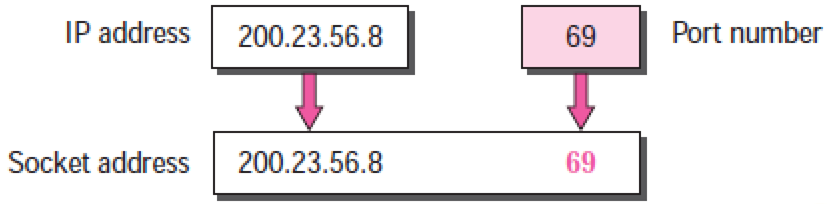


Port Numbers

- Internet Corporation for Assigned Names and Numbers (**ICANN**) has divided the port numbers into three ranges: well-known, registered, and dynamic (or private).

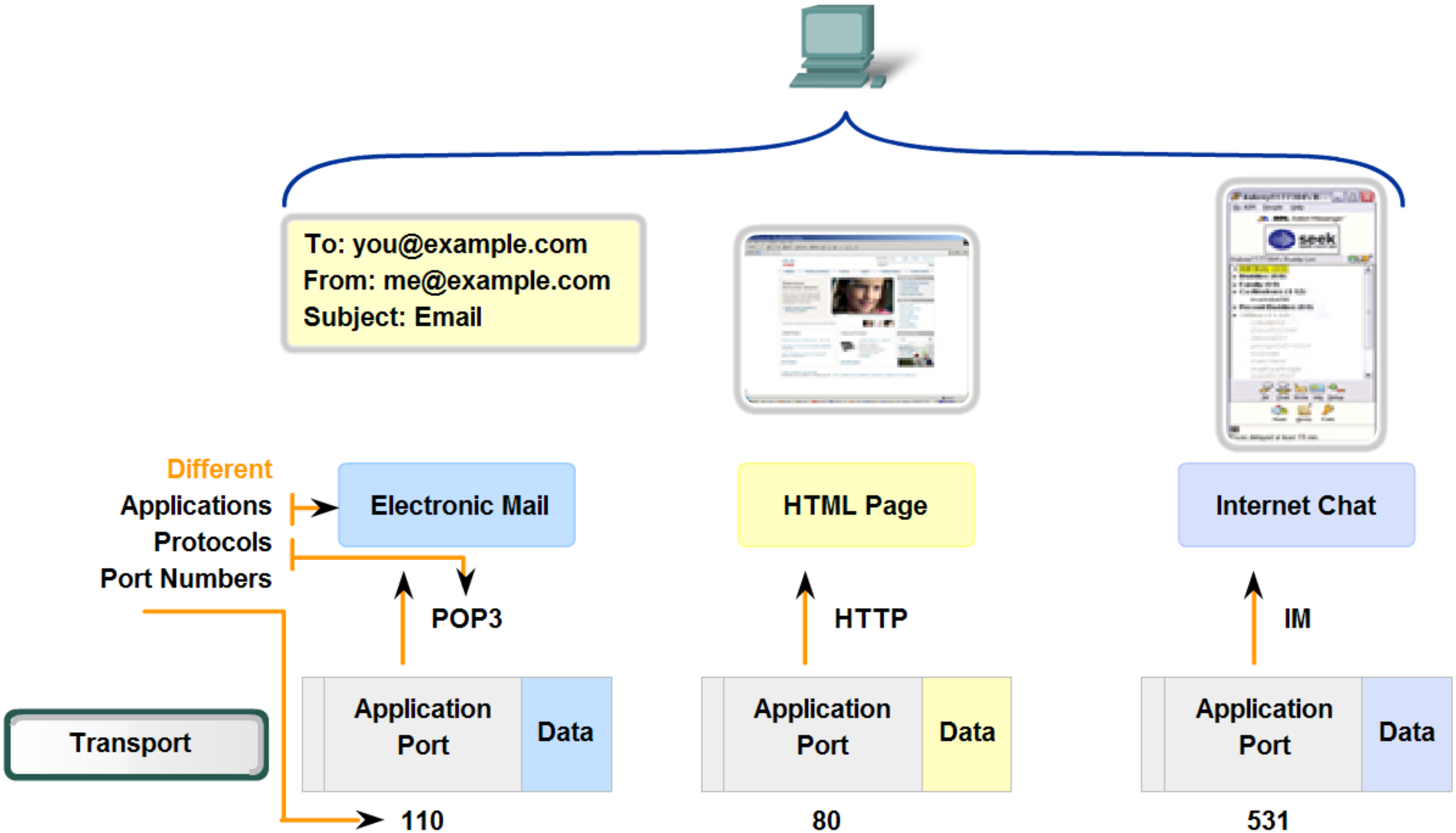


- Socket address: combination of an IP address and a port number.



Example

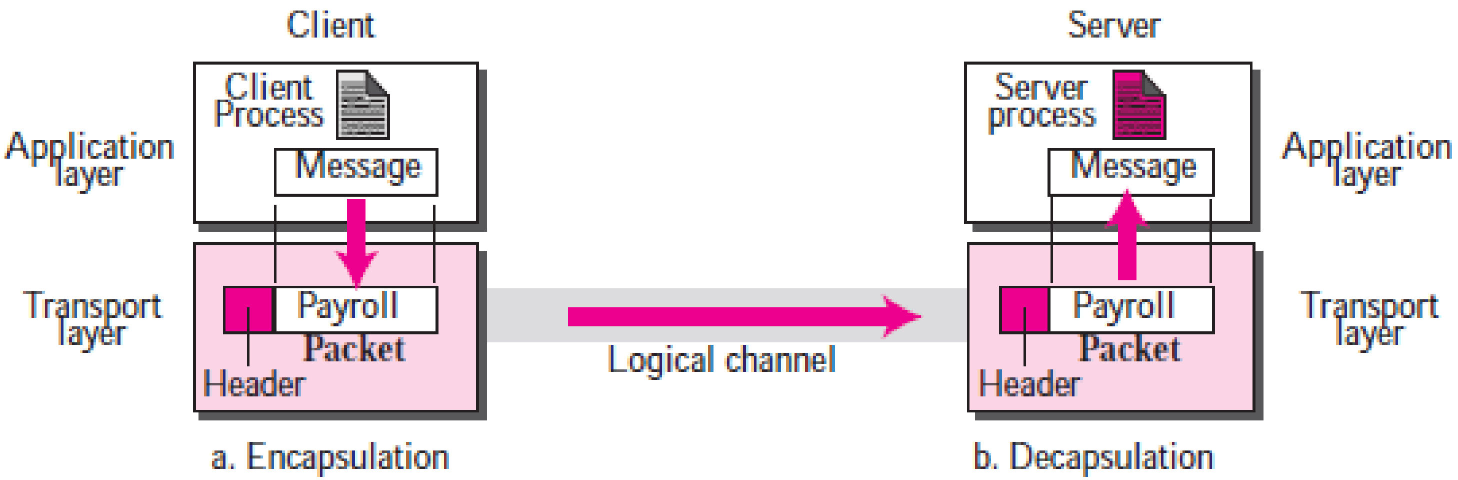
Port Addressing



Data for different applications is directed to the correct application because each application has a unique port number.

Encapsulation and Decapsulation

- To send a message from one process to another, the transport layer protocol encapsulates and decapsulates messages.



Multiplexing and Demultiplexing

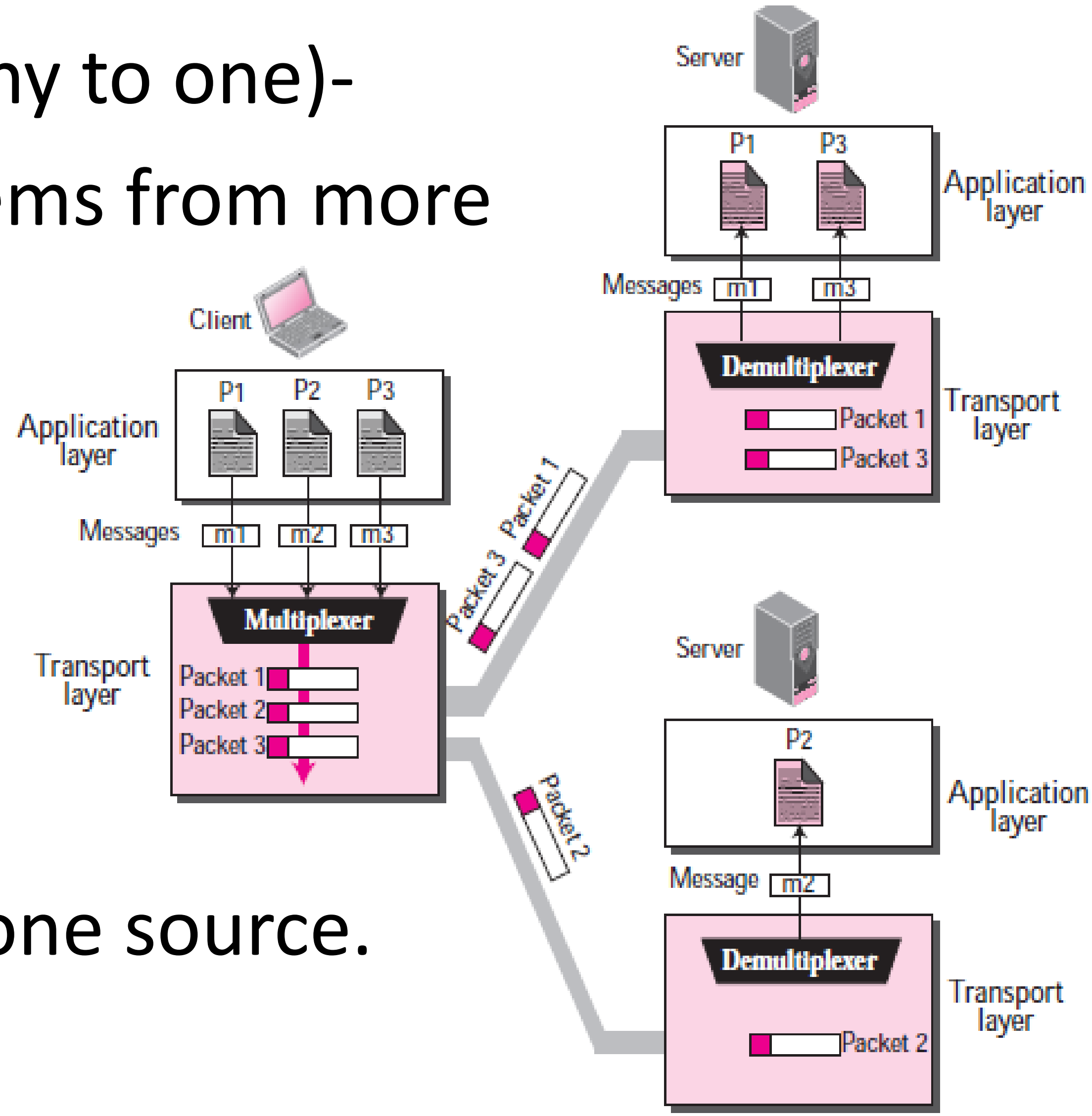
- **Multiplexing** (many to one)-

an entity accepts items from more than one source.

- **Demultiplexing**

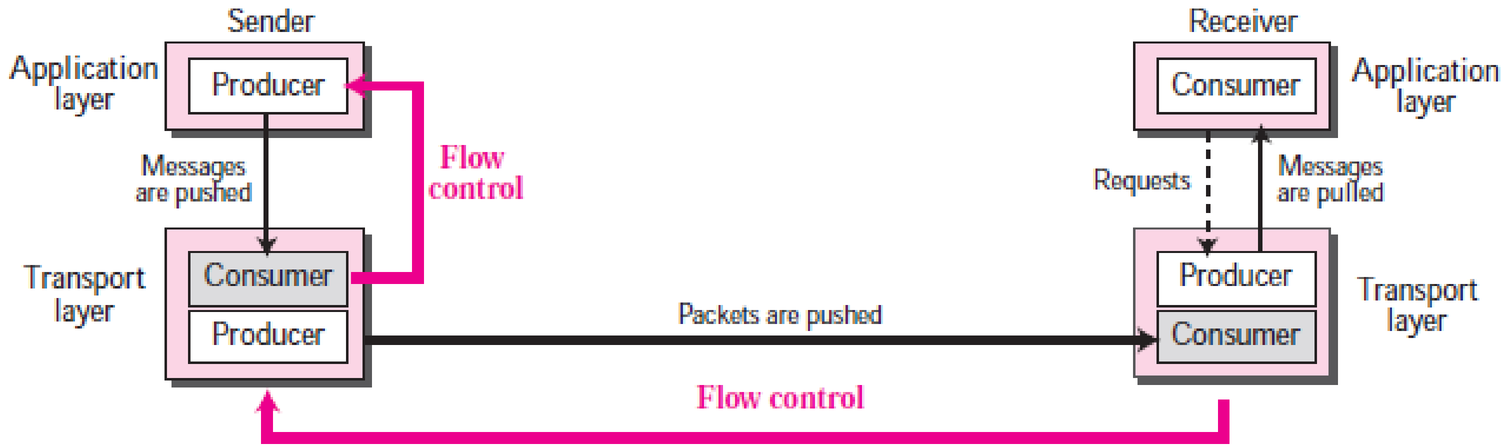
(one to many) –

an entity delivers items to more than one source.



Flow Control at Transport Layer

- In communication at the transport layer, we are dealing with four entities: **sender process**, **sender transport layer**, **receiver transport layer**, and **receiver process**.



Error Control

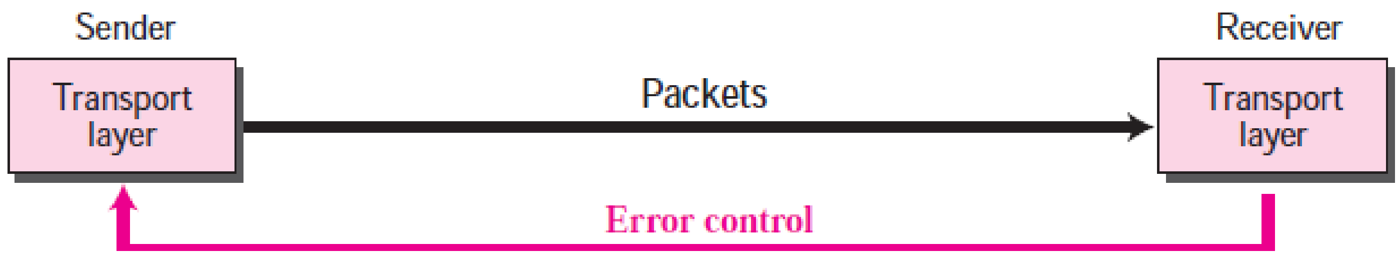
- We need to make the transport layer reliable if required by the application.

1. Detect and discard corrupted packets.

2. Keep track of lost and discarded packets and resend them.

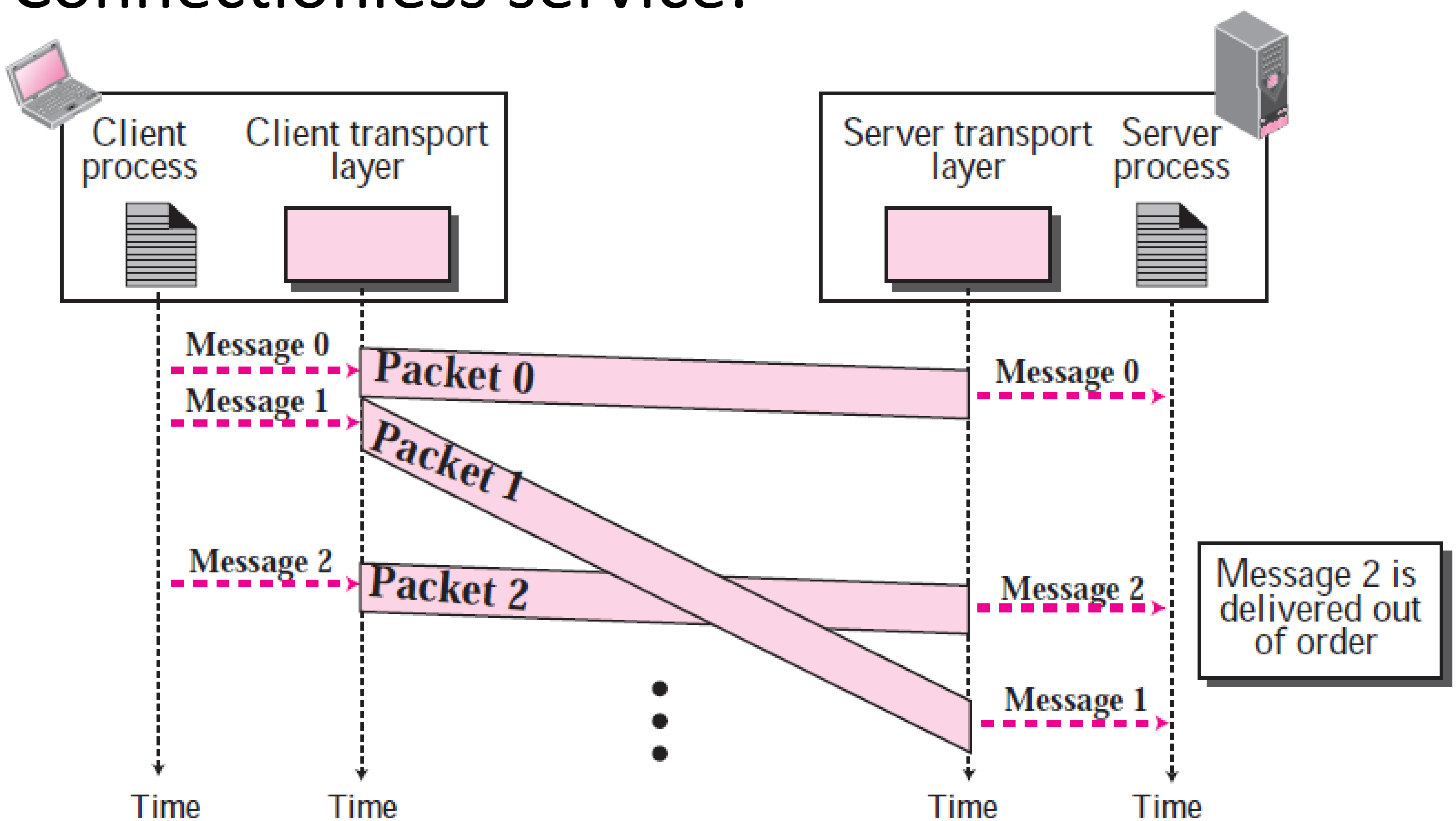
3. Recognize duplicate packets and discard them.

4. Buffer out-of-order packets until the missing packets arrive.



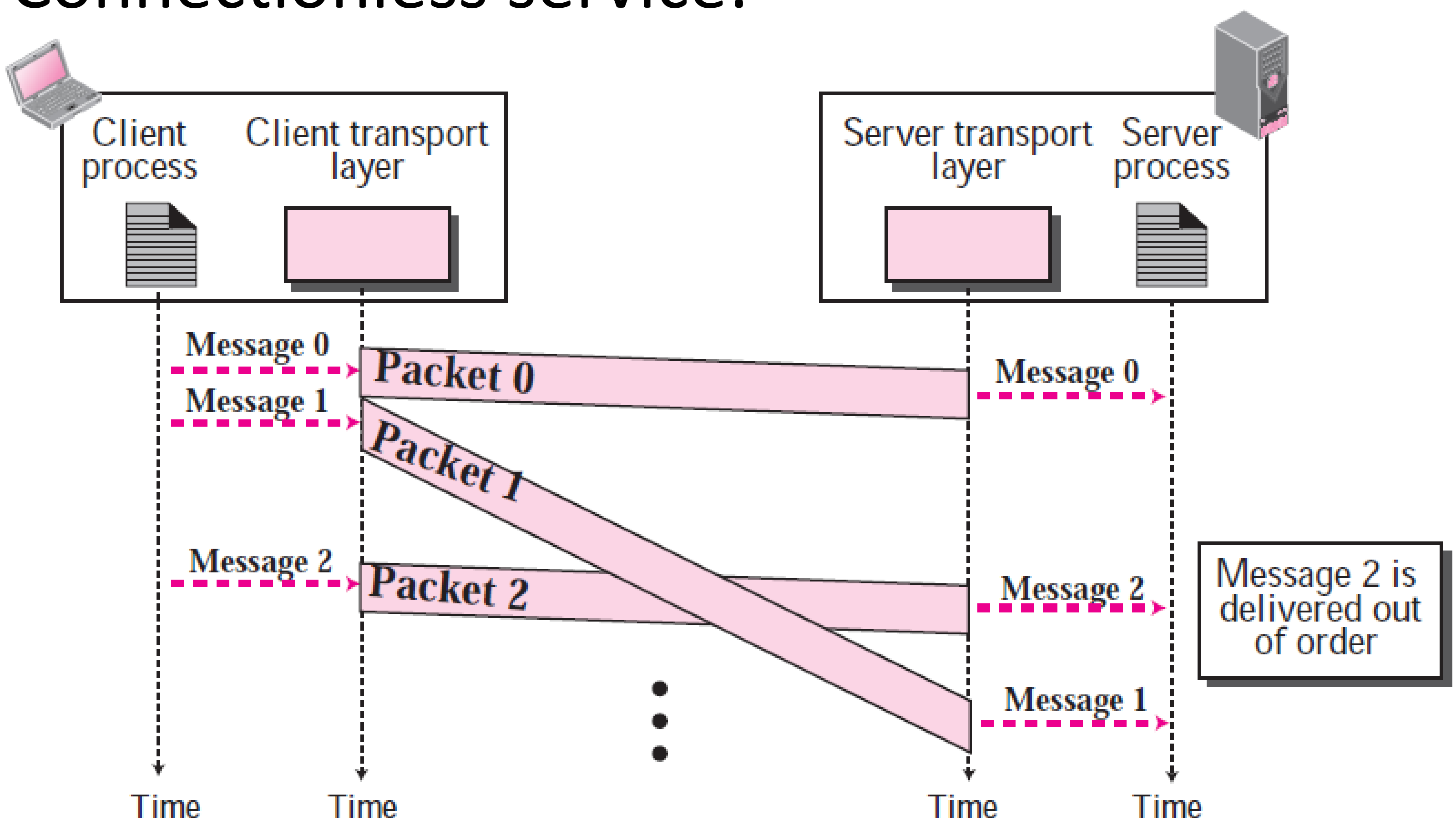
Connectionless vs. Connection-Oriented Service

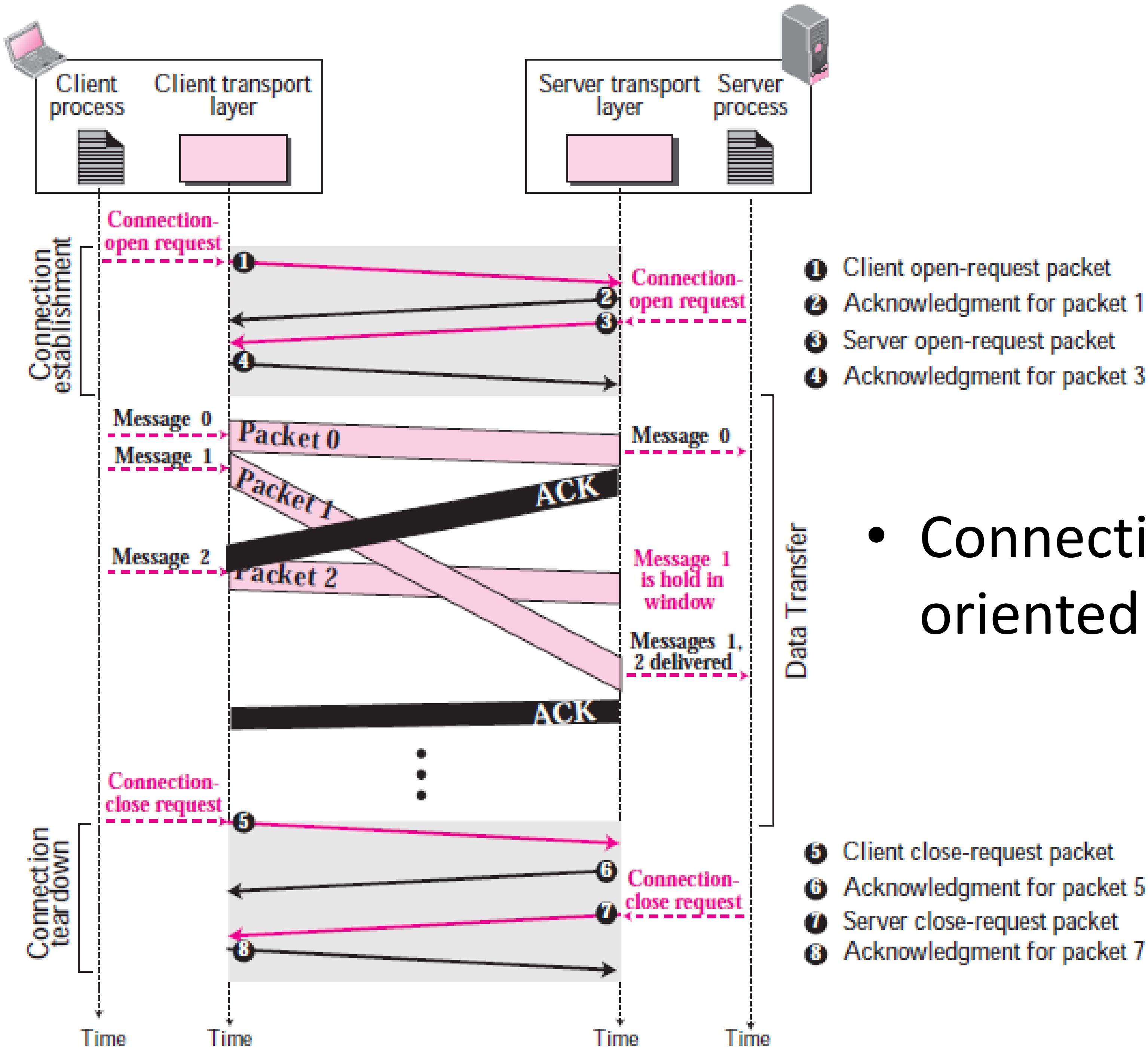
- Connectionless service:



Connectionless vs. Connection-Oriented Service

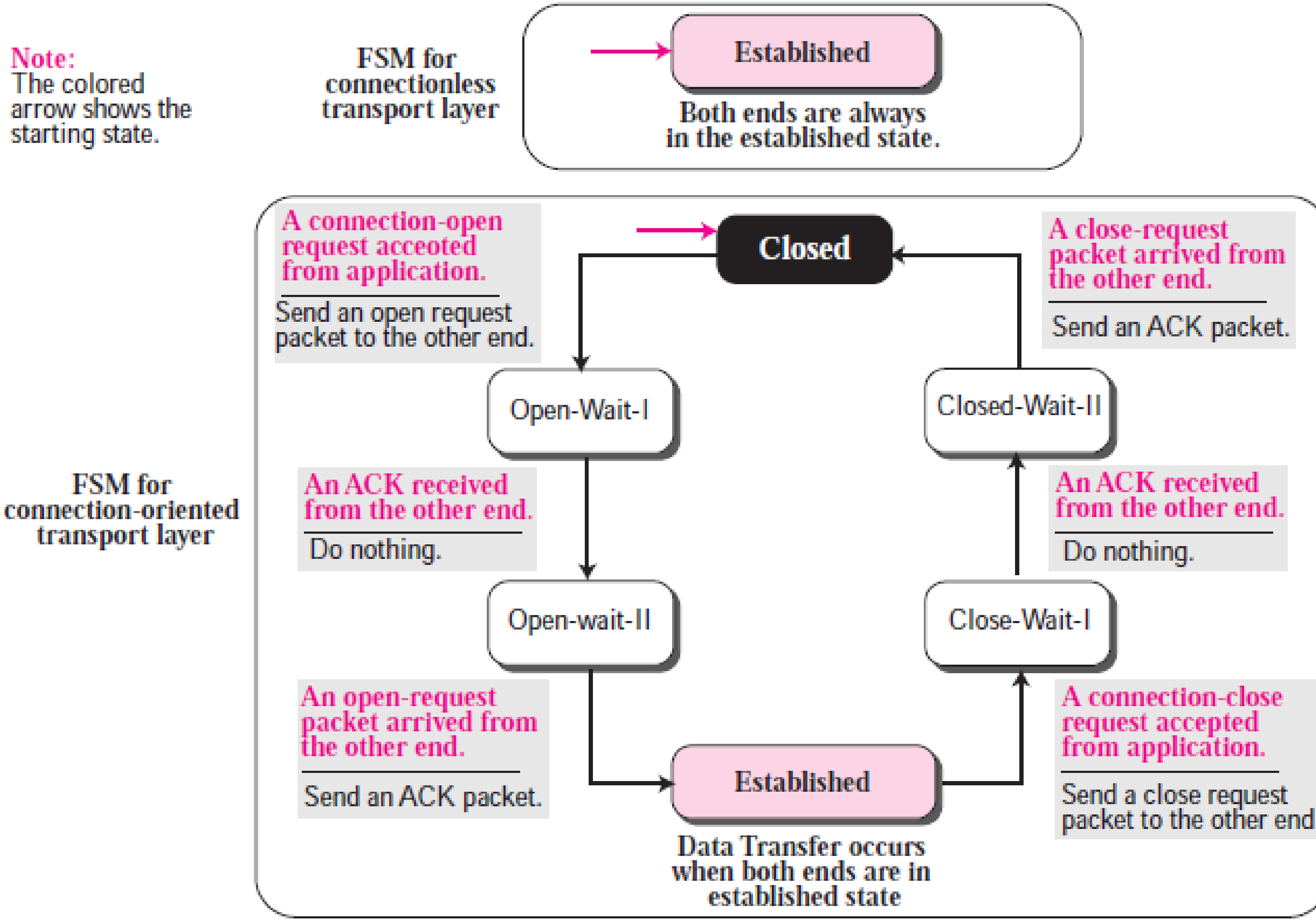
- Connectionless service:





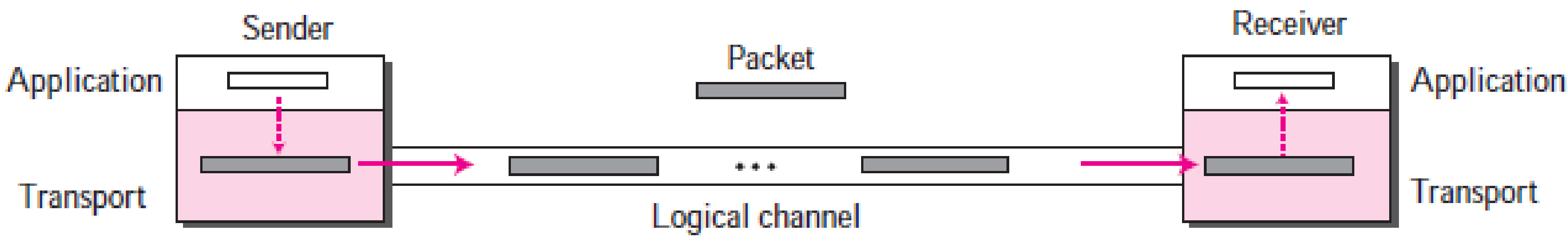
- Connection-oriented service

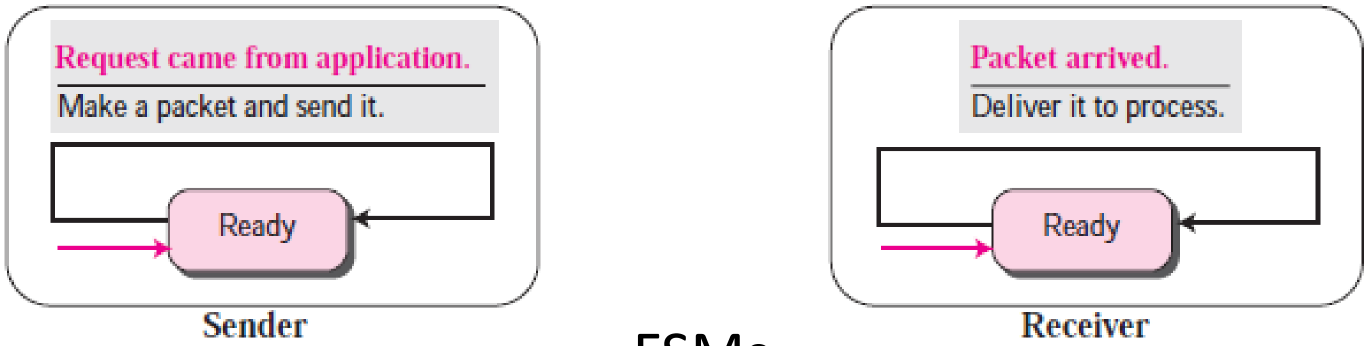
Finite State Machine (FSM) Representation



Simple Protocol

- A connectionless protocol that provides neither flow nor error control.





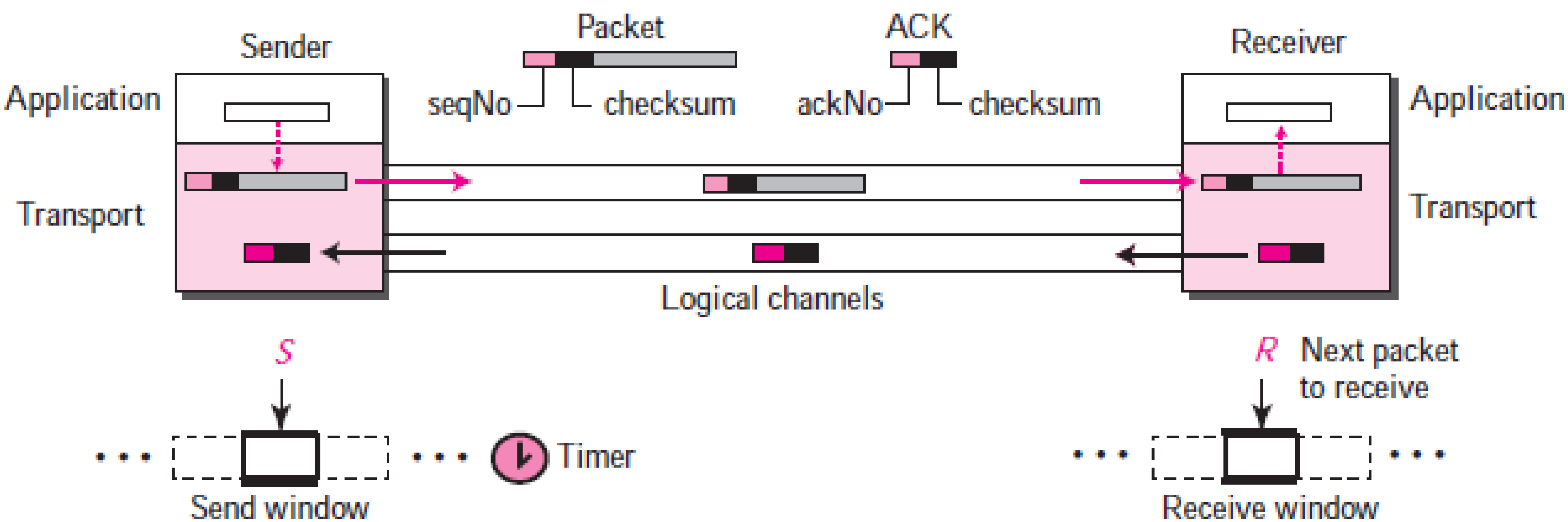
FSMs

Stop-and-Wait Protocol

- A connection-oriented protocol that provides flow and error control.
- The sender sends one packet at a time and waits for an acknowledgment before sending the next one.
- To detect corrupted packets, we need to add a checksum to each data packet.
- The silence of the receiver is a signal for the sender that a packet was either corrupted or lost.

Stop-and-Wait Protocol

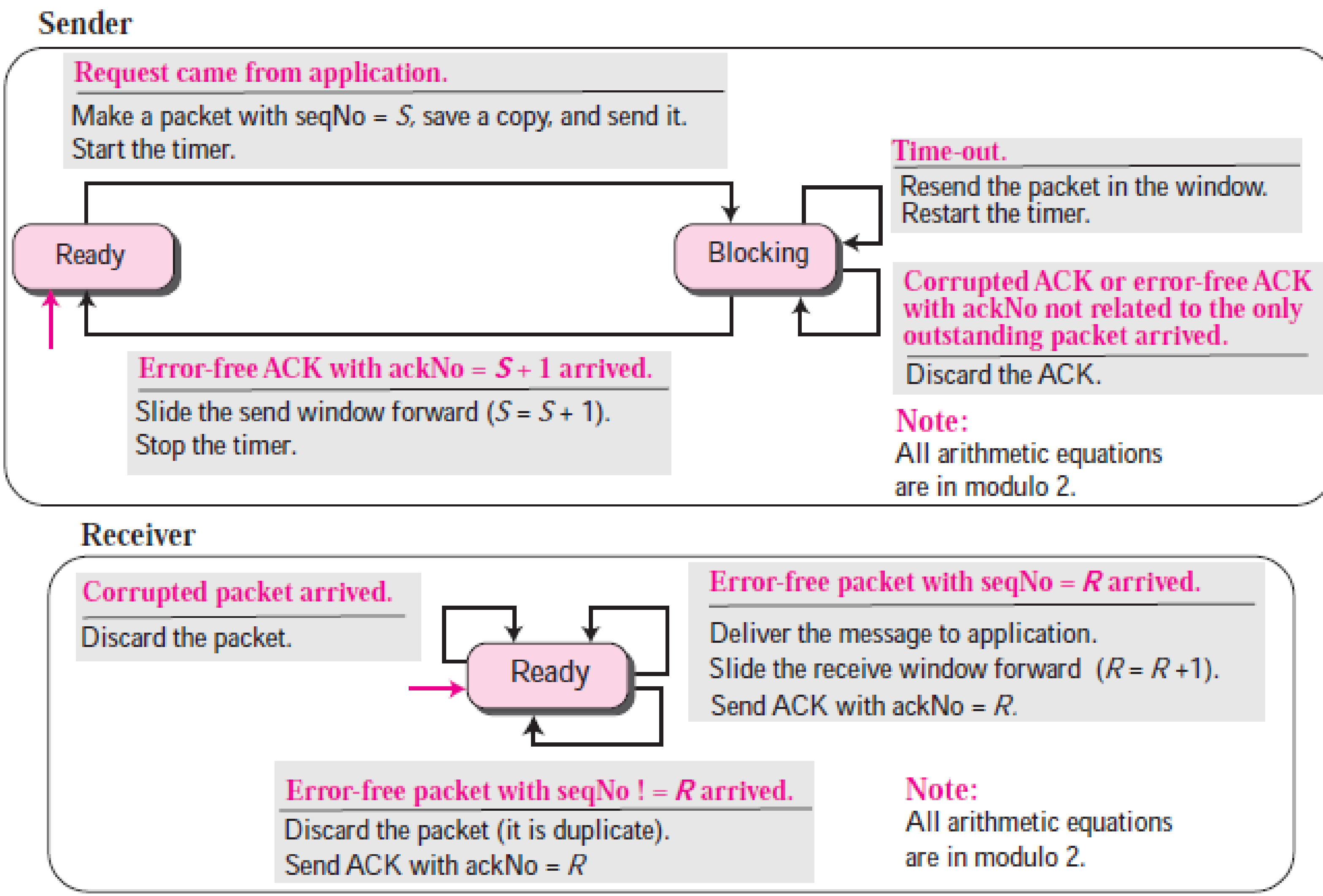
- Every time the sender sends a packet, it starts a timer. If an acknowledgment arrives before the timer expires, the timer is stopped and the sender sends the next packet.



Understand

- How does **Stop-and-Wait protocol** provide flow and error control?
- **In Stop-and-Wait protocol, flow control is achieved by forcing the sender to wait for an acknowledgment, and**
- **Error control is achieved by discarding corrupted packets and letting the sender resend unacknowledged packets when the timer expires.**

Stop-and-Wait Protocol FSM



Two transport layer protocols in the Internet

- **Transmission Control Protocol (TCP)** – “ a connection-oriented, end-to-end reliable protocol designed to fit into a layered hierarchy of protocols which support multi-network applications.” - RFC793
- **User Datagram Protocol (UDP)** – “ a minimal protocol mechanism w/c is transaction oriented, and delivery and duplicate protection are not guaranteed”. –RFC768

Understand

Transport Layer Functions

The Transport layer divides the data into pieces and adds a header for delivery over the network.

APPLICATION LAYER DATA		
Piece 1	Piece 2	Piece 3

UDP Datagram Or **TCP Segment**

UDP Datagram	
Header	Piece 1
Header	Piece 2
Header	Piece 3

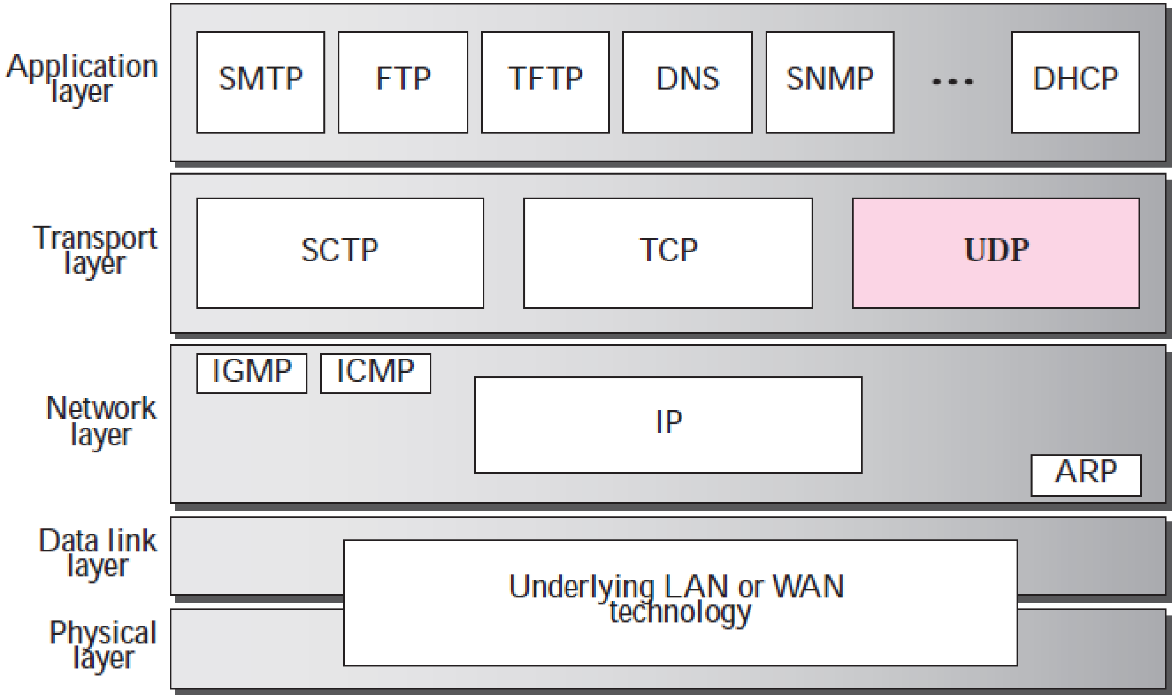
TCP Segment	
Header	Piece 1
Header	Piece 2
Header	Piece 3

UDP Header provides for:
- Source and destination (ports)

TCP Header provides for:
- Source & destination (ports)
- Sequencing for same order delivery
- Acknowledgement of received segments
- Flow control and congestion management

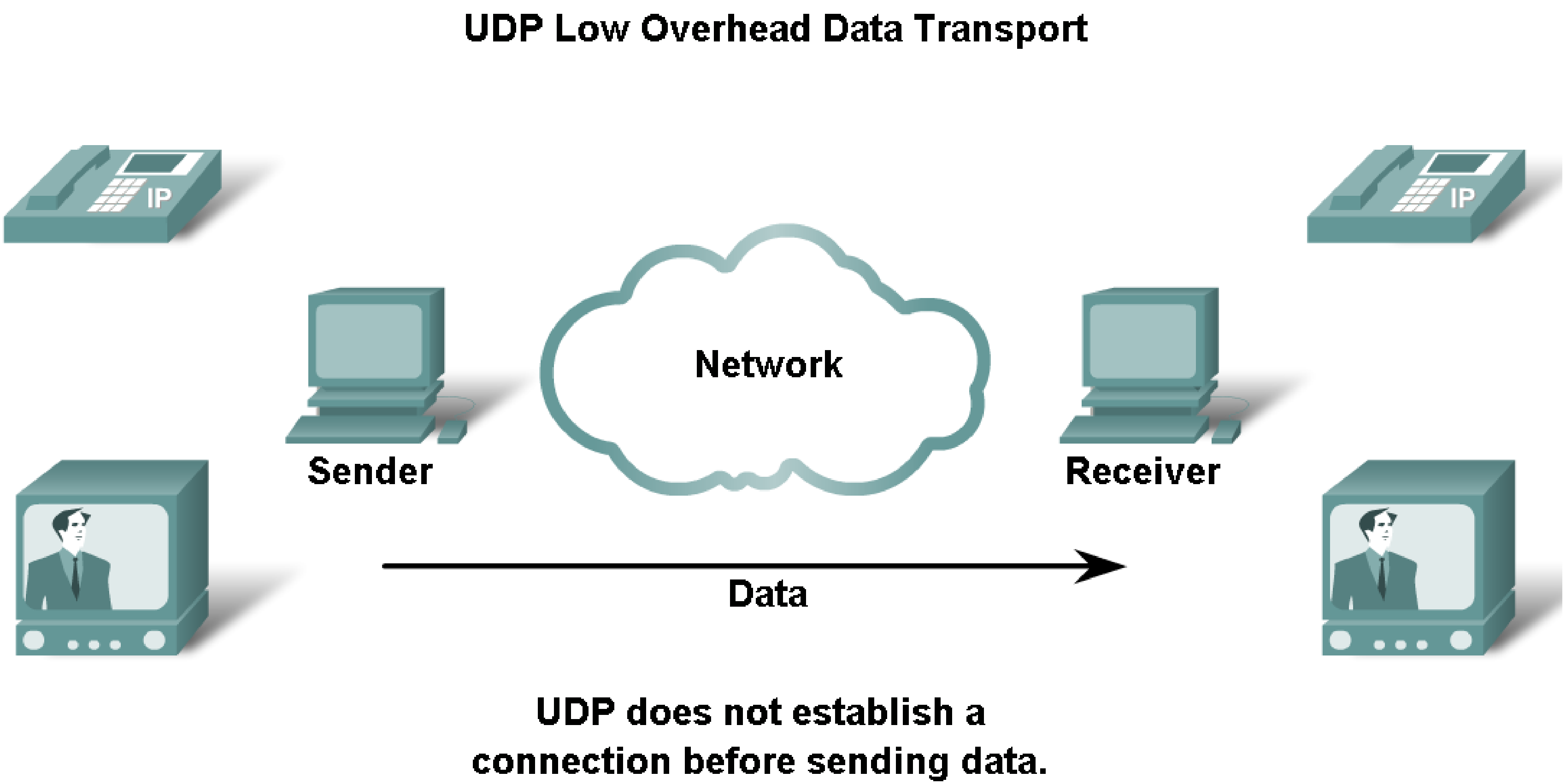
User Datagram Protocol (UDP)

- A connectionless, unreliable transport protocol.



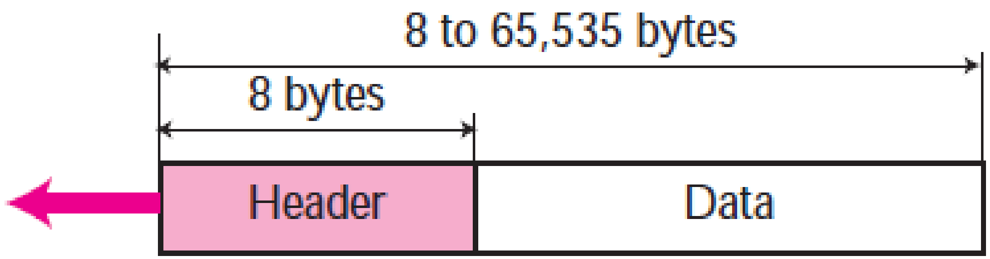
- UDP is an example of the connectionless simple protocol with the exception of an optional checksum added to packets for error detection.

User Datagram Protocol (UDP)

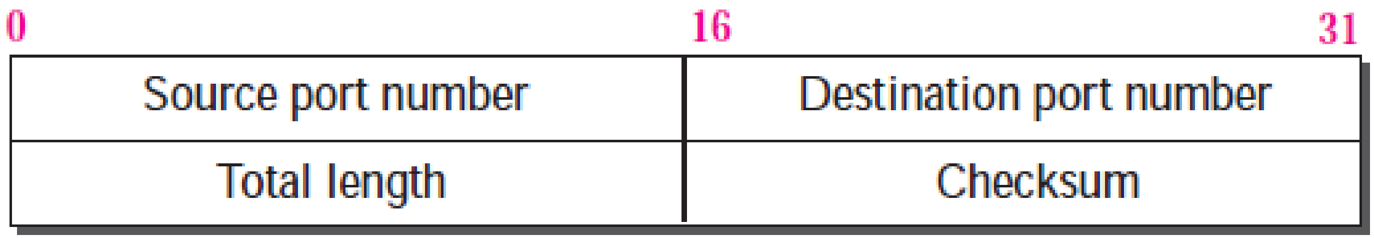


User Datagram Protocol (UDP)

- UDP packets, called **user datagrams,** have a fixed-size header of 8 bytes.



a. UDP user datagram



b. Header format

User Datagram Protocol (UDP)

- **Source port number.** This is the port number used by the process running on the source host. It is 16 bits long, which means that the port number can range from 0 to 65,535.
- **Destination port number.** This is the port number used by the process running on the destination host. It is also 16 bits long.
- **Length.** This is a 16-bit field that defines the total length of the user datagram, header plus data.

  UDP length = IP length − IP header's length
- **Checksum.** This field is used to detect errors over the entire user datagram.

Example

- The following is a dump of a UDP header in hexadecimal format.

CB84000D001C001C

a. What is the source port number?

b. What is the destination port number?

c. What is the total length of the user datagram?

d. What is the length of the data?

e. Is the packet directed from a client to a server or vice versa?

f. What is the client process?

Answer

a. The source port number is the first four hexadecimal digits (CB8416), which means that the source port number is 52100.

b. The destination port number is the second four hexadecimal digits (000D16), which means that the destination port number is 13.

c. The third four hexadecimal digits (001C16) define the length of the whole UDP packet as 28 bytes.

d. The length of the data is the length of the whole packet minus the length of the header, or 28 – 8 = 20 bytes.

e. Since the destination port number is 13 (well-known port), the packet is from the client to the server.

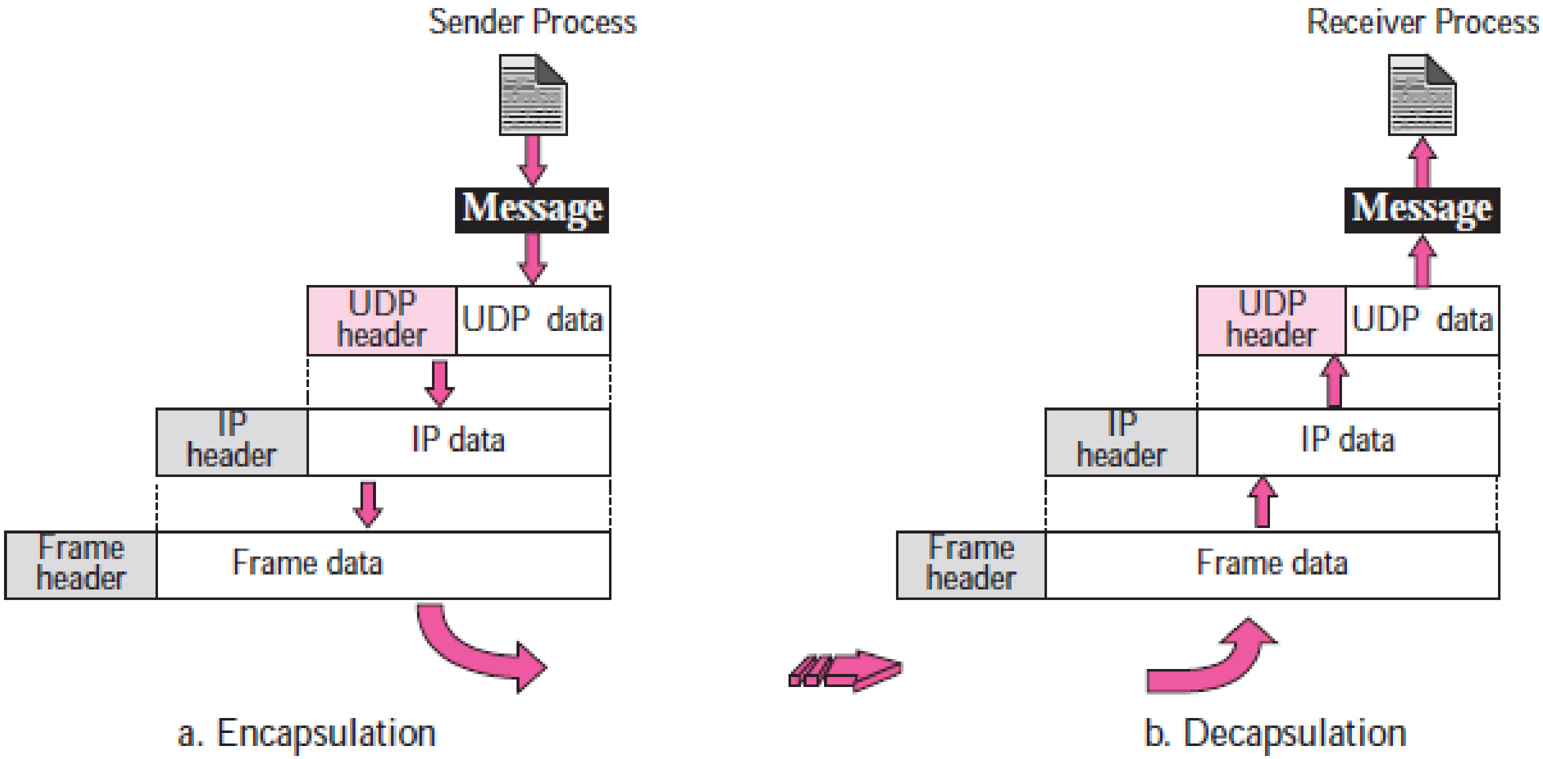
f. The client process is the Daytime.

Well-known Ports in UDP

Port	*Protocol*	*Description*
7	Echo	Echoes a received datagram back to the sender
9	Discard	Discards any datagram that is received
11	Users	Active users
13	Daytime	Returns the date and the time
17	Quote	Returns a quote of the day
19	Chargen	Returns a string of characters
53	Domain	Domain Name Service (DNS)
67	Bootps	Server port to download bootstrap information
68	Bootpc	Client port to download bootstrap information
69	TFTP	Trivial File Transfer Protocol
111	RPC	Remote Procedure Call
123	NTP	Network Time Protocol
161	SNMP	Simple Network Management Protocol
162	SNMP	Simple Network Management Protocol (trap)

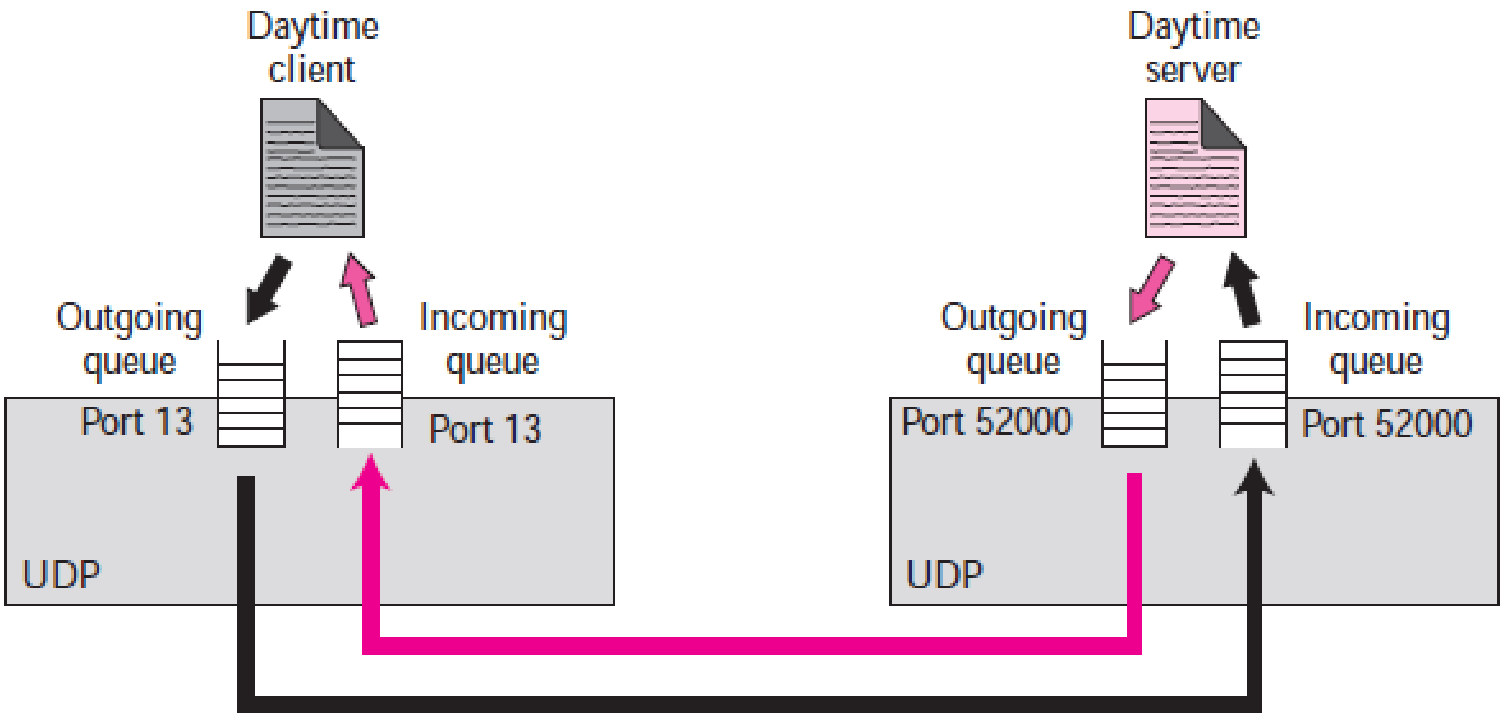
UDP Encapsulation and Decapsulation

- When a process has a message to send through UDP, it passes the message to UDP along with a pair of socket addresses and the length of data.



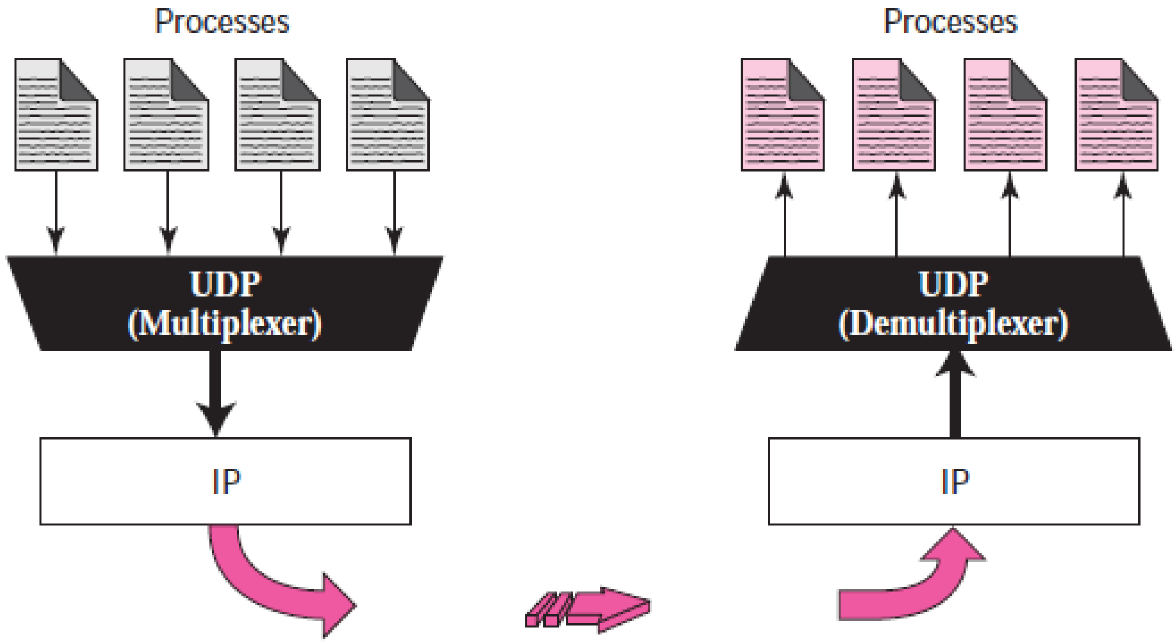
UDP Queues

- If a process wants to communicate, it obtains only one port number and one outgoing and one incoming queue.

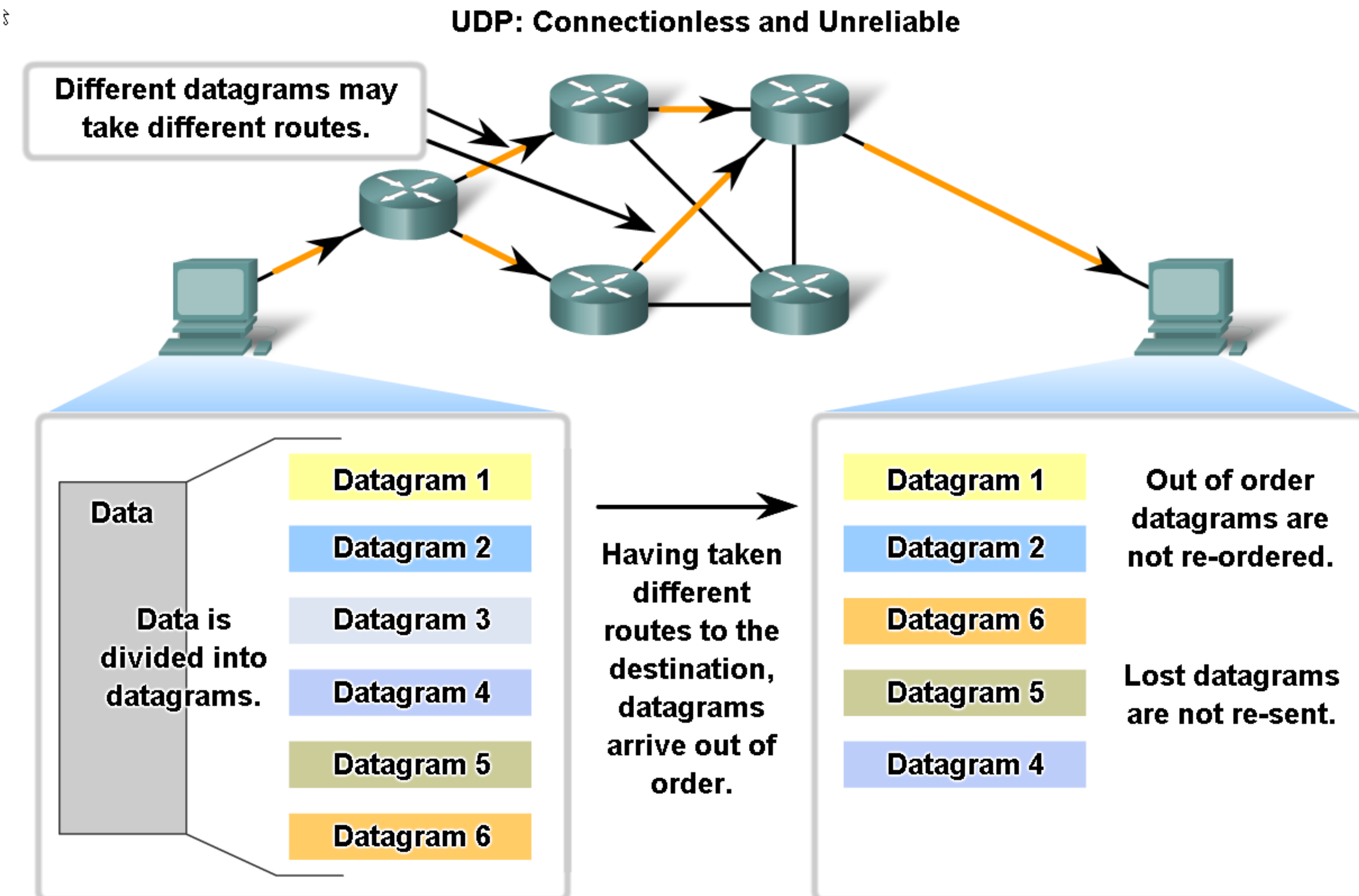


Multiplexing and Demultiplexing

- In a host running a TCP/IP protocol suite, there is only one UDP but possibly several processes that may want to use the services of UDP.



UDP Data Transfer



Typical Applications

- UDP is suitable for a process that requires simple request-response communication with little concern for flow and error control. It is not usually used for a process such as FTP that needs to send bulk data.
- UDP is suitable for a process with internal flow and error-control mechanisms. For example, the Trivial File Transfer Protocol (TFTP) process includes flow and error control.
- UDP is used for management processes such as SNMP.

Typical Applications

- UDP is a suitable transport protocol for multicasting. Multicasting capability is embedded in the UDP software but not in the TCP software.
- UDP is normally used for real-time applications that cannot tolerate uneven delay between sections of a received message.
- UDP is used for some route updating protocols such as Routing Information Protocol (RIP).

Transmission Control Protocol

- **Connection-oriented, reliable**

  - Provides connection-oriented/stream-oriented communication over a connectionless network layer protocol (IP).

- **End-to-end full duplex link**

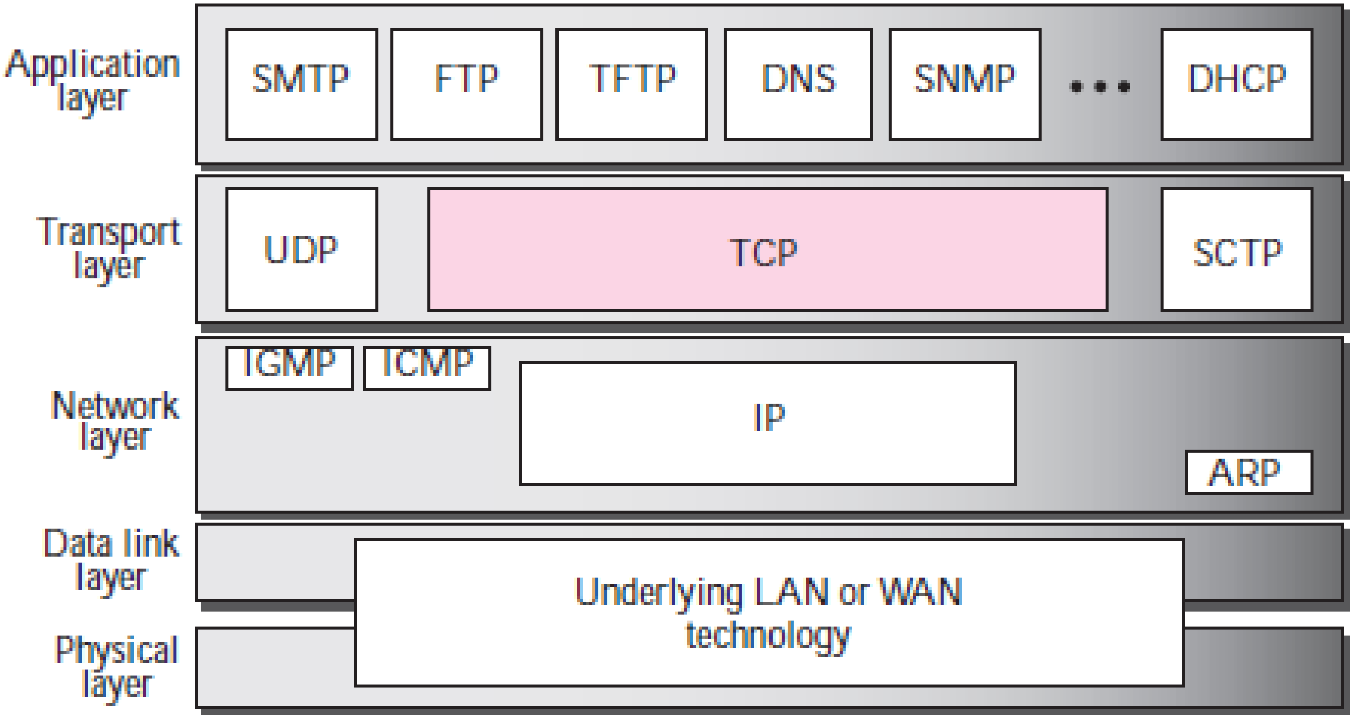
  - Exactly two end points

  - Multicasting or broadcasting is not supported

- Supports flow control and error control
- Described in RFCs 793, 1122, 5681

Transmission Control Protocol

- TCP lies between the application layer and the network layer, and serves as the intermediary between the application programs and the network operations.



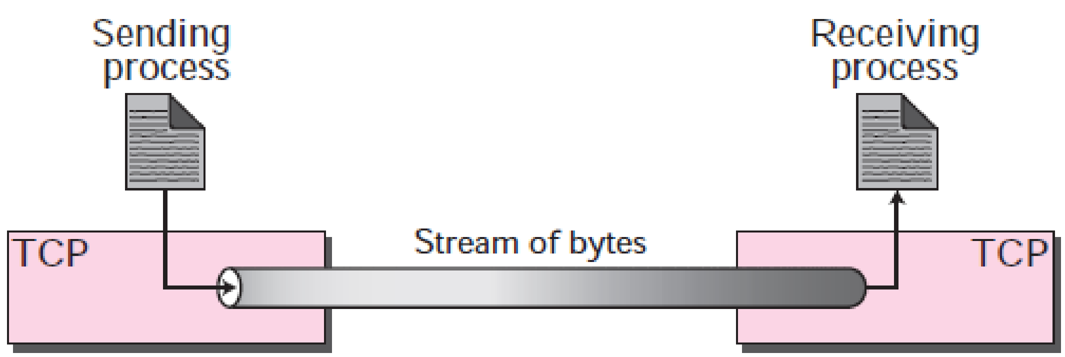
Process-to-Process Communication

- As with UDP, TCP provides process-to-process communication using port numbers.

Port	*Protocol*	*Description*
7	Echo	Echoes a received datagram back to the sender
9	Discard	Discards any datagram that is received
11	Users	Active users
13	Daytime	Returns the date and the time
17	Quote	Returns a quote of the day
19	Chargen	Returns a string of characters
20 and 21	FTP	File Transfer Protocol (Data and Control)
23	TELNET	Terminal Network
25	SMTP	Simple Mail Transfer Protocol
53	DNS	Domain Name Server
67	BOOTP	Bootstrap Protocol
79	Finger	Finger
80	HTTP	Hypertext Transfer Protocol

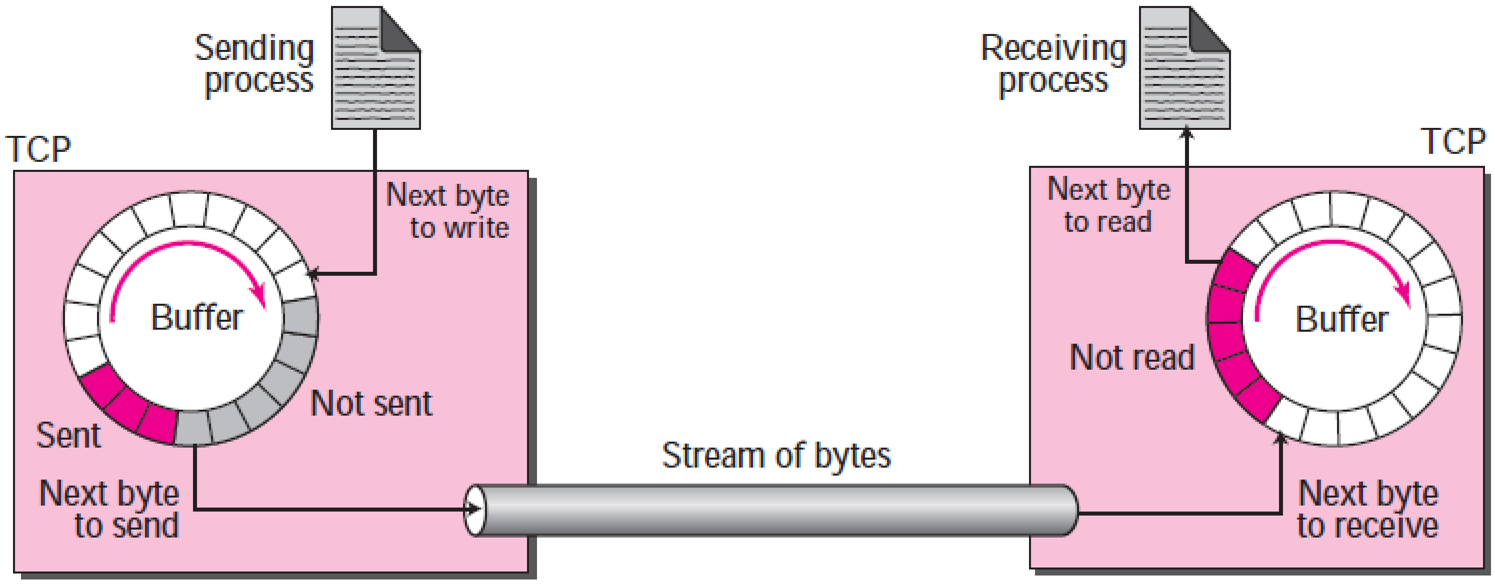
Stream Delivery Service

- TCP, unlike UDP, is a stream-oriented protocol.
- Recall: UDP does not recognize any relationship between the datagrams (Connectionless)
- TCP creates an environment in which the two processes seem to be connected by an imaginary “tube” that carries their bytes across the Internet.



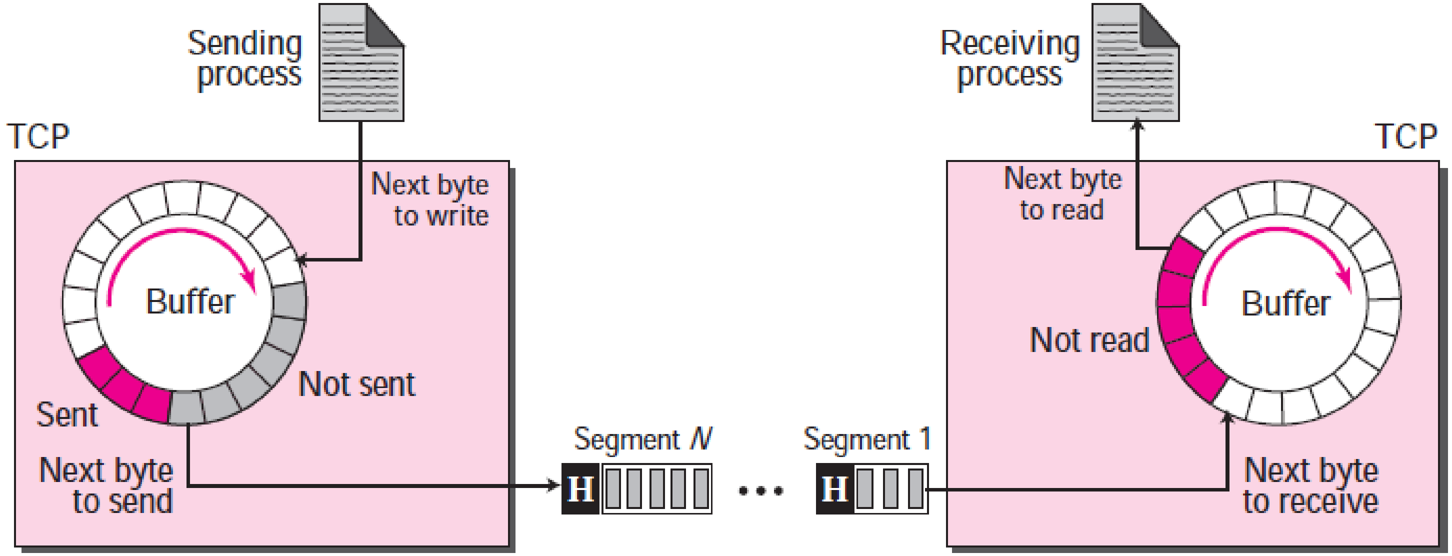
Sending and Receiving Buffers

- Sending and the receiving processes may not necessarily write or read data at the same rate, thus, TCP needs buffers for storage.



Segmentation

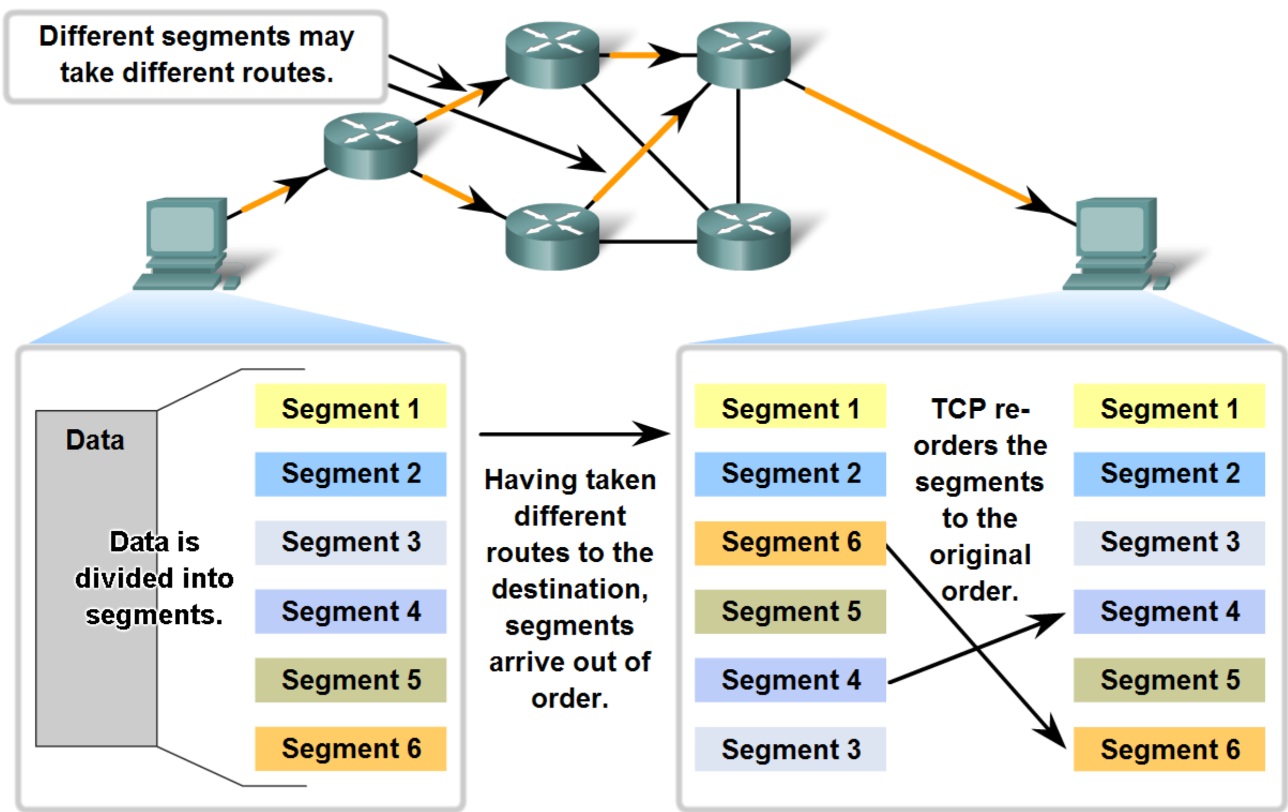
- The IP layer, as a service provider for TCP, needs to send data in packets, not as a stream of bytes.
- At the transport layer, TCP groups a number of bytes together into a packet called a ***segment***.



Sequence Numbers

- TCP sequence numbers are used to reconstruct the data stream with segments placed in the correct order.

TCP Segments Are Re-Ordered at the Destination

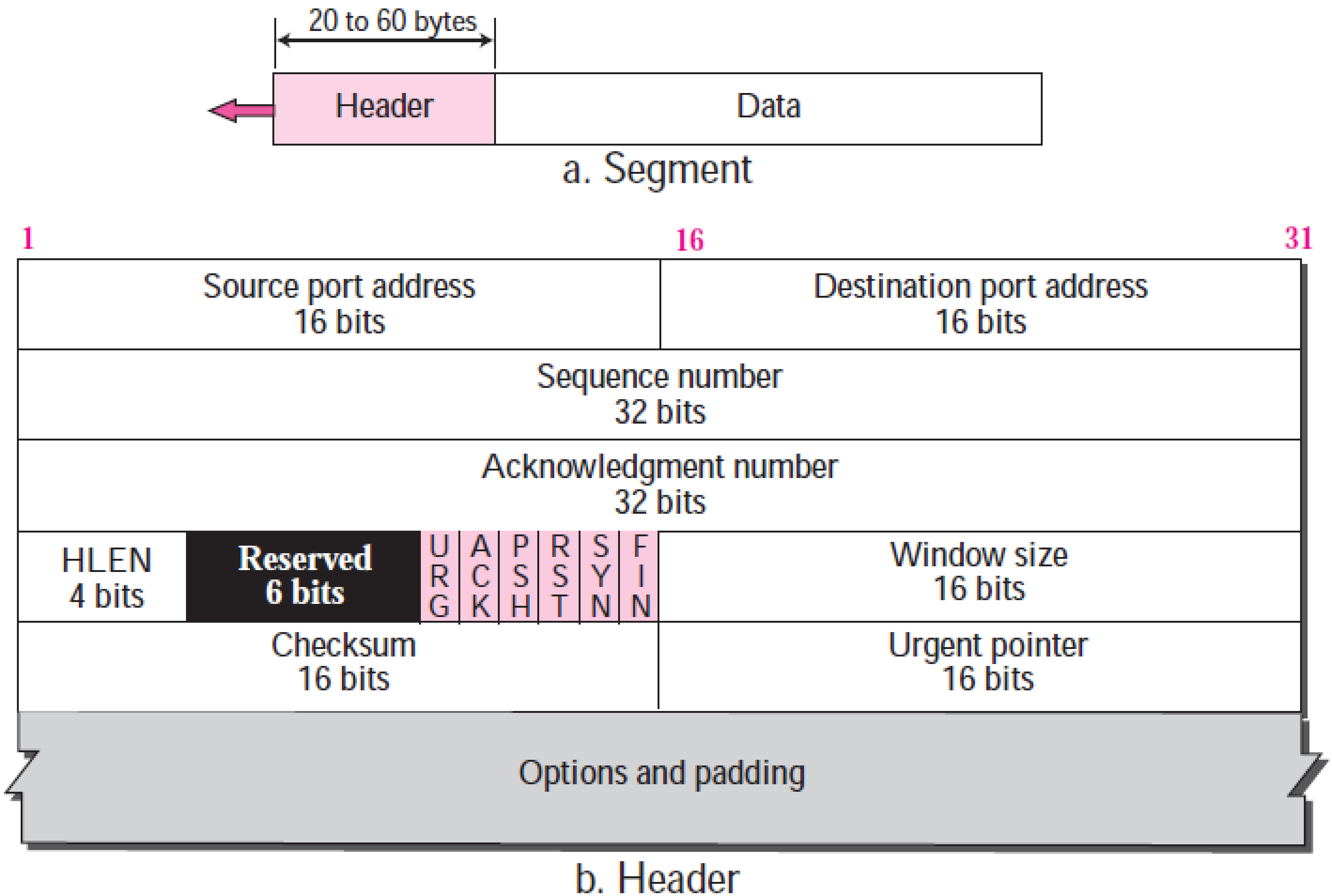


Other TCP Characteristics

- TCP offers ***full-duplex service***, where data can flow in both directions at the same time.
- Like UDP, TCP performs multiplexing at the sender and demultiplexing at the receiver.
- TCP, unlike UDP, is a reliable transport protocol. It uses an acknowledgment mechanism to check the safe and sound arrival of data.
- TCP provides flow, error, and congestion control.

TCP Segment Format

- The segment consists of a header of 20 to 60 bytes, followed by data from the application.



TCP Segment

- **Source port address.** This is a 16-bit field that defines the port number of the application program in the host that is sending the segment.
- **Destination port address.** This is a 16-bit field that defines the port number of the application program in the host that is receiving the segment.
- **Sequence number.** This 32-bit field defines the number assigned to the first byte of data contained in this segment. To ensure connectivity, each byte to be transmitted is numbered.

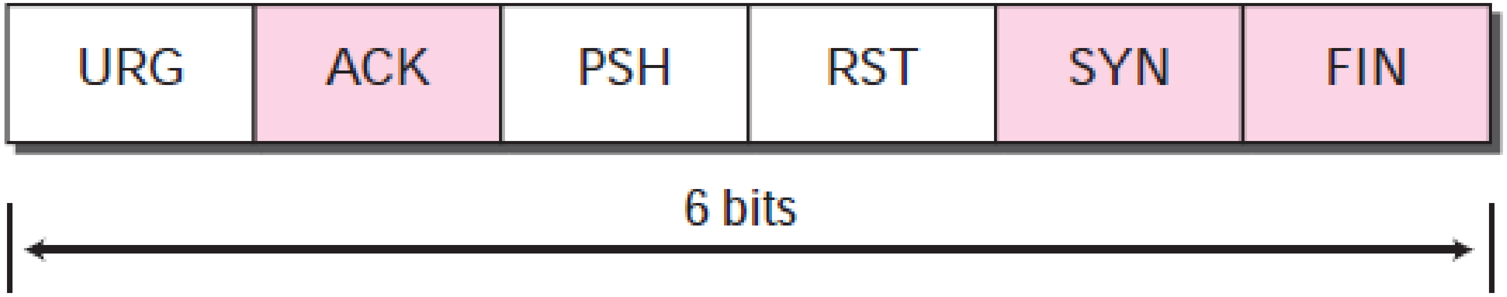
TCP Segment

- **Acknowledgment number.** This 32-bit field defines the byte number that the receiver of the segment is expecting to receive from the other party.
- **Header length.** This 4-bit field indicates the number of 4-byte words in the TCP header. The length of the header can be between 20 and 60 bytes.
- **Reserved.** This is a 6-bit field reserved for future use.

TCP Segment

- **Control.** enables flow control, connection establishment and termination, connection abortion, and the mode of data transfer in TCP.

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

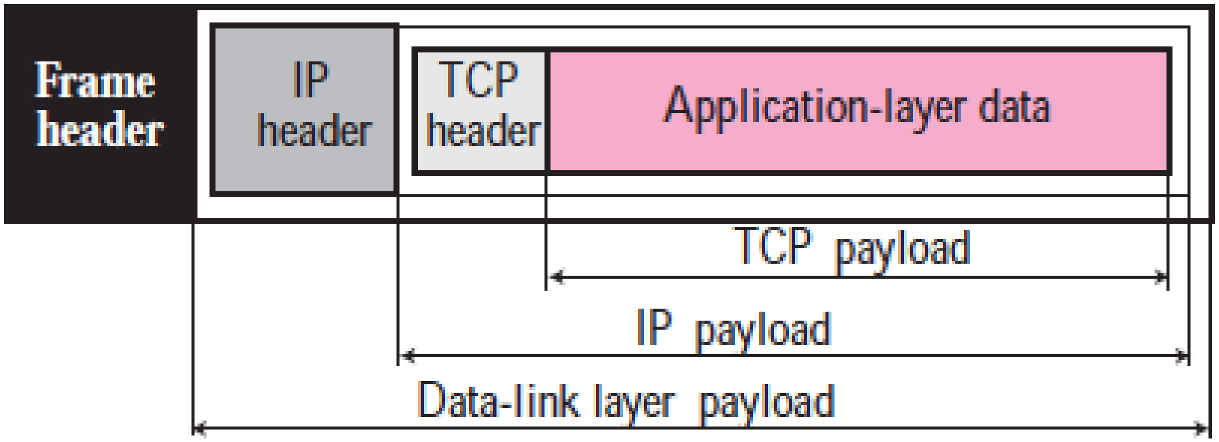


TCP Segment

- **Window size.** This field defines the window size of the sending TCP in bytes. (length = 16 bits, maximum size of window is 65,535 bytes.)
- **Checksum.** This 16-bit field contains the checksum.
- **Urgent pointer.** 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.** There can be up to 40 bytes of optional information in the TCP header.

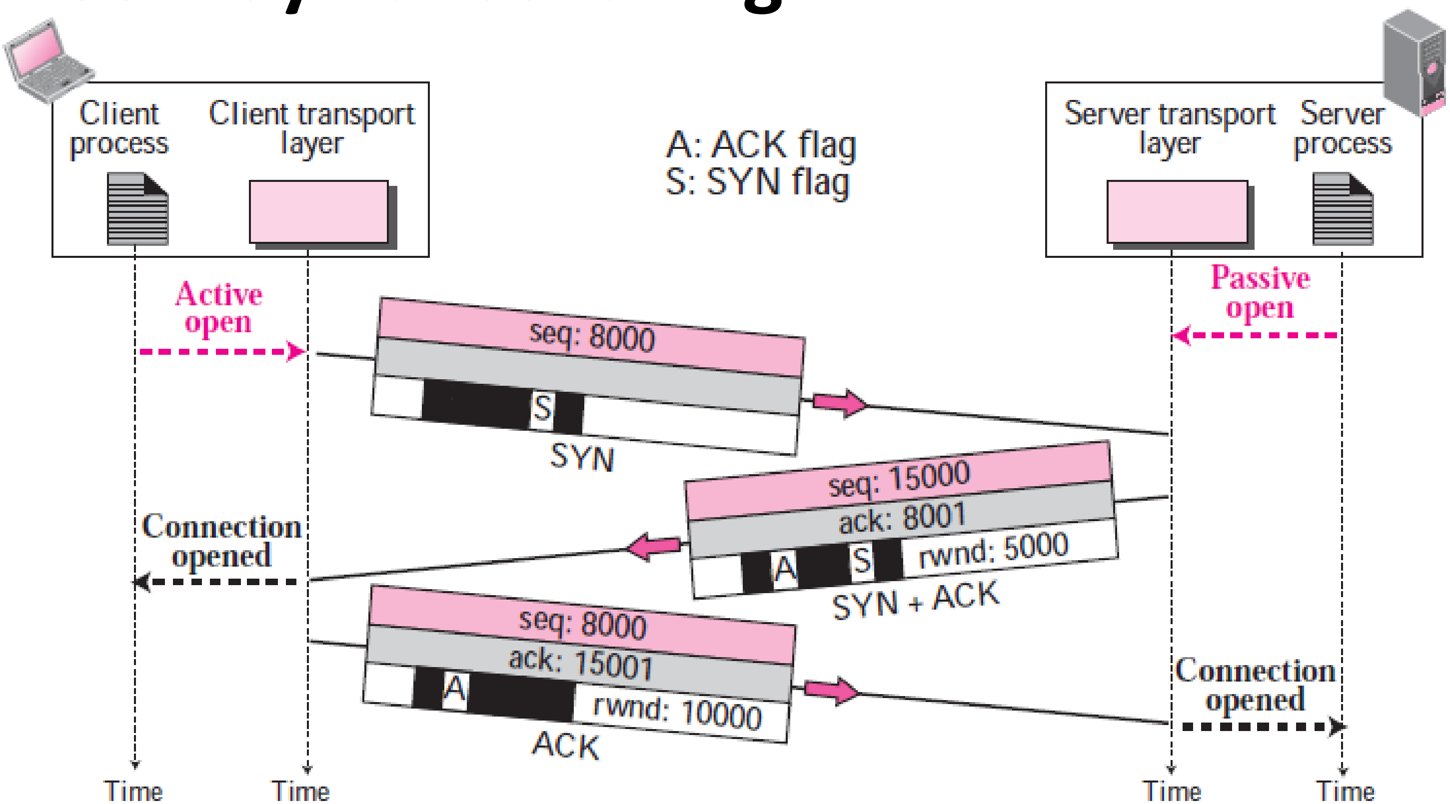
Encapsulation

- A TCP segment encapsulates the data received from the application layer.
- The TCP segment is encapsulated in an IP datagram, which in turn is encapsulated in a frame at the data-link layer



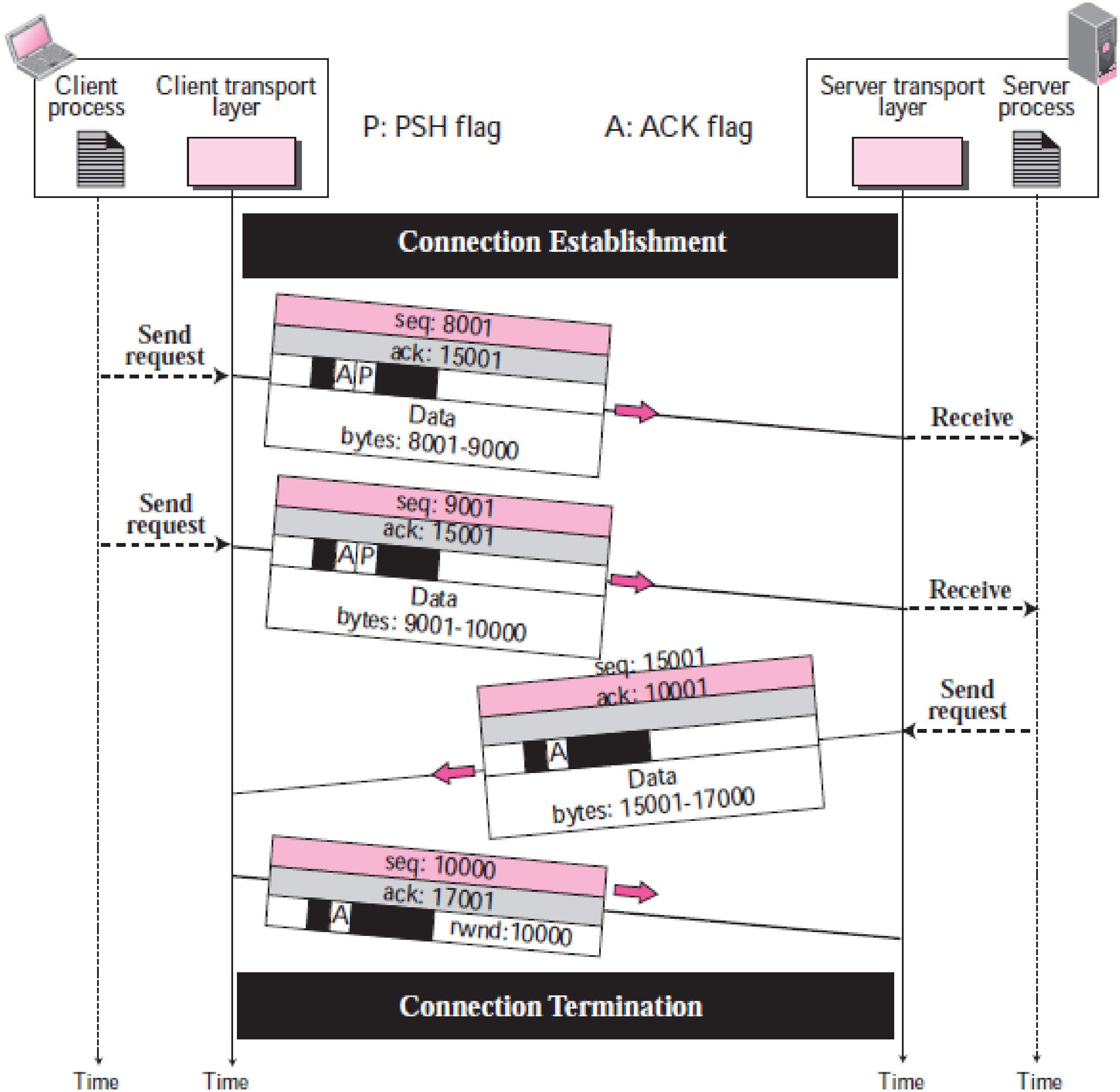
TCP Connection Establishment

- The connection establishment in TCP is called **three-way handshaking.**



A SYN segment cannot carry data, but it consumes one sequence number.
A SYN + ACK segment cannot carry data, but does consume one sequence number.

TCP Data Transfer

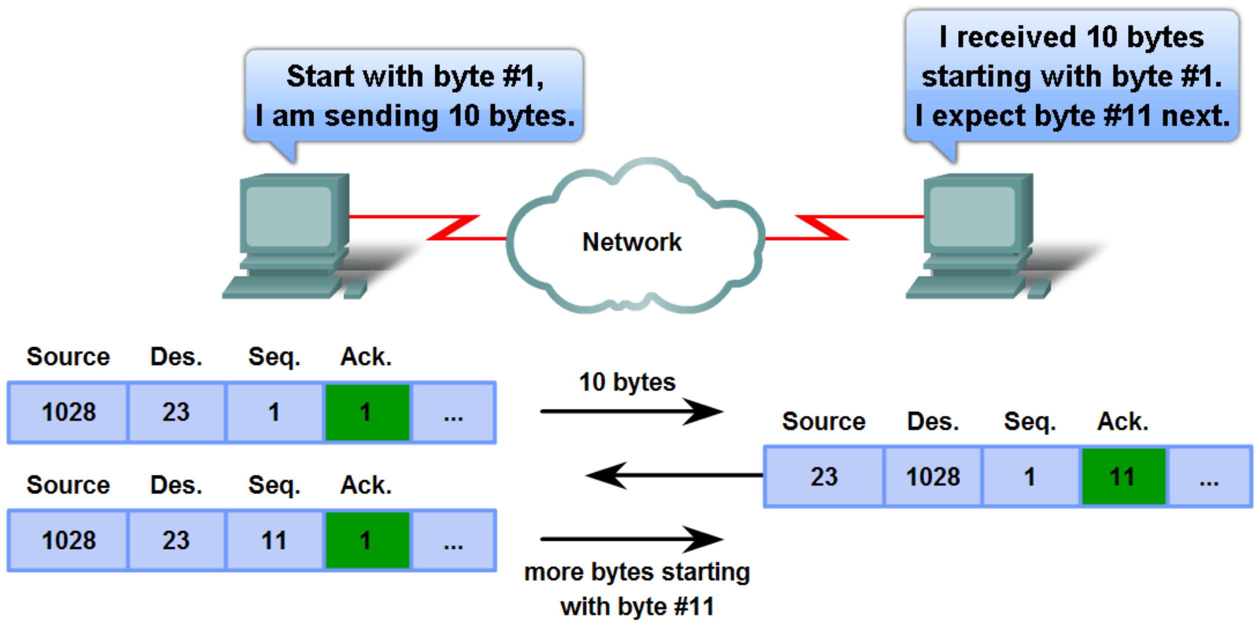


TCP Data Transfer Simplified

- Sequence numbers and acknowledgement numbers are used to manage exchanges in a conversation.

Acknowledgement of TCP Segments

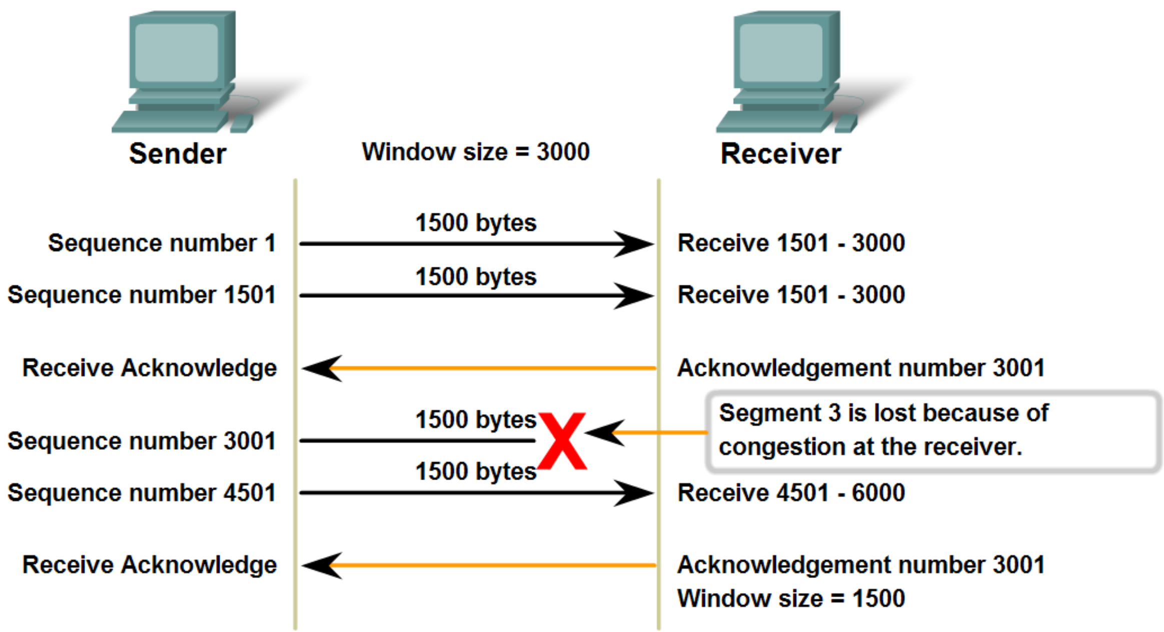
Source Port	Destination Port	Sequence Number	Acknowledgement Numbers	...



TCP Congestion and Flow Control

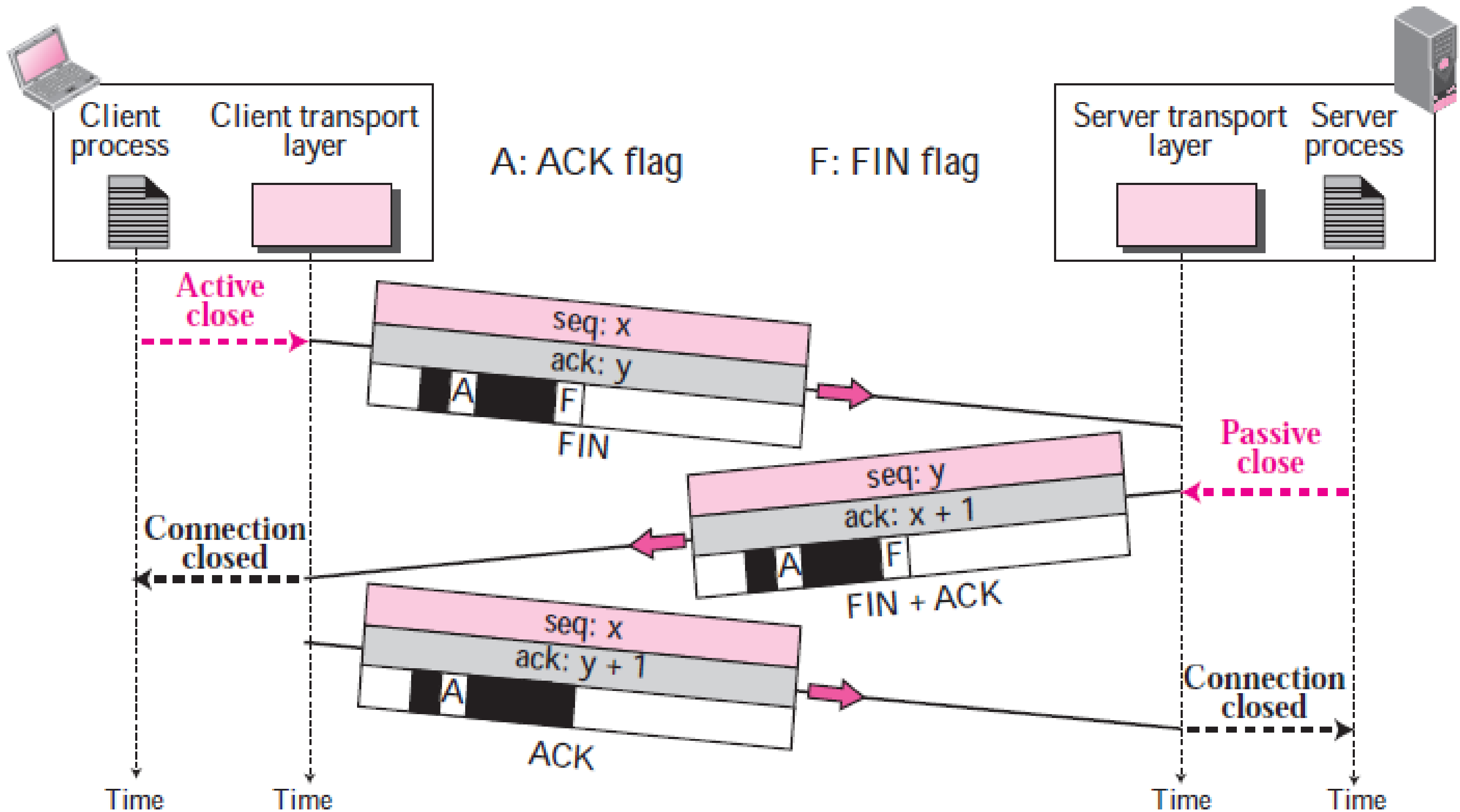
- TCP manages the window size, data loss and congestion during a session.

TCP Congestion and Flow Control



If segments are lost because of congestion, the Receiver will acknowledge the last received sequential segment and reply with a reduced window size.

TCP Connection Termination



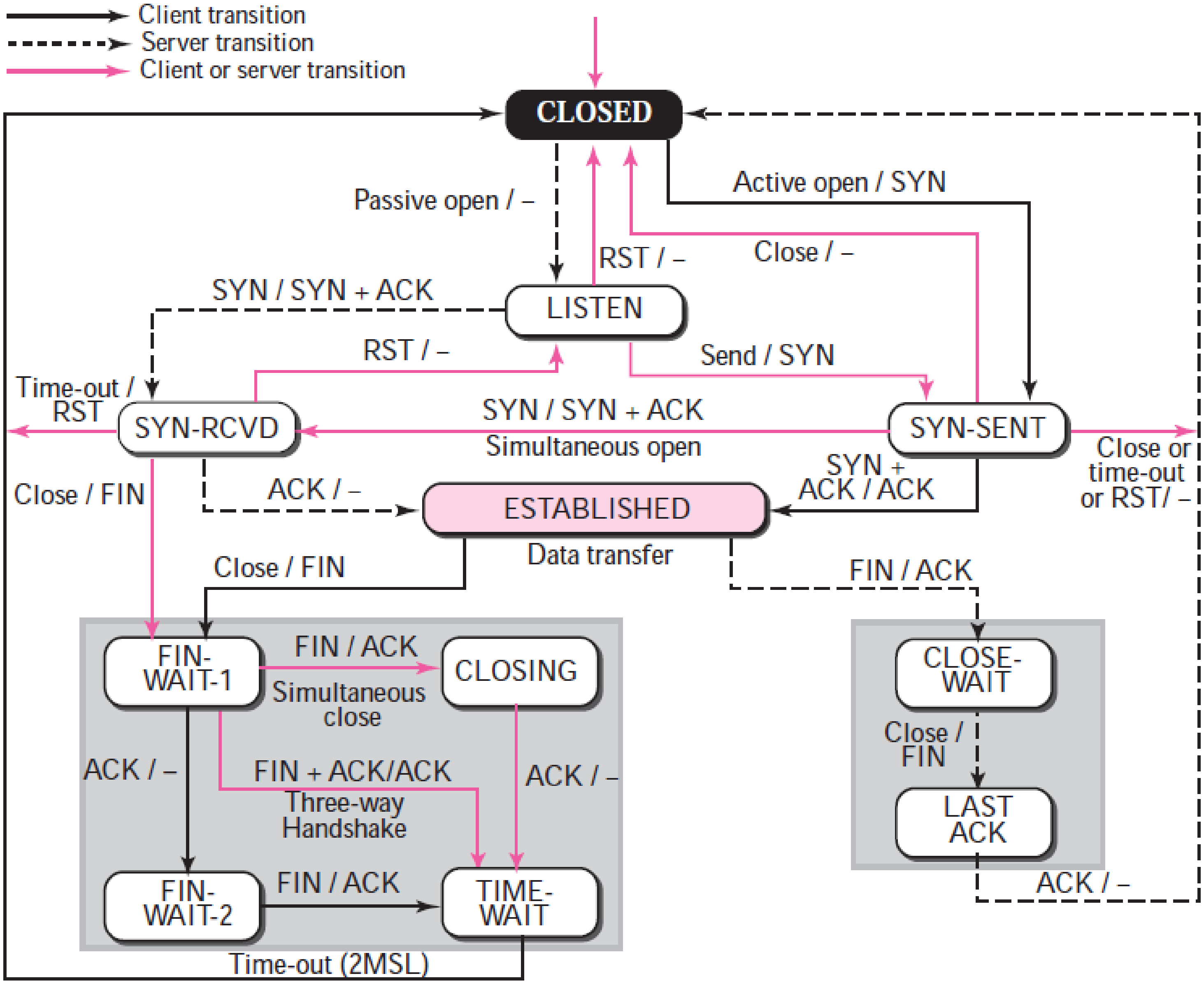
Example

```
C:\Users\User>netstat -a

Active Connections

  Proto  Local Address          Foreign Address        State
  TCP    0.0.0.0:135            User-PC:0              LISTENING
  TCP    0.0.0.0:445            User-PC:0              LISTENING
  TCP    0.0.0.0:1087           User-PC:0              LISTENING
  TCP    0.0.0.0:1088           User-PC:0              LISTENING
  TCP    10.1.1.101:1307        nk11p01st-hpaj392838-bz:5223  ESTABLISHED
  TCP    10.1.1.101:1338        hg-in-f138:https       ESTABLISHED
  TCP    10.1.1.101:3880        User-PC:0              LISTENING
  TCP    127.0.0.1:1029         User-PC:5354           ESTABLISHED
  TCP    127.0.0.1:1030         User-PC:16384          ESTABLISHED
 ...
  UDP    0.0.0.0:319            *:*
  UDP    0.0.0.0:320            *:*
  UDP    0.0.0.0:500            *:*
  UDP    0.0.0.0:1434           *:*
  UDP    0.0.0.0:2343           *:*
```

TCP State Transition Diagram



TCP States

State	*Description*
CLOSED	No connection exists
LISTEN	Passive open received; waiting for SYN
SYN-SENT	SYN sent; waiting for ACK
SYN-RCVD	SYN+ACK sent; waiting for ACK
ESTABLISHED	Connection established; data transfer in progress
FIN-WAIT-1	First FIN sent; waiting for ACK
FIN-WAIT-2	ACK to first FIN received; waiting for second FIN
CLOSE-WAIT	First FIN received, ACK sent; waiting for application to close
TIME-WAIT	Second FIN received, ACK sent; waiting for 2MSL time-out
LAST-ACK	Second FIN sent; waiting for ACK
CLOSING	Both sides decided to close simultaneously

TCP vs. UDP Comparison

Characteristic / Description	UDP	TCP
General Description	Simple, high-speed, low-functionality "wrapper" that interfaces applications to the network layer and does little else.	Full-featured protocol that allows applications to send data reliably without worrying about network layer issues.
Protocol Connection Setup	Connectionless; data is sent without setup.	Connection-oriented; connection must be established prior to transmission.
Data Interface To Application	Message-based; data is sent in discrete packages by the application.	Stream-based; data is sent by the application with no particular structure.

TCP vs. UDP Comparison

Reliability and Acknowledgments	Unreliable, best-effort delivery without acknowledgments.	Reliable delivery of messages; all data is acknowledged.
Retransmissions	Not performed. Application must detect lost data and retransmit if needed.	Delivery of all data is managed, and lost data is retransmitted automatically.
Features Provided to Manage Flow of Data	None	Flow control using sliding windows; window size adjustment heuristics; congestion avoidance algorithms.
Overhead	Very low	Low, but higher than UDP
Transmission Speed	Very high	High, but not as high as UDP

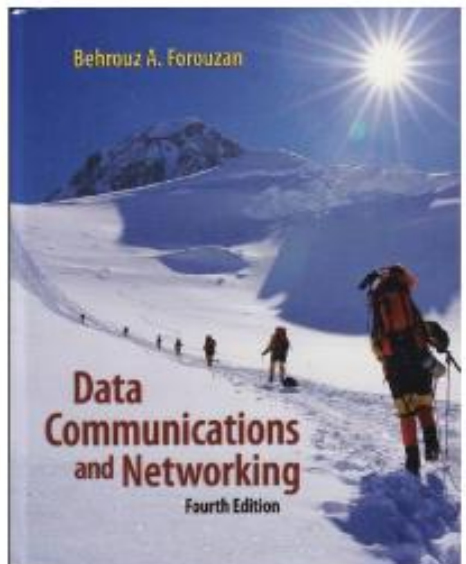
TCP vs. UDP Comparison

Data Quantity Suitability	Small to moderate amounts of data (up to a few hundred bytes)	Small to very large amounts of data (up to gigabytes)
Types of Applications That Use The Protocol	Applications where data delivery speed matters more than completeness, where small amounts of data are sent; or where multicast/broadcast are used.	Most protocols and applications sending data that must be received reliably, including most file and message transfer protocols.
Well-Known Applications and Protocols	Multimedia applications, DNS, BOOTP, DHCP, TFTP, SNMP, RIP, NFS	FTP, Telnet, SMTP, DNS, HTTP, POP, NNTP, IMAP, BGP, IRC, NFS
	(early versions)	(later versions)

References

TEXTBOOK:

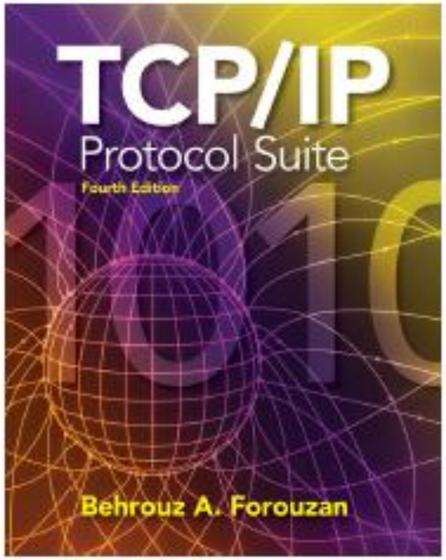
- Data Communications and Networking, Behrouz Forouzan, 4th Edition, McGraw-Hill, 2007



References

SECONDARY SOURCE:

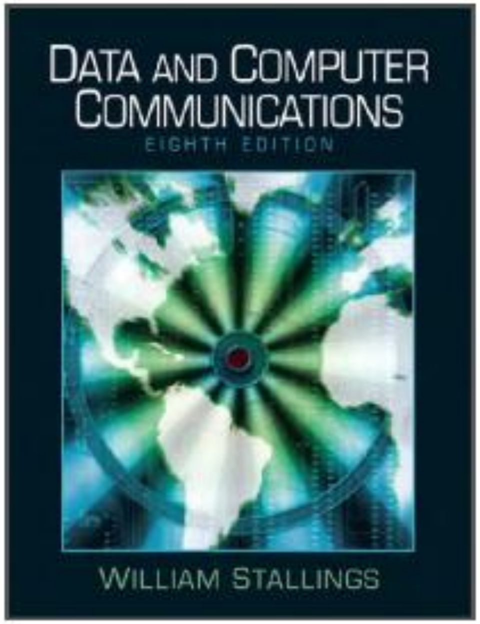
- TCP/IP Protocol Suite, Behrouz Forouzan, 4th edition, 2010



References

SECONDARY SOURCE:

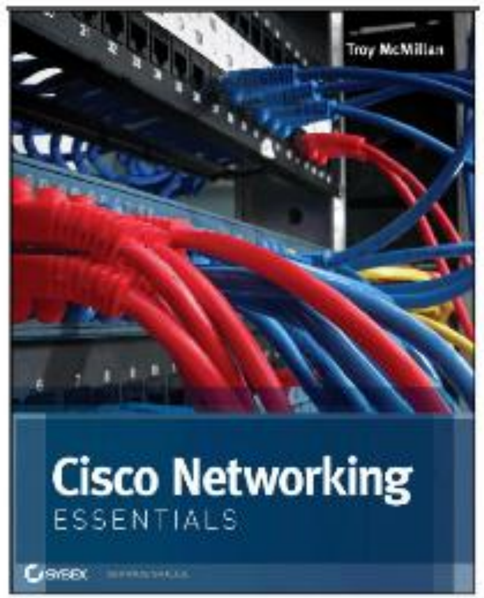
- Data and Computer Communications
  William Stallings, 2007



References

SECONDARY SOURCE:

- CISCO Networking Essentials, Troy McMillan, 2012



References

SECONDARY SOURCE:

- Network Fundamentals, Cisco Networking Academy, 2007

End