Data Communications and Networking Fourth Edition

Forouzan

Chapter 2

Network Models

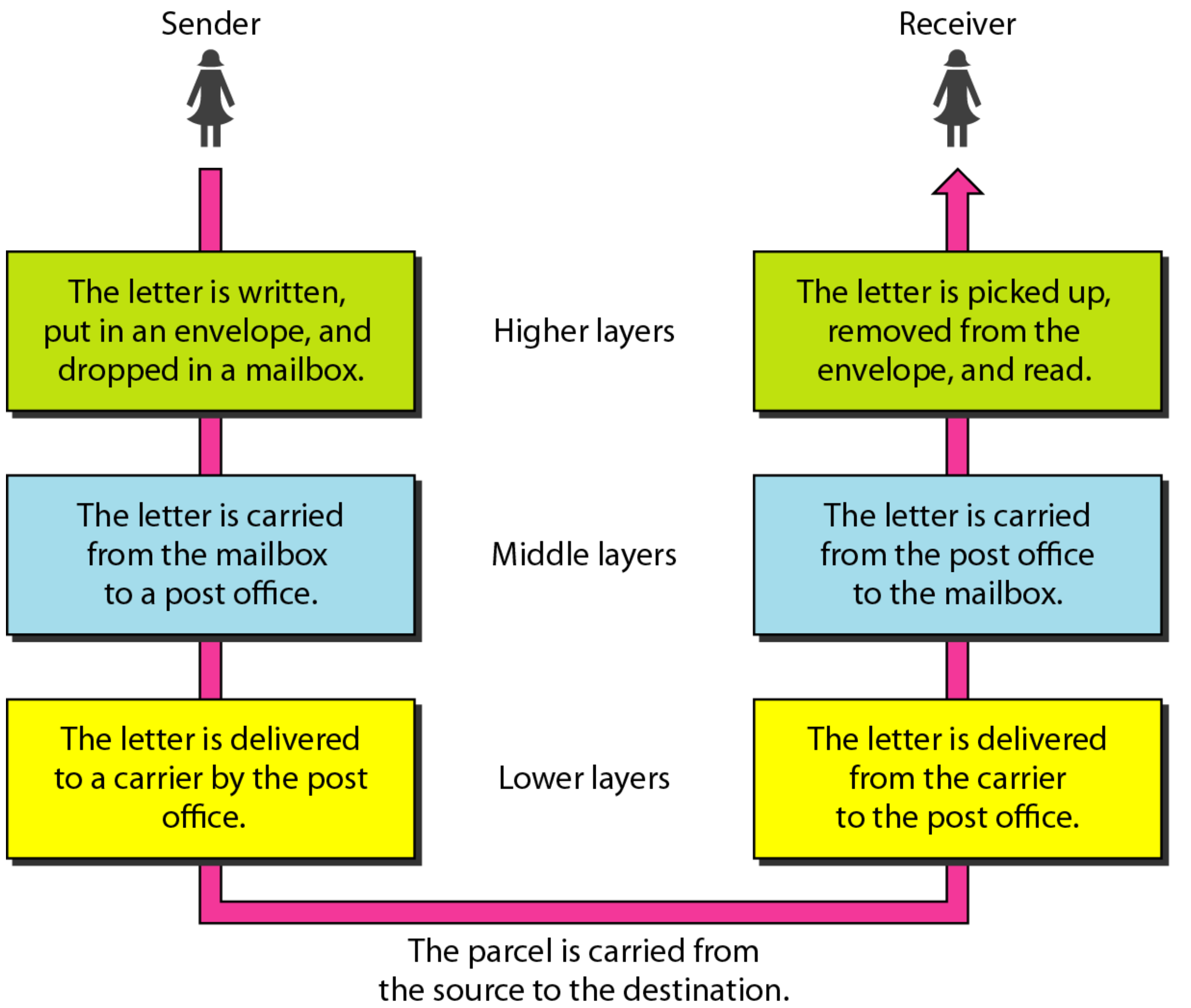
2-1 LAYERED TASKS

We use the concept of layers in our daily life. As an example, let us consider two friends who communicate through postal mail. The process of sending a letter to a friend would be complex if there were no services available from the post office.

Topics discussed in this section:

Sender, Receiver, and Carrier
Hierarchy

Figure 2.1 Tasks involved in sending a letter



2-2 THE OSI MODEL

Established in 1947, the International Standards Organization (ISO) is a multinational body dedicated to worldwide agreement on international standards. An ISO standard that covers all aspects of network communications is the Open Systems Interconnection (OSI) model. It was first introduced in the late 1970s.

Topics discussed in this section:

Layered Architecture
Peer-to-Peer Processes
Encapsulation

Note

ISO is the organization.
OSI is the model.

Figure 2.2 *Seven layers of the OSI model*

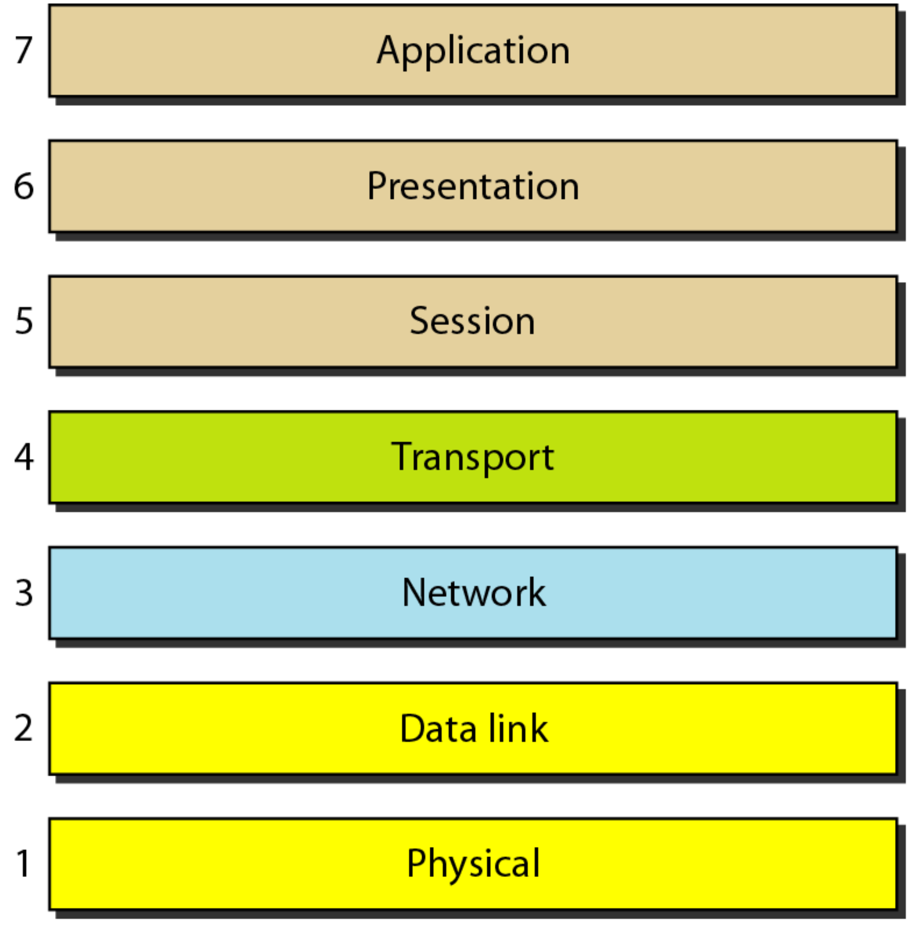
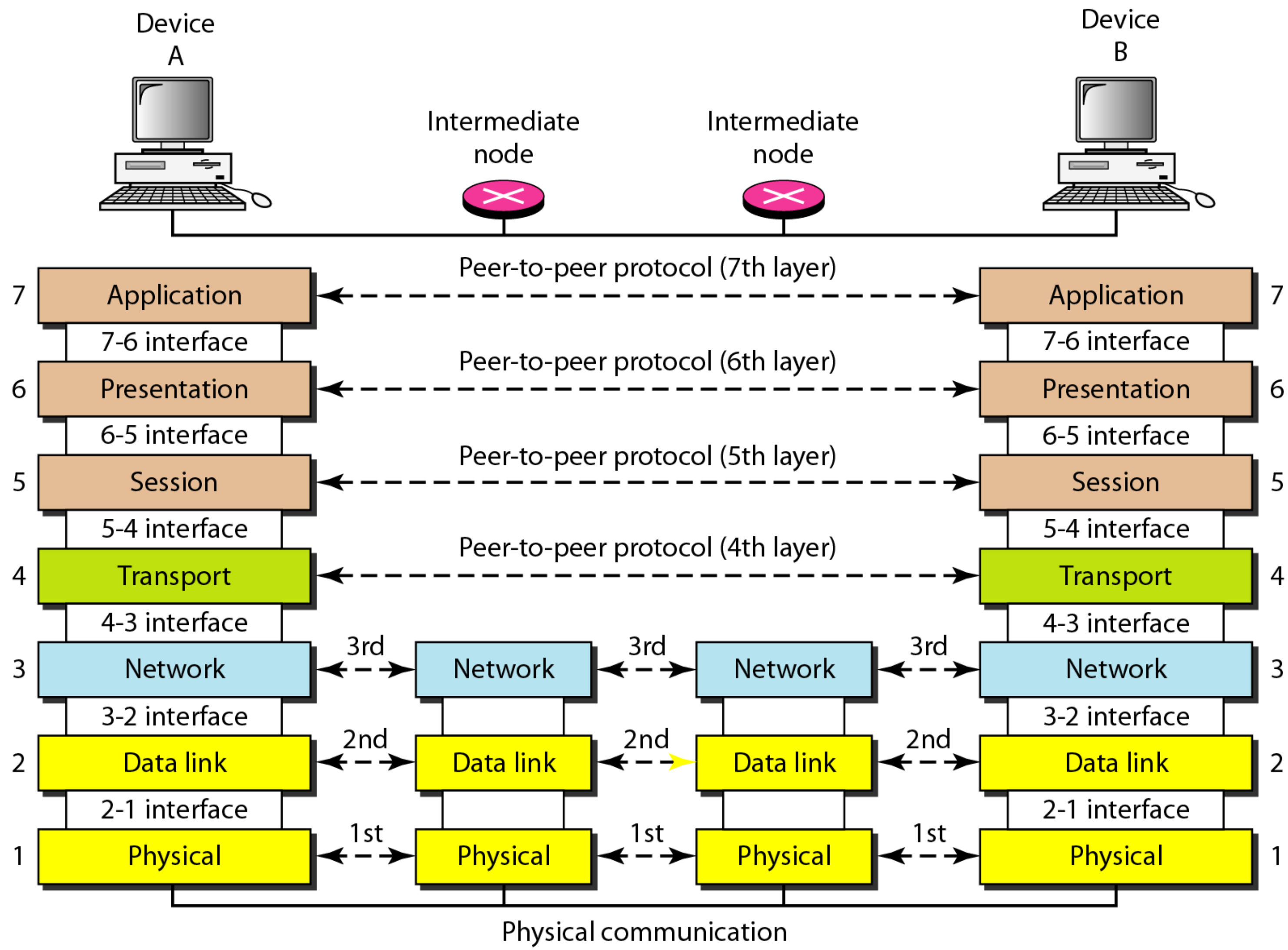


Figure 2.3 *The interaction between layers in the OSI model*



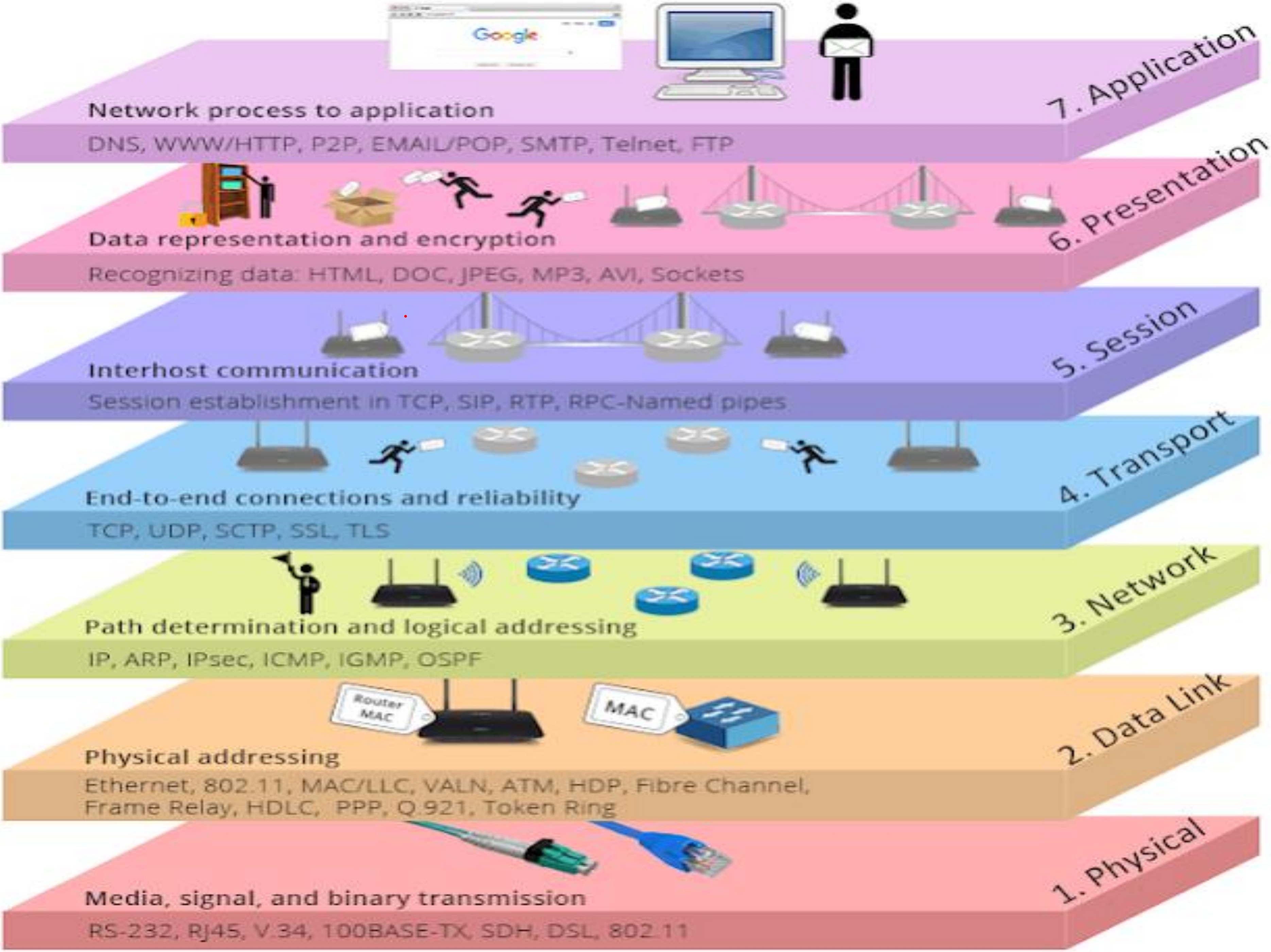
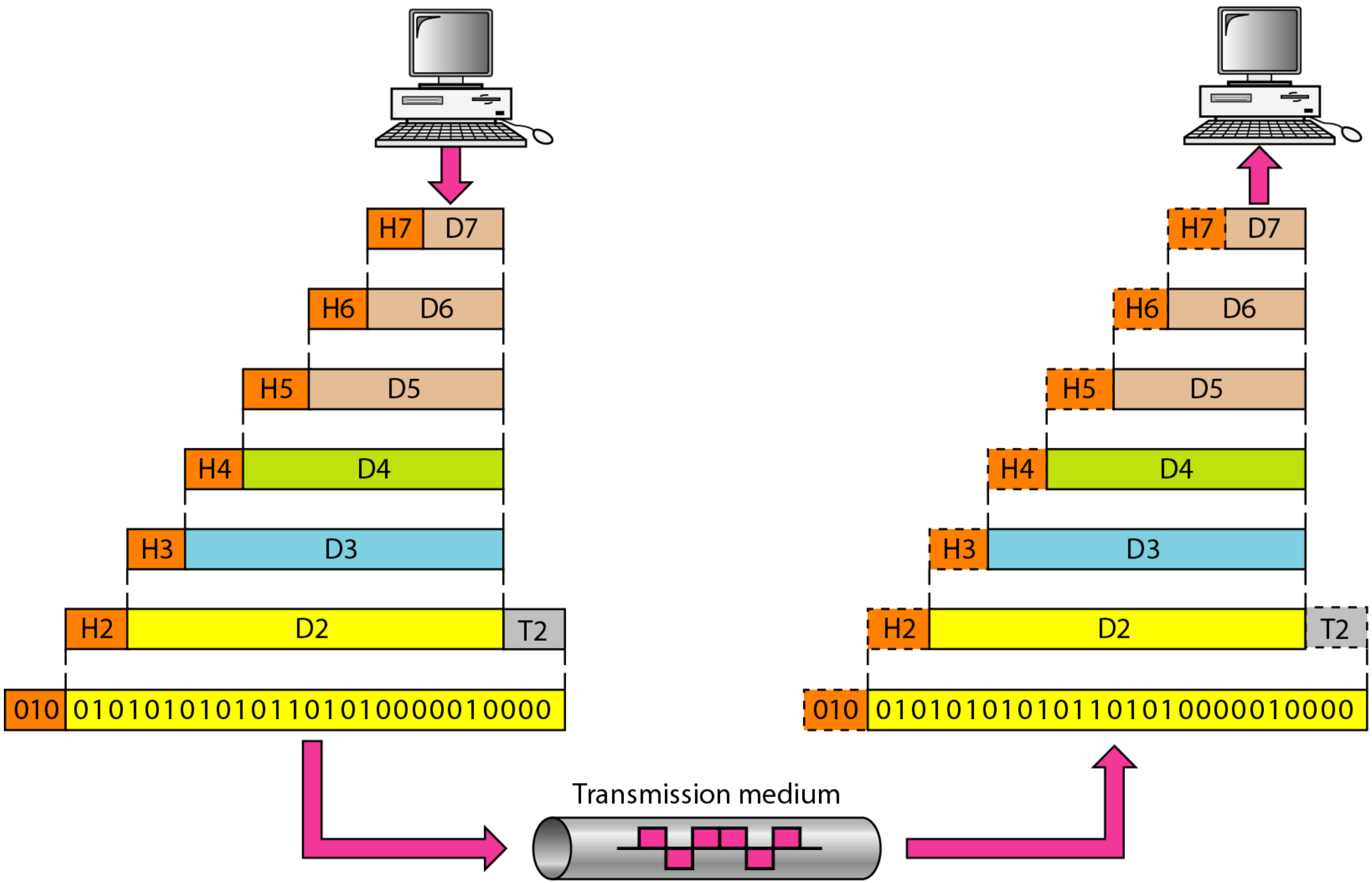

7. Application
Network process to application
DNS, WWW/HTTP, P2P, EMAIL/POP, SMTP, Telnet, FTP
6. Presentation
Data representation and encryption
Recognizing data: HTML, DOC, JPEG, MP3, AVI, Sockets
5. Session
Interhost communication
Session establishment in TCP, SIP, RTP, RPC-Named pipes
4. Transport
End-to-end connections and reliability
TCP, UDP, SCTP, SSL, TLS
3. Network
Path determination and logical addressing
IP, ARP, IPsec, ICMP, IGMP, OSPF
2. Data Link
Router MAC
MAC
Physical addressing
Ethernet, 802.11, MAC/LLC, VALN, ATM, HDP, Fibre Channel,
Frame Relay, HDLC, PPP, Q.921, Token Ring
1. Physical
Media, signal, and binary transmission
RS-232, RJ45, V.34, 100BASE-TX, SDH, DSL, 802.11

Figure 2.4 *An exchange using the OSI model*



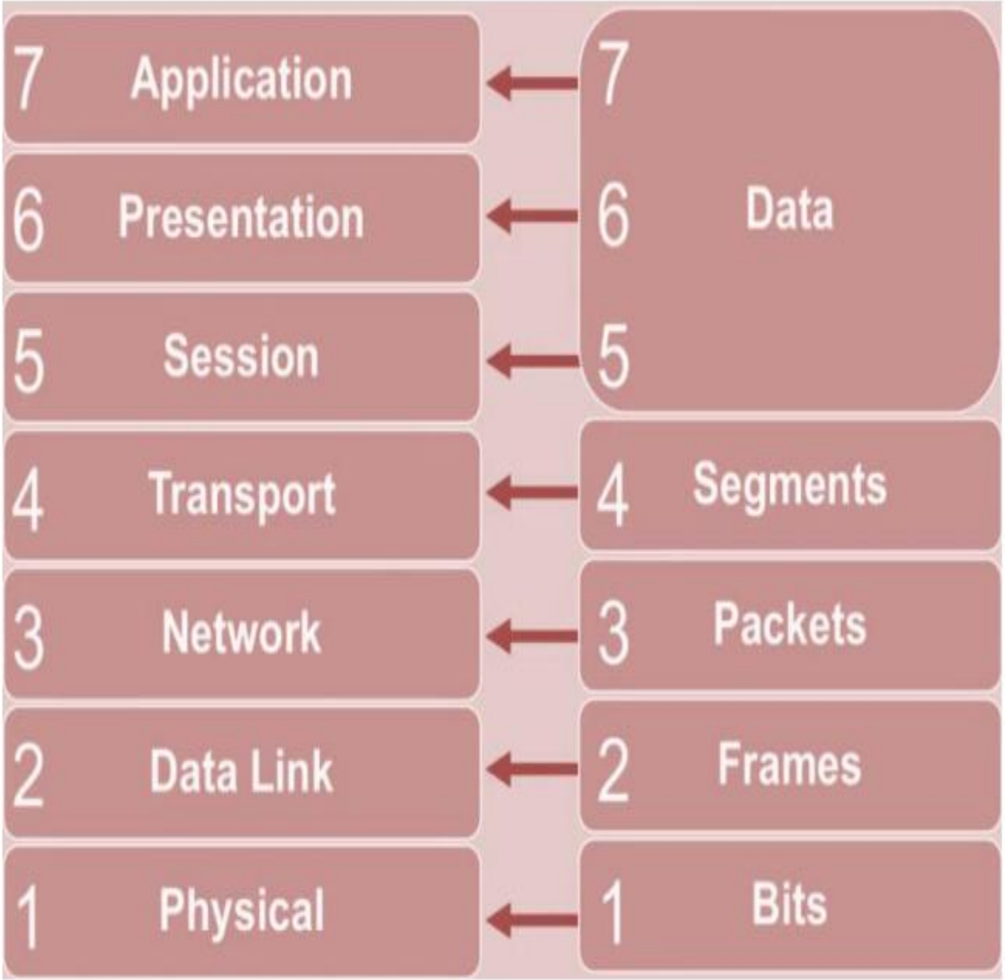
2-3 LAYERS IN THE OSI MODEL

In this section we briefly describe the functions of each layer in the OSI model.

Topics discussed in this section:

Physical Layer
Data Link Layer
Network Layer
Transport Layer
Session Layer
Presentation Layer
Application Layer

Data Types in OSI Model



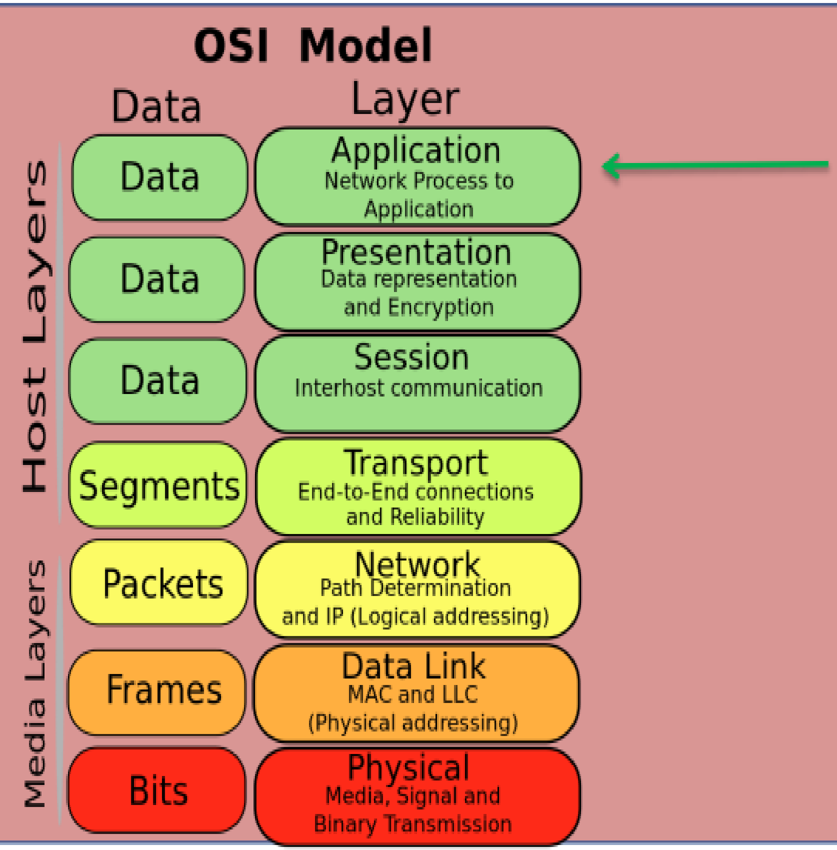
Don't Some People Fear Birthdays?

A
G

Benefits of OSI Model

1. It breaks network communication into smaller, more manageable parts.
2. It standardizes network components to allow multiple vendor development and support.
3. It allows different types of network hardware and software to communicate with each other.
4. It prevents changes in one layer from affecting other layers.
5. It divides network communication into smaller parts to make learning it easier to understand.

The Application Layer: 2-8 Layer (7)



Application Layer

- Application Layer is responsible for providing Networking Services to the user.
- It is also known as Desktop Layer.
- Identification of Services is done using Port Numbers.
- Ports are Entry and Exit Points to the Layer

Total No. Ports – 65535

Reserved Ports – 1023

Open Client Ports 1024 – 65535

Examples of Networking Services

Service	Port No.
HTTP	80
FTP	21
SMTP	25
TELNET	23
TFTP	69

Layer 7- Application Layer

Examples at Layer 7

- E-mail (POP3, IMAP, SMTP)

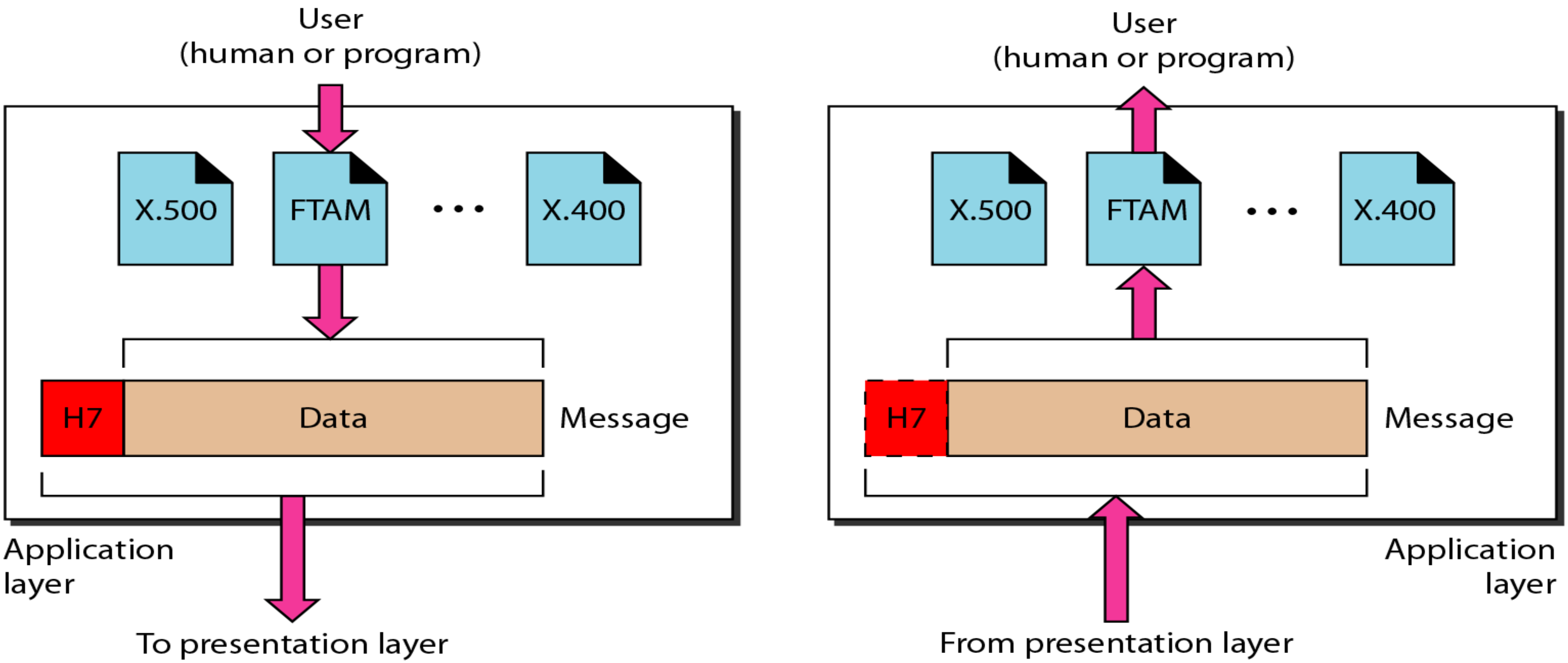
- Web Browsing (HTTP, HTTPS)
- Domain Name Service (DNS)
- File Transfer Protocol (FTP, FTPS)

- Remote Access (TELNET, SSH)
- Simple Network Management Protocol (SNMP)

OSI Layer 7 : Application Layer

NOTE:- The application layer is responsible for providing services to the user.

Header which protocol will use FTP , HTTP, SMTP, DNS

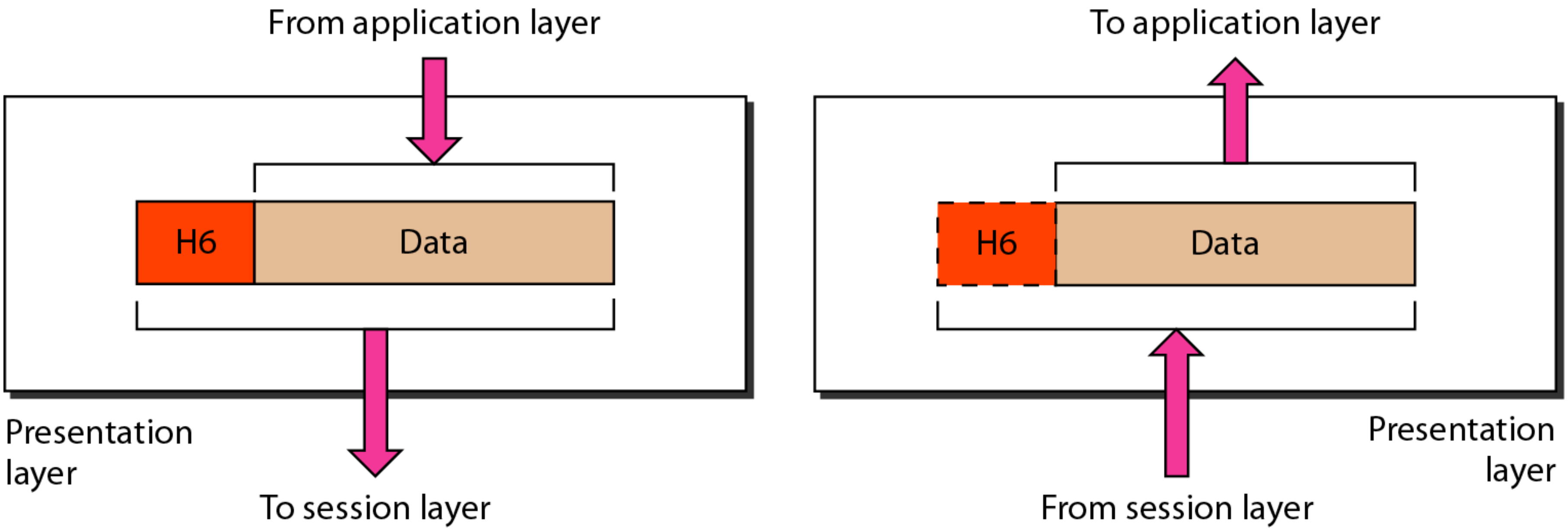


OSI Layer 6 : Presentation

- rather than being concerned with *moving* information the presentation layer is concerned with the *interpretation of information representation*
- ensures that the *syntax* and meaning is the same for each participant in a communication
- provides for standard representation and may provide capabilities for conversion of data
- It *translates* information from text/numeric into the bitstream.
- It also *encrypts* the information for security purposes and *compresses* the information to reduce the number of bits in the information.

NOTE:- The presentation layer is responsible for translation, compression, and encryption.

OSI Layer 6 : Presentation



Header contain translation, compression, and encryption algorithms

Layer 6- Presentation Layer

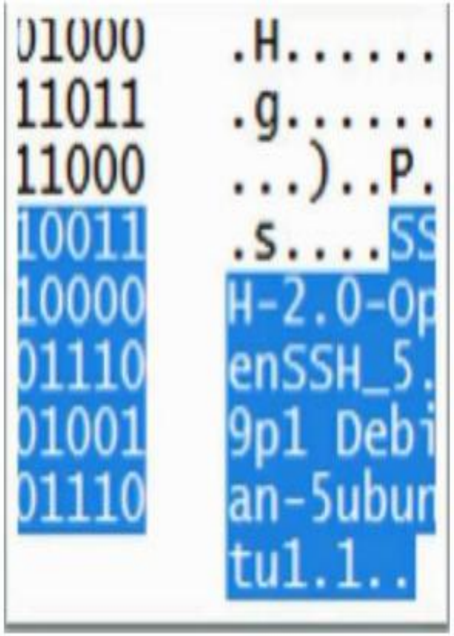
- Responsible for formatting the data exchanged and securing that data with proper encryption

- Functions
  - Data formatting
  - Encryption

Layer 6- Presentation Layer

Data Formatting

- Formats data for proper compatibility between devices
  - ASCII
  - GIF
  - JPG



- Ensures data is readable by receiving system

- Provides proper data structures

- Negotiates data transfer syntax for the Application Layer (Layer 7)

Layer 6- Presentation Layer

Encryption

- Used to scramble the data in transit to keep it secure from prying eyes
- Provides confidentiality of data
- Example:
  - TLS to secure data between your PC and website

Layer 6- Presentation Layer

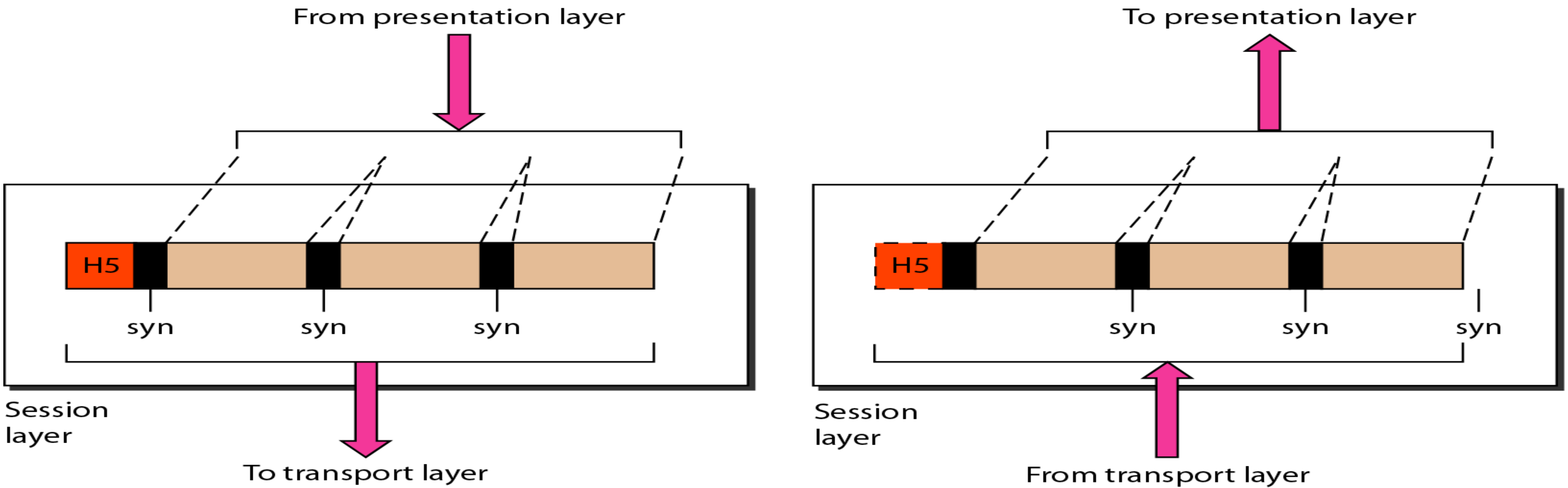
Examples at Layer 6

- HTML, XML, PHP, JavaScript, …
- ASCII, EBCDIC, UNICODE, …
- GIF, JPG, TIF, SVG, PNG, …
- MPG, MOV, …
- TLS, SSL, …

OSI Layer 5 : Session

- sort of an *unwanted layer*, this layer is usually very *thin* and little more than a pass through for most protocols
- manages dialog control (e.g. may manage who’s turn to talk in a high-level half-duplex protocol)
- manages synchronization of transactions which may need to be able to *roll back* in case of a crash

NOTE:- The session layer is responsible for dialog control and synchronization.



Layer 5- Session Layer

- Think of a session as a conversation that must be kept separate from others to prevent intermingling of the data
- Setting up sessions
- Maintaining sessions
- Tearing down sessions

Layer 5- Session Layer

Setting up Session

- Check user credentials
- Assign numbers to session to identify them
- Negotiate services needed for session
- Negotiate who begins sending data

Layer 5- Session Layer

Maintaining a Session

Maintaining a Session

- Transfer the data
- Reestablish a disconnected session
- Acknowledging receipt of data

Layer 5- Session Layer

Examples at Layer 5

- H.323
  - Used to setup, maintain, and tear down a voice/video connection

Face Time- Skype
Which Operates over Real Time Protocol (RTP) using Port 1720 over TCP.

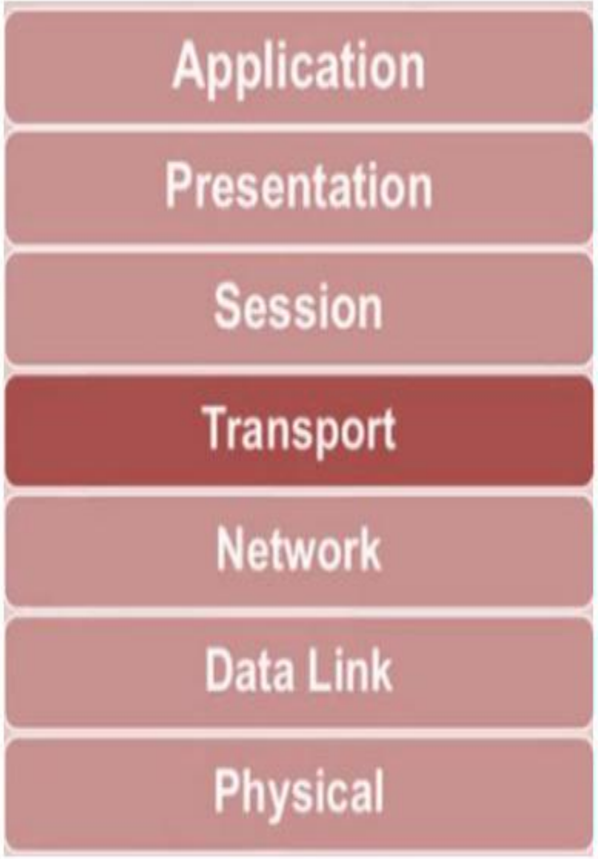
- NetBIOS
  - Used by computers to share files over a network

Layer 4 Transport Layer

- Transport Layer is responsible for end-to-end connectivity. It is also known as the heart of OSI Layers.
- The following tasks are performed at the Transport Layer: -
  - Identifying Service
  - Multiplexing & De-multiplexing
  - Segmentation
  - Sequencing & Reassembling
  - Error Correction
  - Flow Control

Layer 4- Transport Layer

- Dividing line between upper and lower layers of the OSI model
- Data is sent as segments
- TCP/UDP
- Windowing
- Buffering



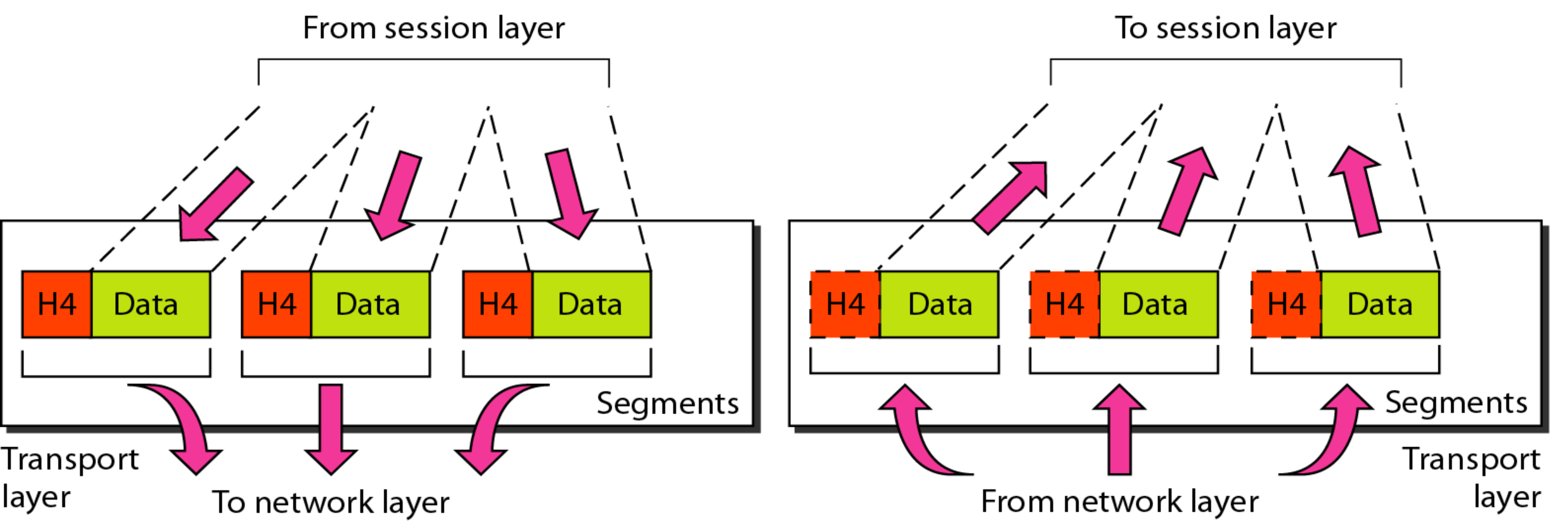
OSI Layer 4 : Transport Layer

- **First end-to-end layer**
- **Uses the network to (most often) provide higher layers with a connection-oriented, reliable, error-free channel that delivers messages (or byte stream) in order**
- **Generally requires address (or naming)**
- **Often performs multiplexing of multiple transport connections over one or more network connections**
- **It divides messages into segments and also reassemble the segments to create an original message.**
- **It can be either connection-oriented or connectionless.**
- **Flow control and error control are also provided by the transport layer.**

OSI Layer 4 : Transport Layer

NOTE:- The transport layer is responsible for the delivery of a message from one process to another.

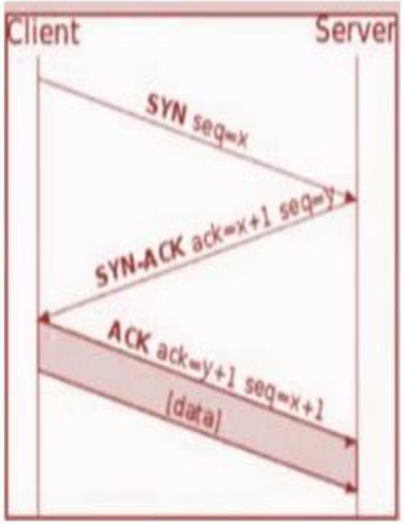
Header contain TCP protocol or UDP protocol



Layer 4- Transport Layer

TCP (Transmission Control Protocol)

- Connection-oriented protocol
- Reliable transport of segments
  - If segment is dropped, protocol detects it and resends segment



- Acknowledgements received for successful communications
- Used for all network data that needs to be assured to get to its destination

Layer 4- Transport Layer

UDP (User Datagram Protocol)

- Connectionless protocol
- Unreliable transport of segments
  - If dropped, sender is unaware
- No retransmission
- Good for audio/video streaming
- Lower overhead for increased performance

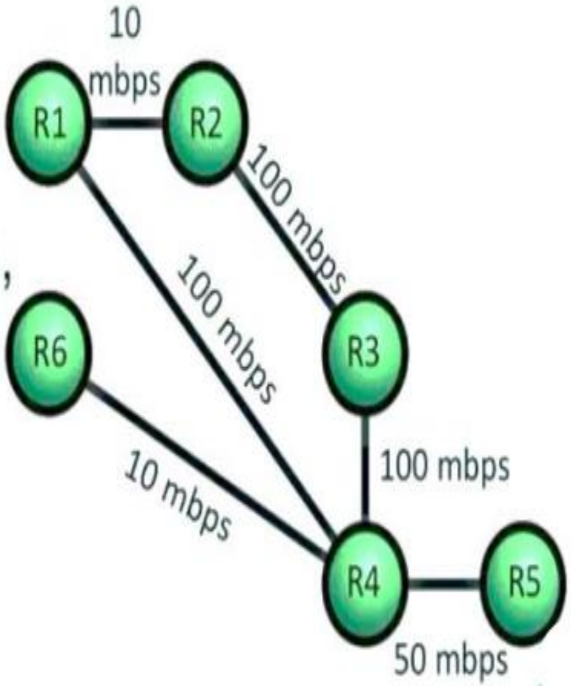
Layer 4- Transport Layer
Windowing

- Allows the clients to adjust the amount of data sent in each segment
- Continually adjusts to send more or less data per segment transmitted
  - Adjusts lower as number of retransmissions occur
  - Adjusts upwards as retransmissions are eliminated

Layer 4- Transport Layer

Buffering

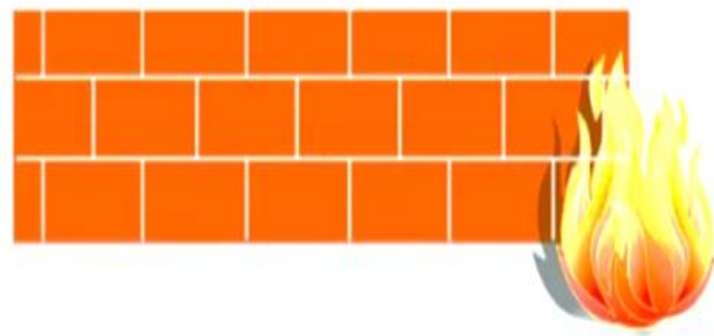
- Devices, such as routers, allocate memory to store segments if bandwidth isn't readily available
- When available, it transmits the contents of the buffer
- If the buffer overflows, segments will be dropped



Layer 4- Transport Layer

Examples at Layer- 4

- TCP



- UDP
- WAN Accelerators

- Load Balancers

- Firewalls

OSI Layer 3 : Network Layer

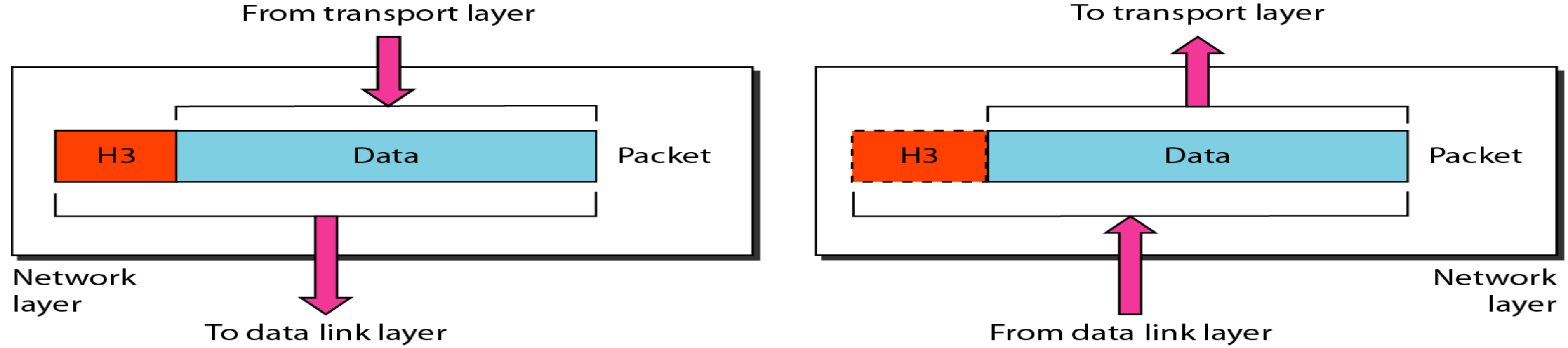
Primary function is controlling the operation of the *subnet* (layers below)

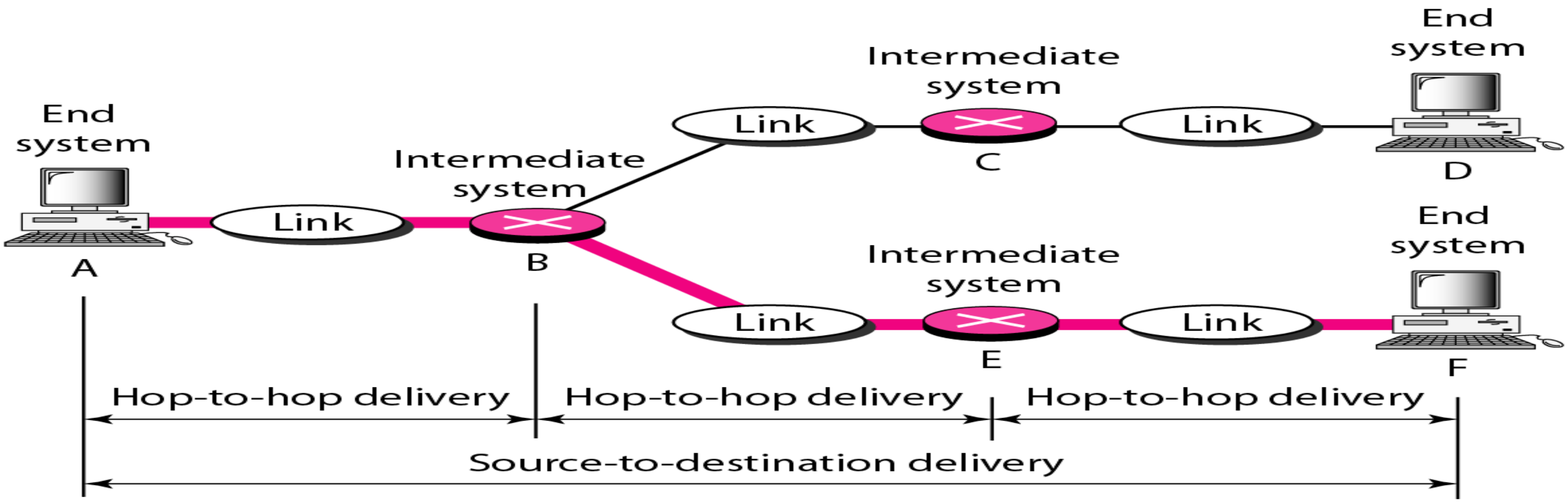
Among the key issues dealt with are:

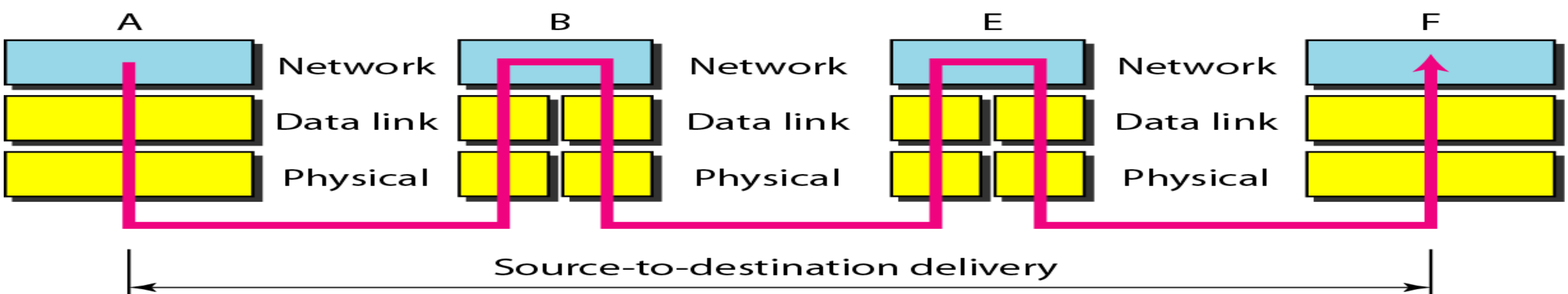
- ✓ **how routing packets from source to destination through the network (or multiple networks) using static or dynamic routing algorithms**
- ✓ **controlling congestion in the subnet**
- ✓ **translating between protocols across heterogeneous networks (address, packet size, …)**
- ✓ **concerned with addressing**
- ✓ **It divides data into number of packets.**
- ✓ **It uses IP address for routing packets to their destination.**
- ✓ **It provides end to end connection.**

NOTE:- The network layer is responsible for the delivery of individual packets from the source host to the destination host.

Header contain source and destination IP address

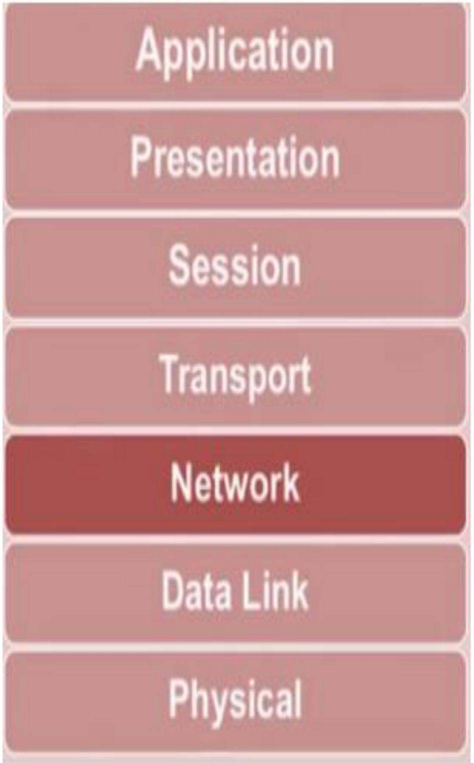

From transport layer
H3
Data
Packet
Network layer
To data link layer
To transport layer
H3
Data
Packet
Network layer
From data link layer


End system
A
Link
Intermediate system
B
Link
Intermediate system
C
Link
End system
D
Link
Intermediate system
E
Link
End system
F
Hop-to-hop delivery
Hop-to-hop delivery
Hop-to-hop delivery
Source-to-destination delivery


A
B
E
F
Network
Data link
Physical
Network
Data link
Physical
Network
Data link
Physical
Source-to-destination delivery

Layer 3- Network Layer

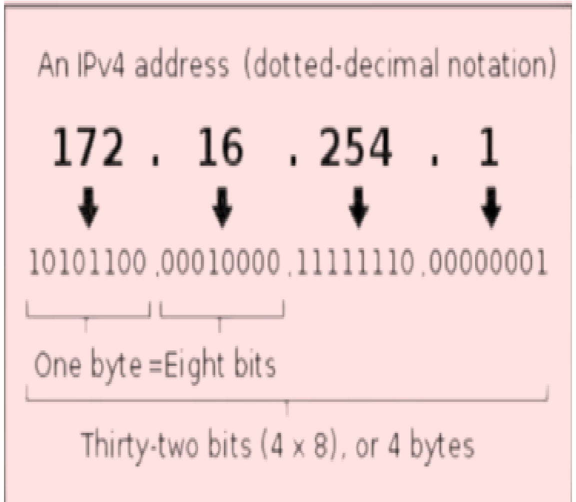
- Forwards traffic (routing) with logical address
  - Example: IP Address (IPv4 or IPv6)
- Logical addressing
- Switching
- Route discovery and selection
- Connection services
- Bandwidth usage
- Multiplexing strategy



Layer 3- Network Layer
Logical Address

- Numerous routed protocols were used for logical addressing over the years:
  - AppleTalk
  - Internetwork Packet Exchange (IPX)
  - Internet Protocol (IP)

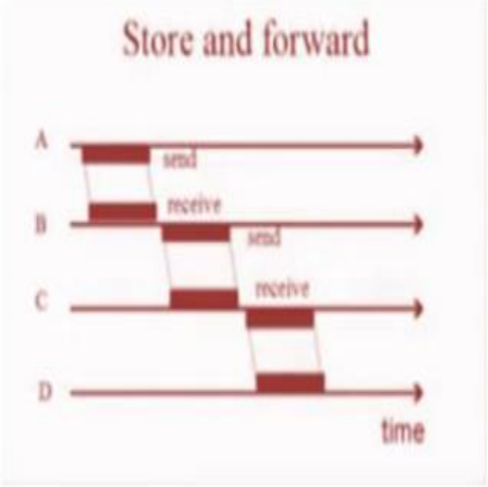
- Only Internet Protocol (IP) remains dominant
  - IP v4
  - IP v6



Layer 3- Network Layer

How Should data be forwarded or Routed?

- Packet switching (known as *routing*)
  - Data is divided into packets and forwarded
- Circuit switching
  - Dedicated communication link is established between two devices
- Message switching
  - Data is divided into messages, similar to packet switching, except these messages may be stored then forwarded

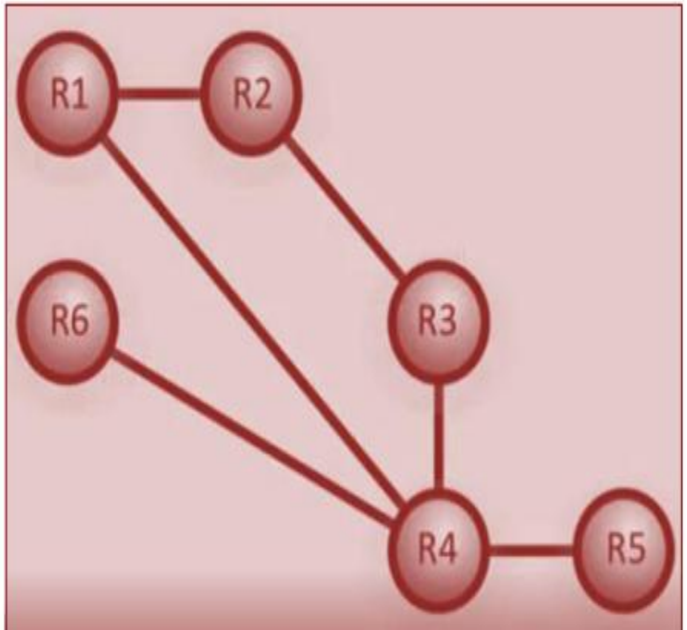


Layer 3- Network Layer

Route Discovery and Selection

- Routers maintain a routing table to understand how to forward a packet based on destination IP address

- Manually configured as a static route or dynamically through a routing protocol
  - RIP
  - OSPF
  - EIGRP



Layer 3- Network Layer

Connection Services

- Layer 3 augment Layer 2 to improve reliability

- Flow control
  - Prevents sender from sending data faster than receiver can get it

- Packet reordering
  - Allows packets to be sent over multiple links and across multiple routes for faster service

Layer 3- Network Layer

Internet Control Message Protocol (ICMP)

- Used to send error messages and operational information about an IP destination

- Not regularly used by end-user applications

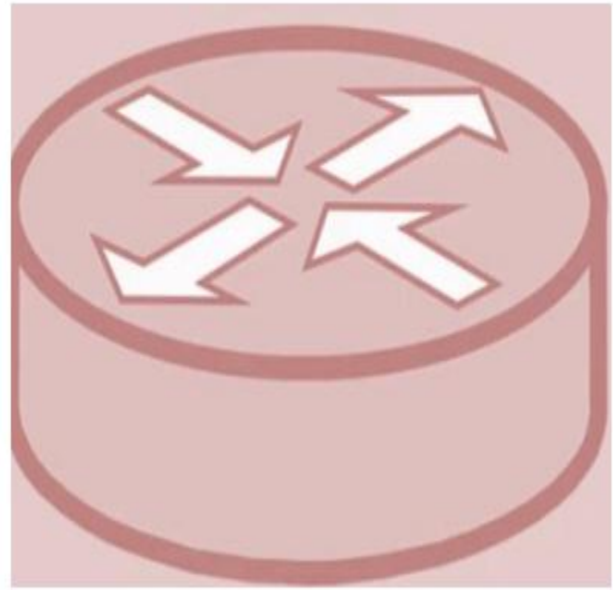
- Used in troubleshooting (*ping* and *traceroute)*

```
$ ping -c 5 www.example.com
PING www.example.com (93.184.216.34): 56 data bytes
64 bytes from 93.184.216.34: icmp_seq=0 ttl=56 time=11.632 ms
64 bytes from 93.184.216.34: icmp_seq=1 ttl=56 time=11.726 ms
64 bytes from 93.184.216.34: icmp_seq=2 ttl=56 time=10.683 ms
64 bytes from 93.184.216.34: icmp_seq=3 ttl=56 time=9.674 ms
64 bytes from 93.184.216.34: icmp_seq=4 ttl=56 time=11.127 ms
```

Layer 3- Network Layer

Examples at Layer 3

- Routers
- Multilayer switches
- IPv4 protocol
- IPv6 protocol
- Internet Control Message Protocol (ICMP)



OSI Layer 2 : Data Link Layer

Primary function is to make Layer 1 into what appears to be a channel *free of undetected errors*

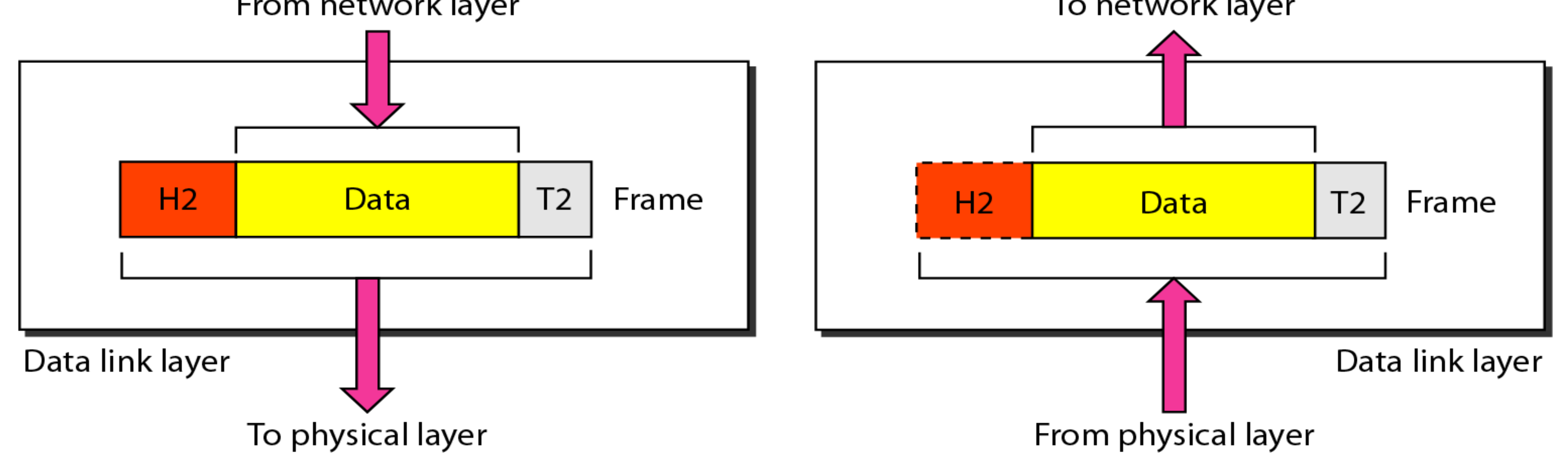
This layer must create/recognize frame boundaries

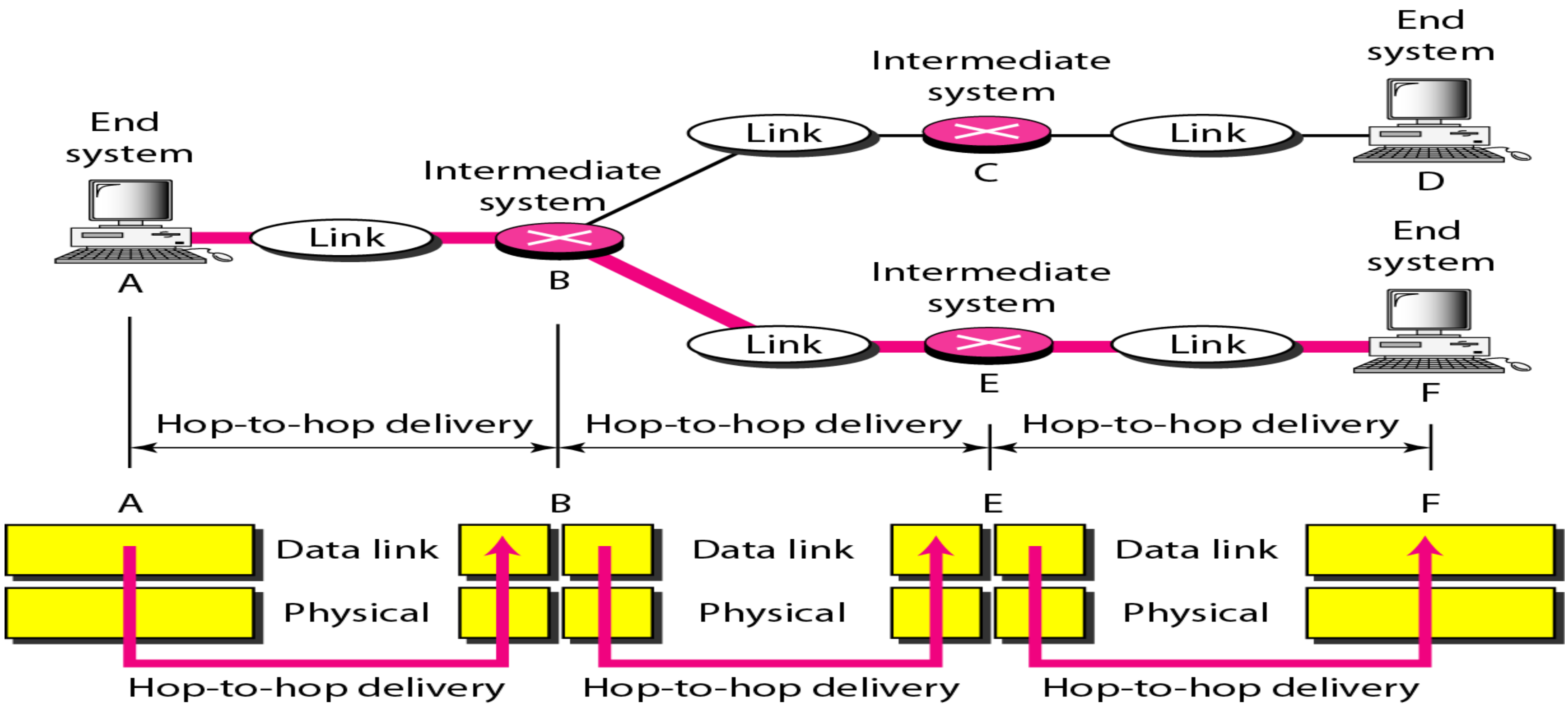
- ✓ **remember - physical layer does not care**
- ✓ **often requires special bit patterns to signal boundaries**
- ✓ **It divides the data into number of frames.**
- ✓ **It uses the MAC address for sending frames from one node to other.**
- ✓ **It provides flow control, error control and access control.**

NOTE:- The data link layer is responsible for moving frames from one hop (node) to the next.

Header contain source and destination MAC address

Trail contain flow control, error control and access control


From network layer
H2
Data
T2
Frame
Data link layer
To physical layer
To network layer
H2
Data
T2
Frame
Data link layer
From physical layer


End system
A
Link
Intermediate system
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Intermediate system
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Link
End system
D
Link
Intermediate system
E
Link
End system
F
Hop-to-hop delivery
Hop-to-hop delivery
Hop-to-hop delivery
A
B
E
F
Data link
Physical
Data link
Physical
Data link
Physical
Hop-to-hop delivery
Hop-to-hop delivery
Hop-to-hop delivery

Layer 2- Data Link Layer

- Packages data into frames and transmitting those frames on the network, performing error detection/correction, and uniquely identifying network devices with an address (MAC), and flow control
- MAC
  - Physical addressing
  - Logical topology
  - Method of Transmission
- LLC
  - Connection services
  - Synchronizing transmissions

Layer 2- Data Link Layer

Media Access Control (MAC)

- Physical addressing   3A:34:65:D2:51:F1
  - Uses 48-bit address assigned to a network interface card (NIC) by manufacturer
  - First 24-bits is the vendor code
  - Second 24-bits is a unique value
- Logical topology
  - Layer 2 devices view networks logically
    - Ring, bus, star, mesh, hub-and-spoke, ...
- Method of transmission
  - Many devices are interconnected
  - Determines whose turn it is to transmit to prevent interference with other devices

Layer 2- Data Link Layer

Logical Link Control (LLC)

- Provides connection services
- Acknowledgement of receipt of a message
- Flow control
  - Limits amount of data sender can send at one time to keep receiver from becoming overwhelmed
- Error control
  - Allows receiver to let sender know when an expected data frame wasn't received or was corrupted by using a checksum

Layer 2- Data Link Layer

Examples at Layer 2

- NICs
- Bridges.
- Switches.

OSI Layer 1 : Physical Layer

Primary function is transmitting raw bits over a physical communications channel

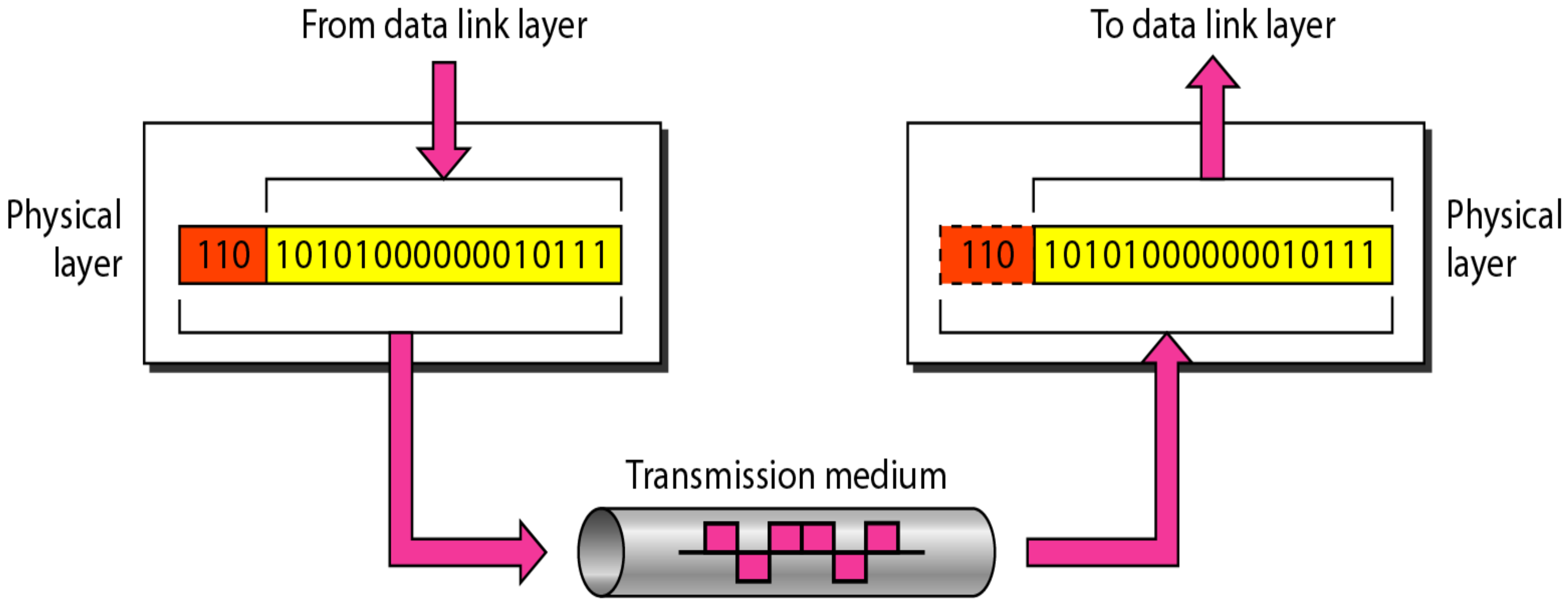
Primary design issues include: mechanical, electrical, coding, physical characteristics

- ✓ how many pins in the connector
- ✓ what voltage represents a “1” versus a “0”

- It defines the transmission of data across the communications medium and translation of binary data into signals.
- Mode of transmission over the link i.e Simplex or Half Duplex or Full Duplex

NOTE:- The physical layer is responsible for movements of individual bits from one hop (node) to the next.

OSI Layer 1 : Physical Layer



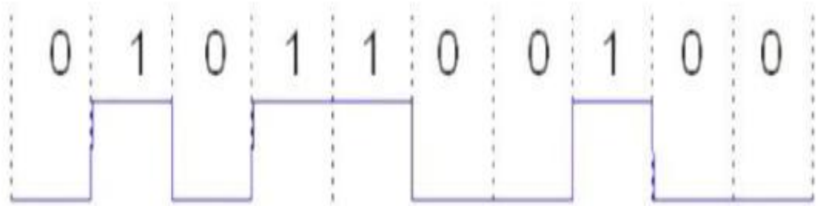
Layer1- Physical Layer

How are bits represented on the medium?

- Electrical voltage (copper wiring) or light (fiber optics) represent 1's and 0's (bits)

- Current State
  - If 0 volts, then 0 is represented
  - If +/- 5 volts, then 1 is represented

- Transition Modulation
  - If it changed during the clock cycle, then a 1 is represented otherwise a 0



Layer1- Physical Layer

How are the cables wired?

- TIA/EIA-568-B is standard wiring for RJ-45 cables and ports

[Straight Through Cross Over Cable Page (95)]

- Crossover cables use T-568A and T-568B

- Straight-thru cables typically use T-568B on both ends, but could use T-568A on both

Pin	Color
1	white/orange
2	orange
3	white/green
4	blue
5	white/blue
6	green
7	white/brown
8	brown

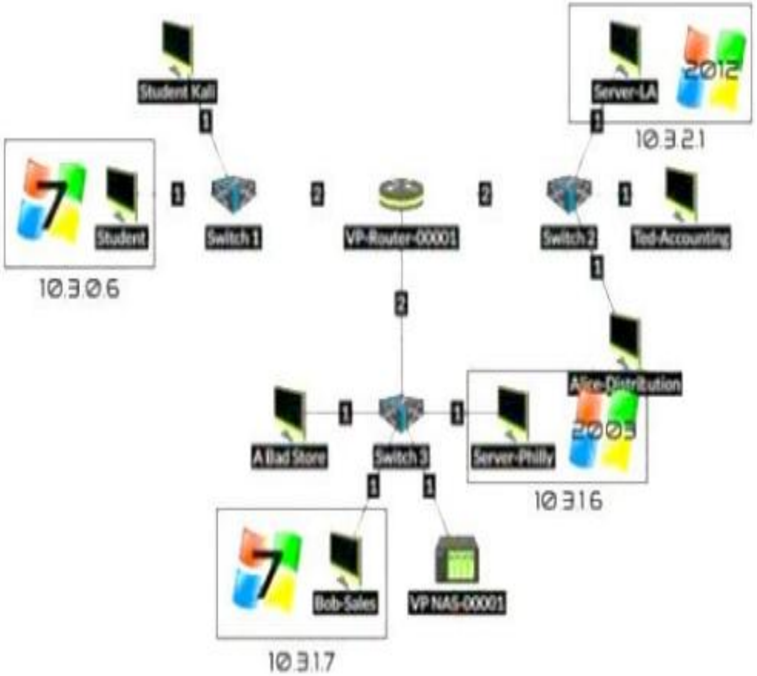
Wiring standards will be address in-depth in the Ethernet module

Layer1- Physical Layer

How are the cables connected?

- Layer 1 devices view networks from a physical topology perspective

- Includes:
  - Bus
  - Ring
  - Star
  - Hub-and-Spoke
  - Full Mesh
  - Partial Mesh



Layer1- Physical Layer

How is bandwidth utilized?

- Broadband
  - Divides bandwidth into separate channels
  - Example:
    - Cable TV

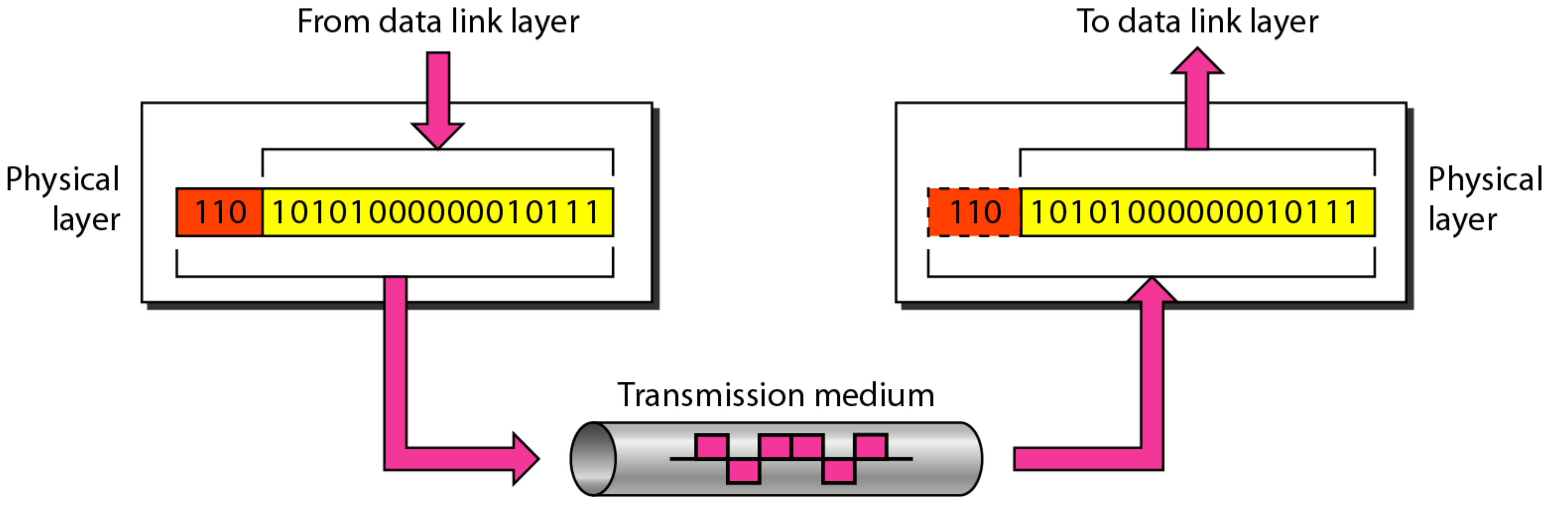
- Baseband
  - Uses all available frequency on a medium (cable) to transmit data and uses a reference clock to coordinate the transmissions by both sender and receiver
  - Example:
    - Ethernet, Telephone call

Layer1- Physical Layer

How can we get more out of a limited network?

- Time-Division Multiplexing (TDM)
  - Each session takes turns, using time slots, to share the medium between all users **(Bathroom)**
- Statistical Time-Division Multiplexing (StatTDM)
  - More efficient version of TDM, it dynamically allocates time slots on an as-needed basis instead of statically assigning
- Frequency-Division Multiplexing (FDM):
  - Medium is divided into various channels based on frequencies and each session is transmitted over a different channel
    - Broadband

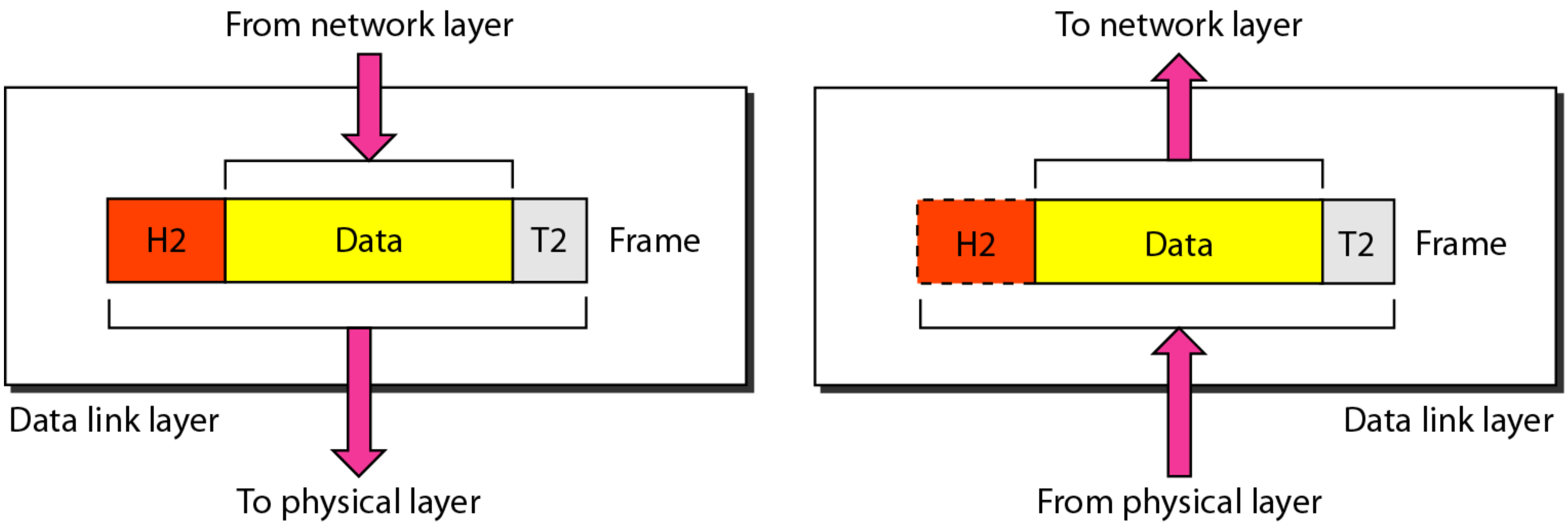
Figure 2.5 *Physical layer*



Note

The physical layer is responsible for movements of individual bits from one hop (node) to the next.

Figure 2.6 *Data link layer*



Note

The data link layer is responsible for moving frames from one hop (node) to the next.

Figure 2.7 *Hop-to-hop delivery*

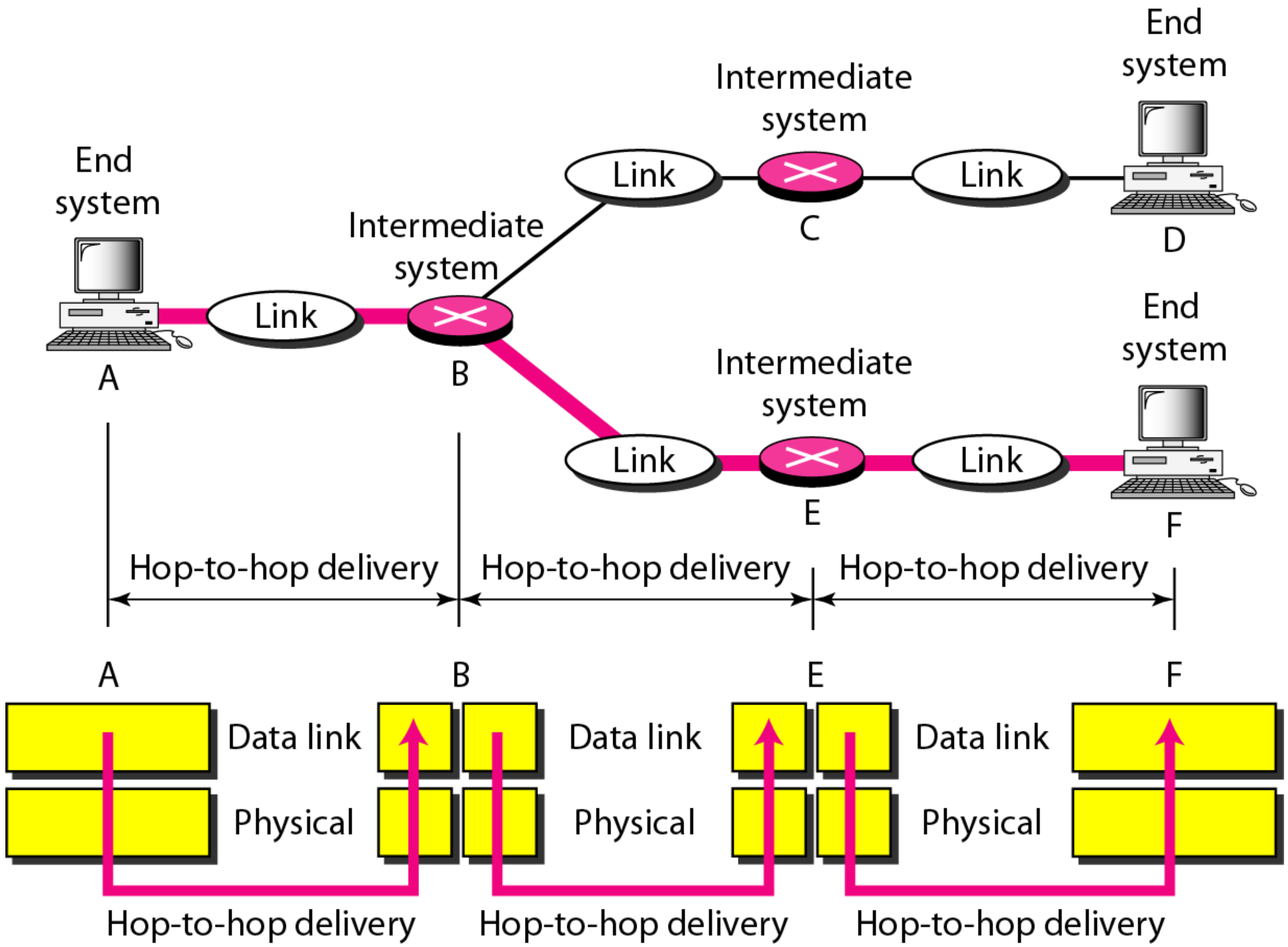
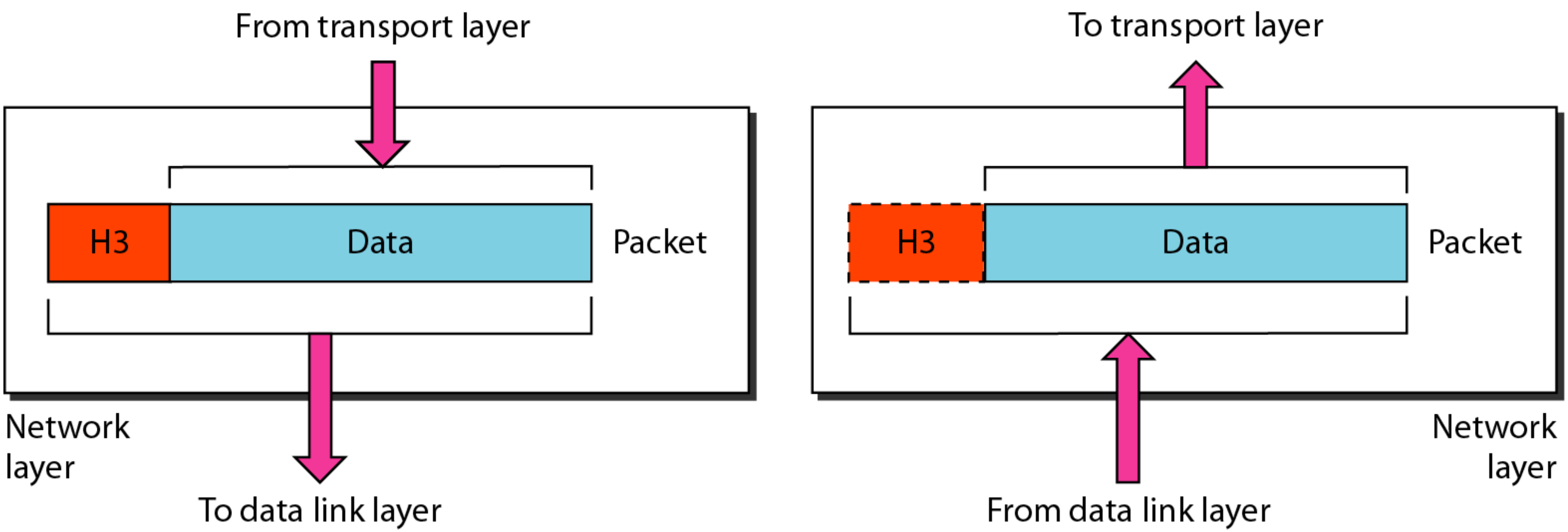


Figure 2.8 *Network layer*



Note

The network layer is responsible for the delivery of individual packets from the source host to the destination host.

Figure 2.9 *Source-to-destination delivery*

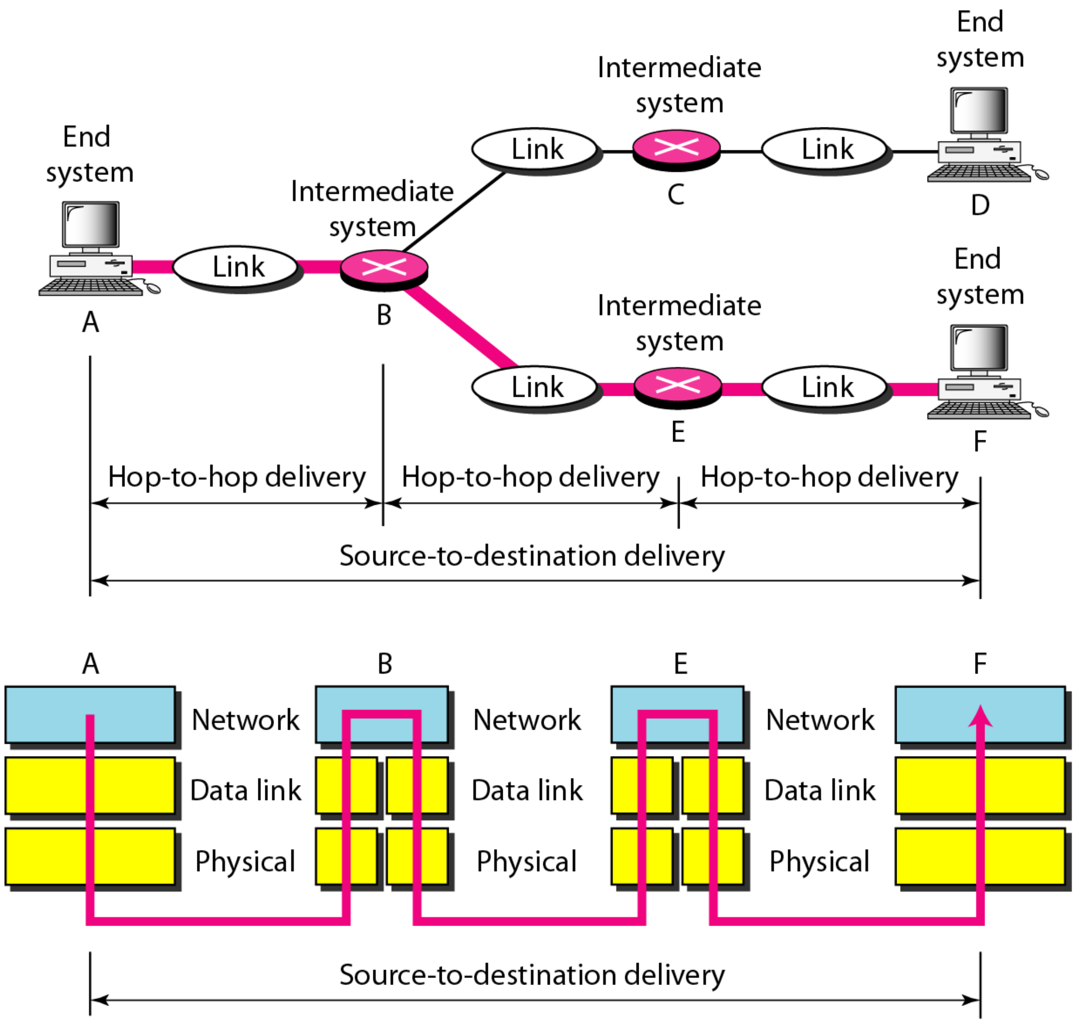
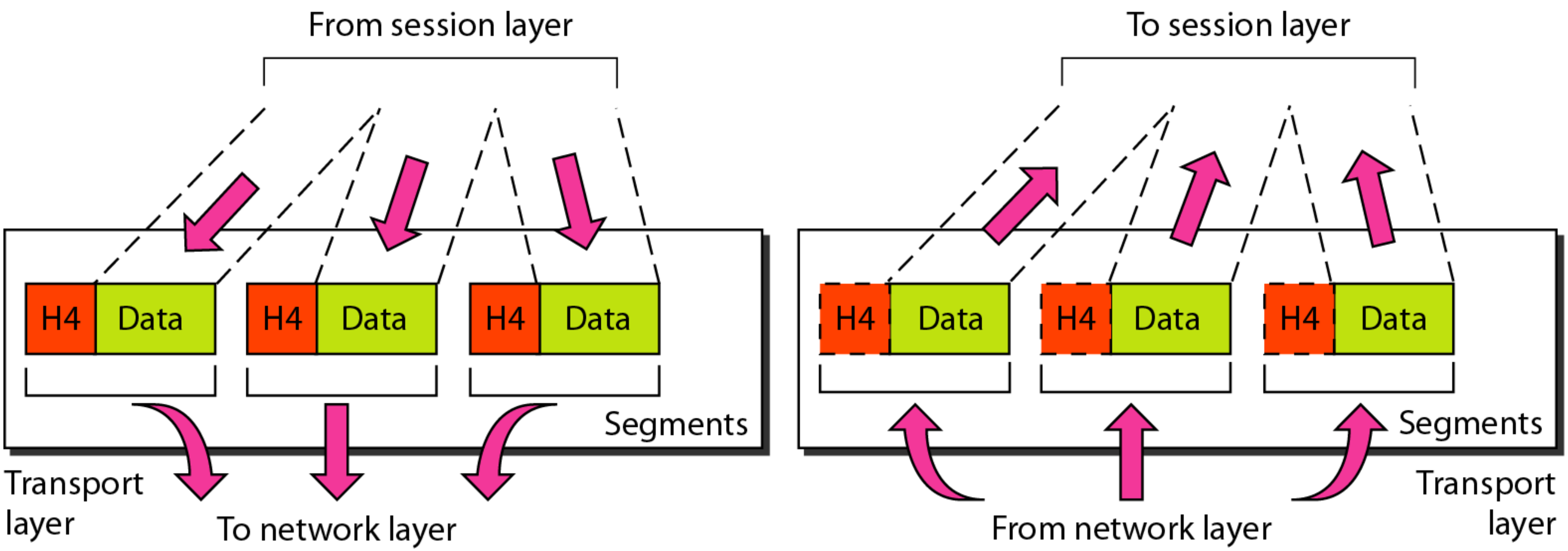


Figure 2.10 *Transport layer*



Note

The transport layer is responsible for the delivery of a message from one process to another.

Figure 2.11 *Reliable process-to-process delivery of a message*

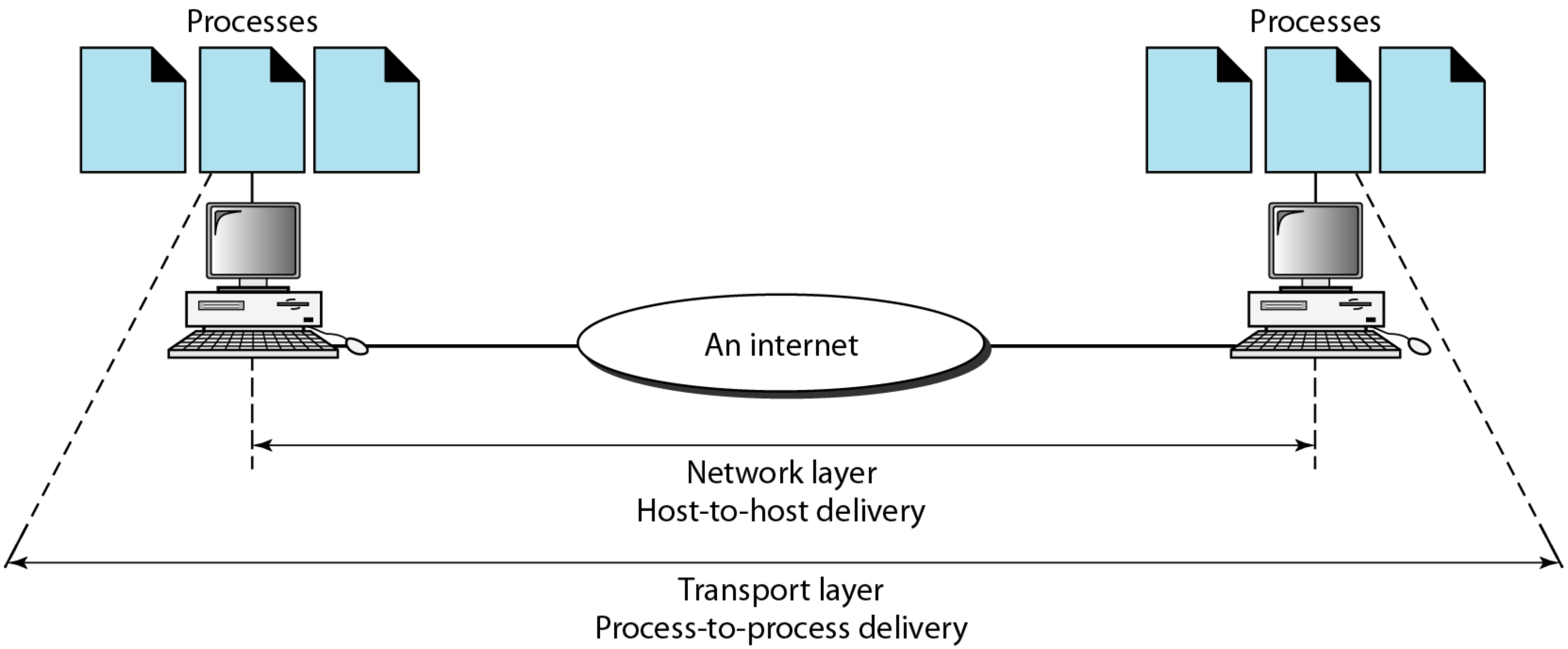
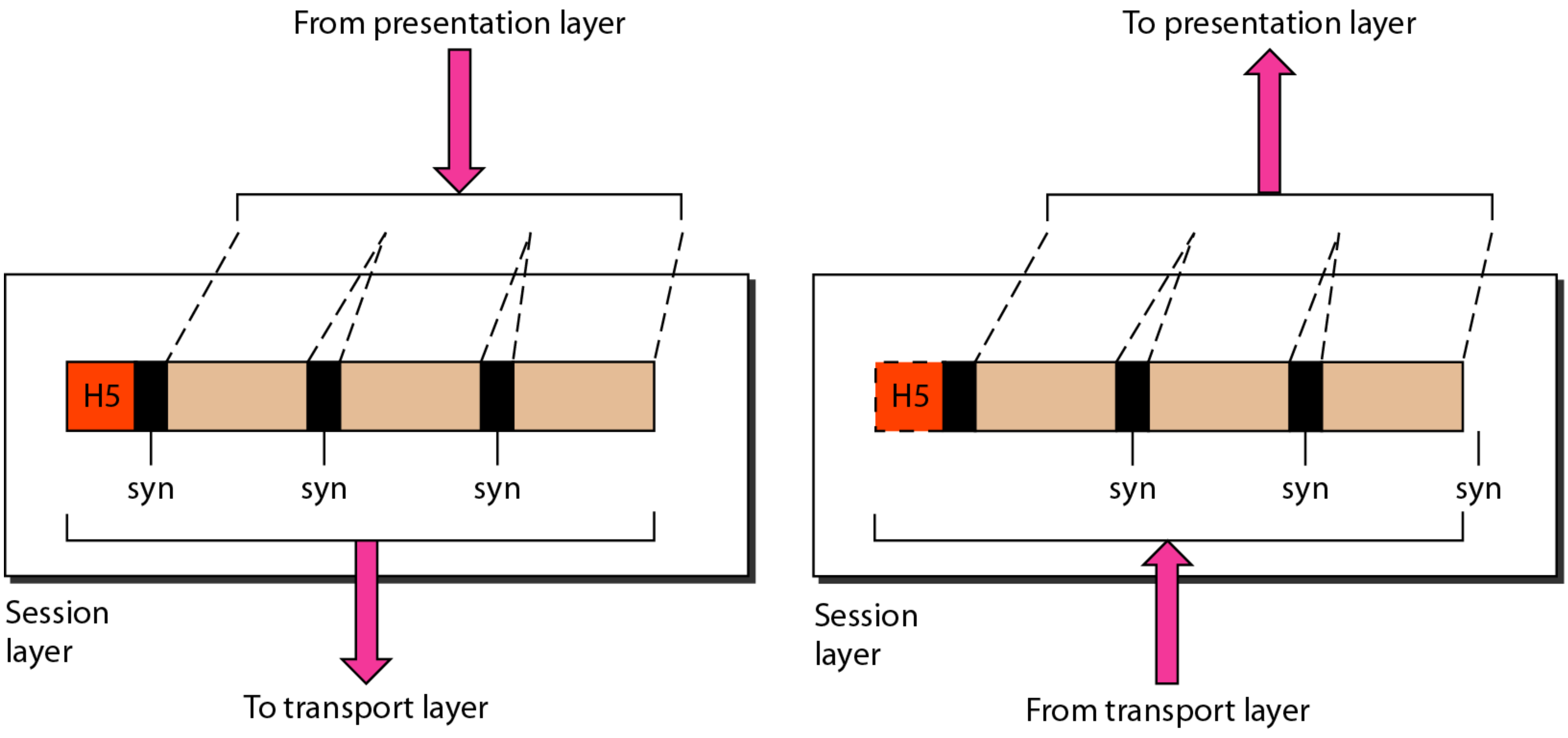


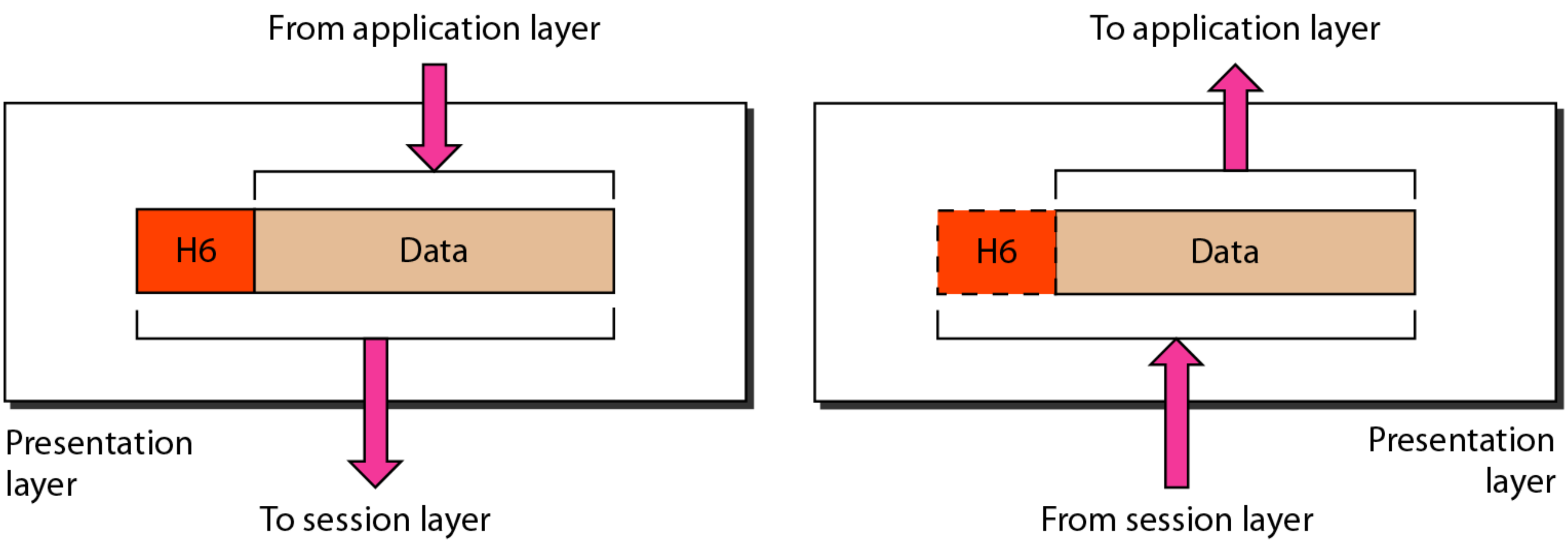
Figure 2.12 *Session layer*



Note

The session layer is responsible for dialog control and synchronization.

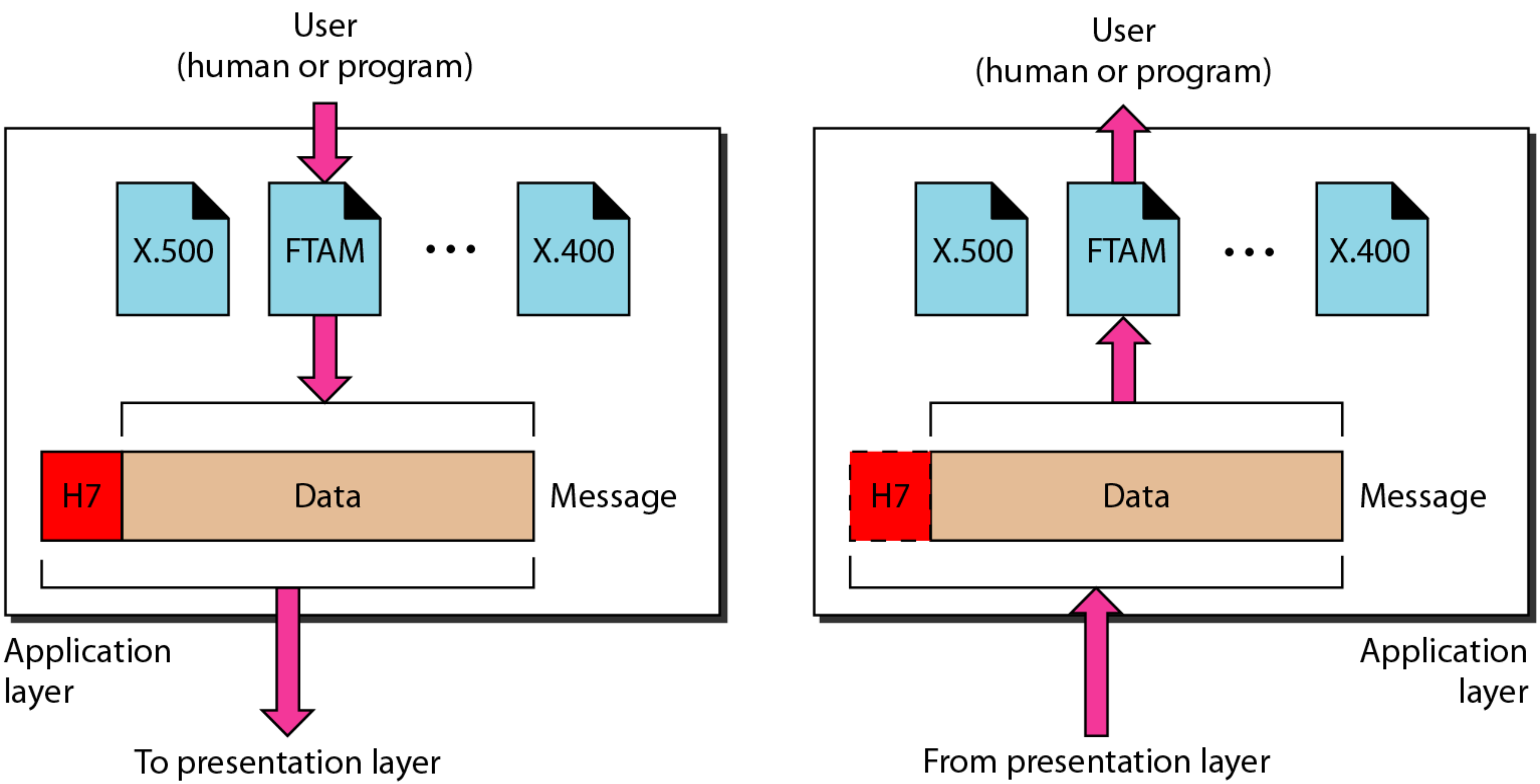
Figure 2.13 *Presentation layer*



Note

The presentation layer is responsible for translation, compression, and encryption.

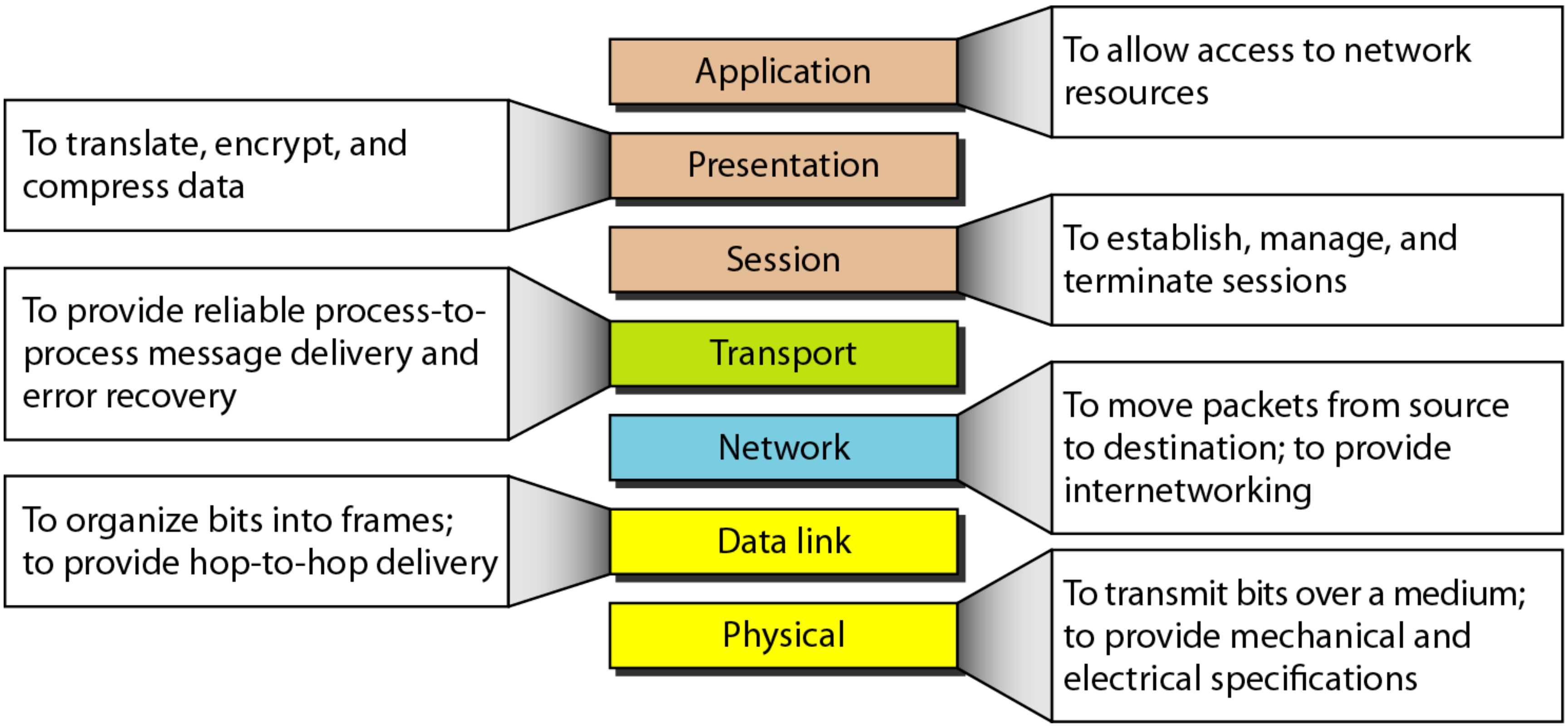
Figure 2.14 *Application layer*



Note

The application layer is responsible for providing services to the user.

Figure 2.15 *Summary of layers*



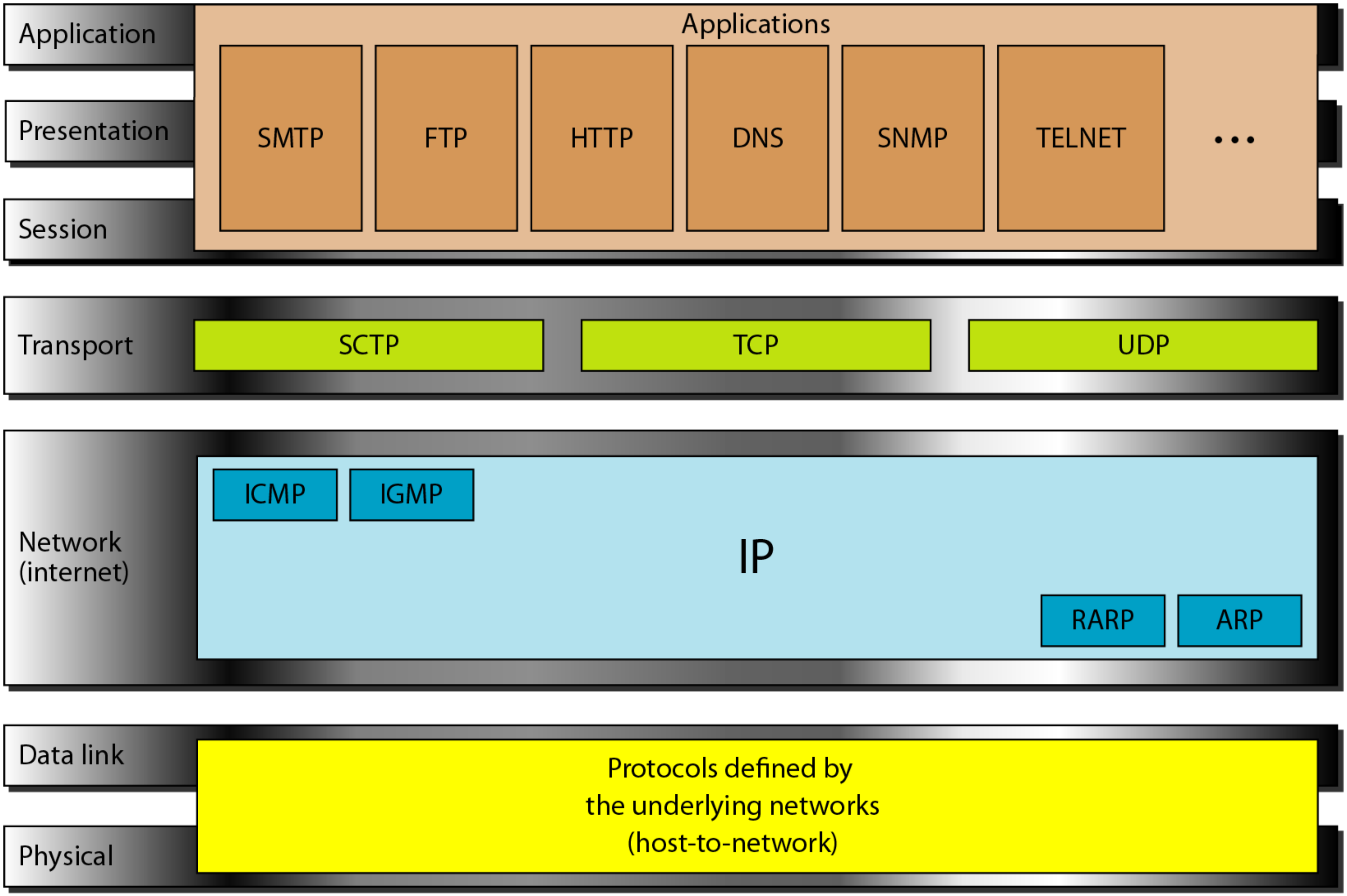
2-4 TCP/IP PROTOCOL SUITE

The layers in the TCP/IP protocol suite do not exactly match those in the OSI model. The original TCP/IP protocol suite was defined as having four layers: host-to-network, internet, transport, and application. However, when TCP/IP is compared to OSI, we can say that the TCP/IP protocol suite is made of five layers: physical, data link, network, transport, and application.

Topics discussed in this section:

Physical and Data Link Layers
Network Layer
Transport Layer
Application Layer

Figure 2.16 *TCP/IP and OSI model*



2-5 ADDRESSING

Four levels of addresses are used in an internet employing the TCP/IP protocols: physical, logical, port, and specific.

Topics discussed in this section:

Physical Addresses
Logical Addresses
Port Addresses
Specific Addresses

Figure 2.17 *Addresses in TCP/IP*

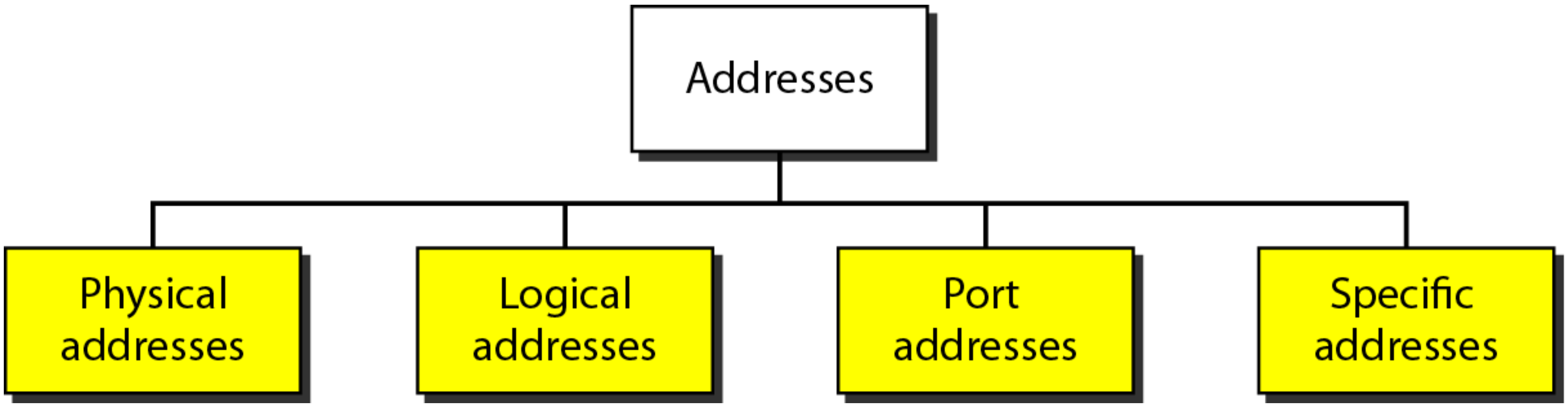
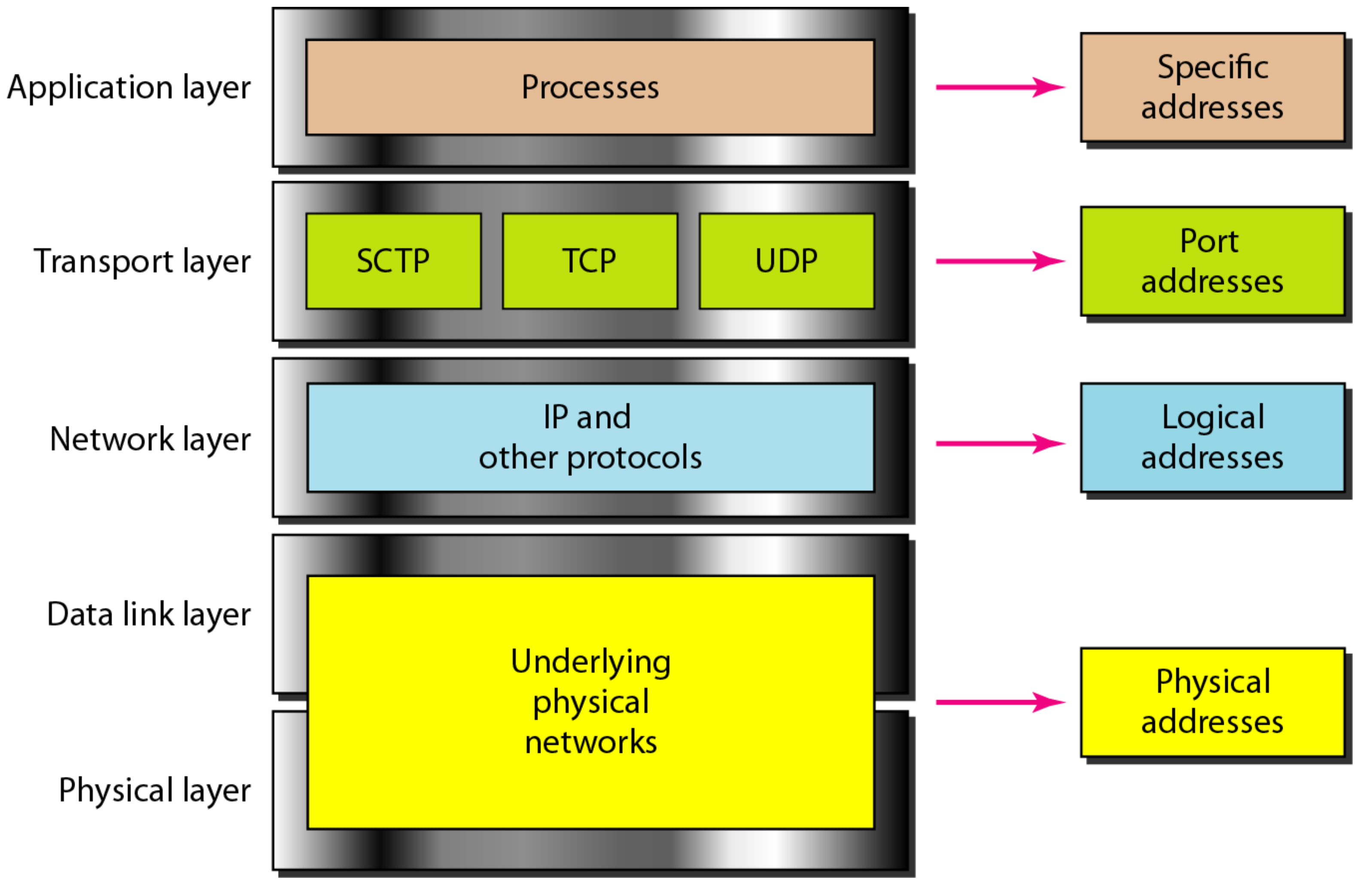


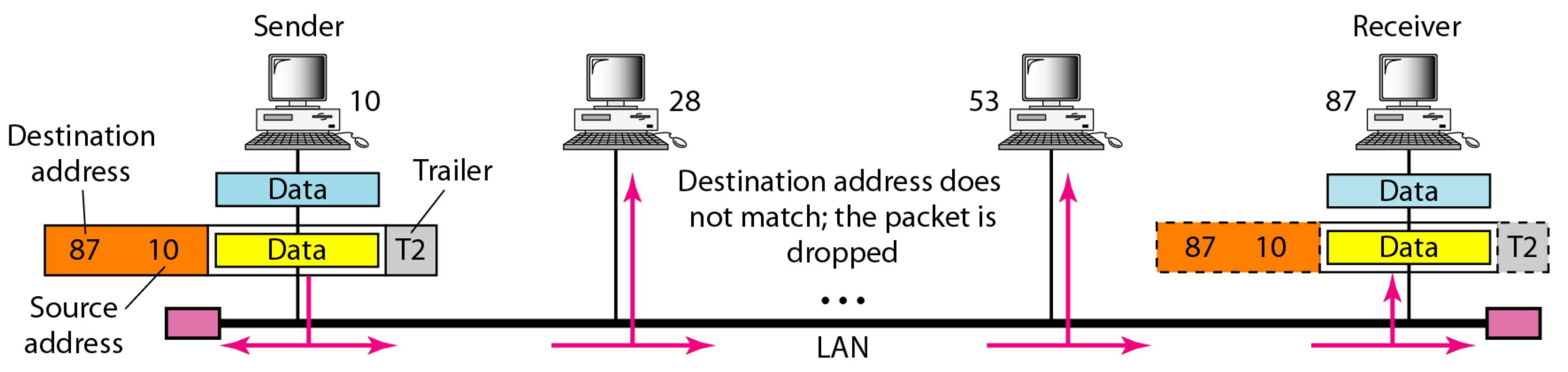
Figure 2.18 *Relationship of layers and addresses in TCP/IP*



Example 2.1

In Figure 2.19 a node with physical address 10 sends a frame to a node with physical address 87. The two nodes are connected by a link (bus topology LAN). As the figure shows, the computer with physical address 10 is the sender, and the computer with physical address 87 is the receiver.

Figure 2.19 *Physical addresses*



Example 2.2

Most local-area networks use a 48-bit (6-byte) physical address written as 12 hexadecimal digits; every byte (2 hexadecimal digits) is separated by a colon, as shown below:

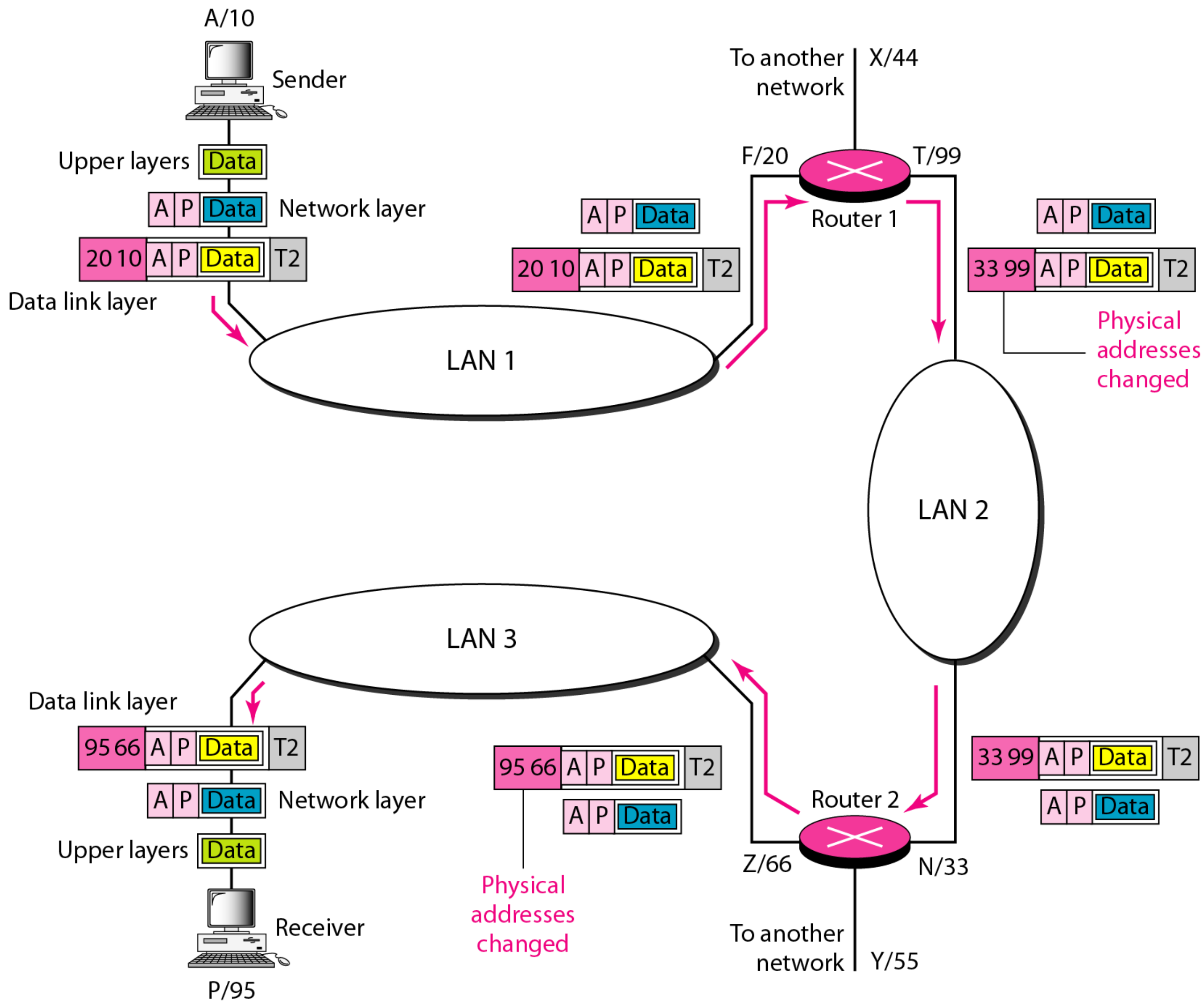
07:01:02:01:2C:4B

A 6-byte (12 hexadecimal digits) physical address.

Example 2.3

Figure 2.20 shows a part of an internet with two routers connecting three LANs. Each device (computer or router) has a pair of addresses (logical and physical) for each connection. In this case, each computer is connected to only one link and therefore has only one pair of addresses. Each router, however, is connected to three networks (only two are shown in the figure). So each router has three pairs of addresses, one for each connection.

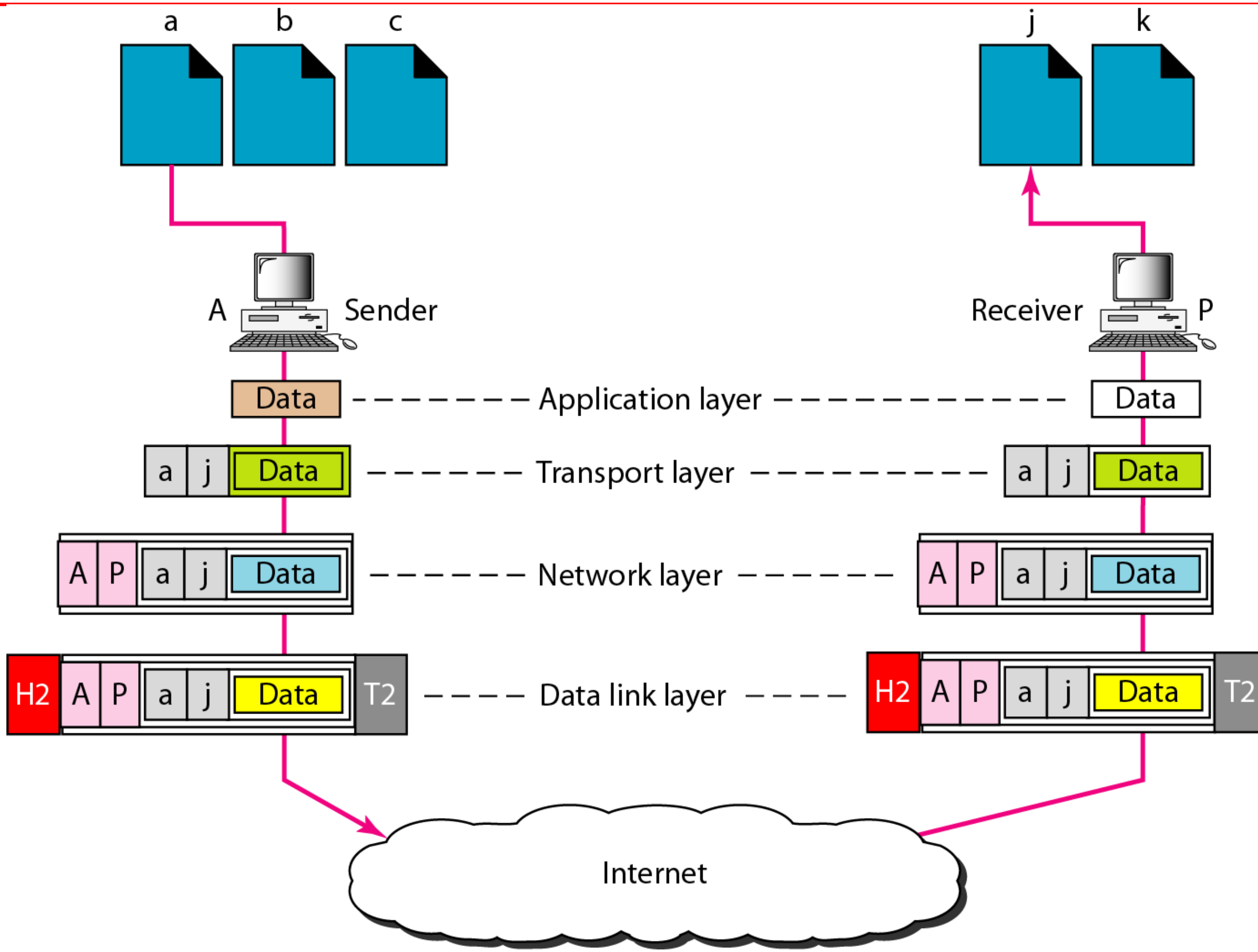
Figure 2.20 *IP addresses*



Example 2.4

Figure 2.21 shows two computers communicating via the Internet. The sending computer is running three processes at this time with port addresses a, b, and c. The receiving computer is running two processes at this time with port addresses j and k. Process a in the sending computer needs to communicate with process j in the receiving computer. Note that although physical addresses change from hop to hop, logical and port addresses remain the same from the source to destination.

Figure 2.21 *Port addresses*



Note

The physical addresses will change from hop to hop, but the logical addresses usually remain the same.

Example 2.5

A port address is a 16-bit address represented by one decimal number as shown.

753

A 16-bit port address represented as one single number.