Data Communications and Networking

Course Outline

- Basic Concepts
  (a) Fundamentals of Data and Signals
  (b) Network hardware and software
  (c) Network topologies and categories
  (d) Reference models and standards
- Principles of Computer Communications
  (a) Physical layer: signal analysis, bandwidth and data rate, transmission media, encoding, transmission
  (b) Data link layer: framing, error control, flow control, multiple access protocols
  (c) Network layer: circuit switching, packet switching, routing, congestion control

Data Communications and Networking

Course Outline

- Standardized Networks
  (a) Ethernet, Fast Ethernet, Gigabit Ethernet, etc.
  (b) Wi-Fi
- Network Programming
  (a) Introduction to internetworking and TCP/IP
  (b) Socket programming
  (c) Client software
  (d) Server software: concurrent, iterative; connection-oriented, connectionless; multi- protocol, multi-service; blocking mode

Chapter 1
Data Communications and Networking

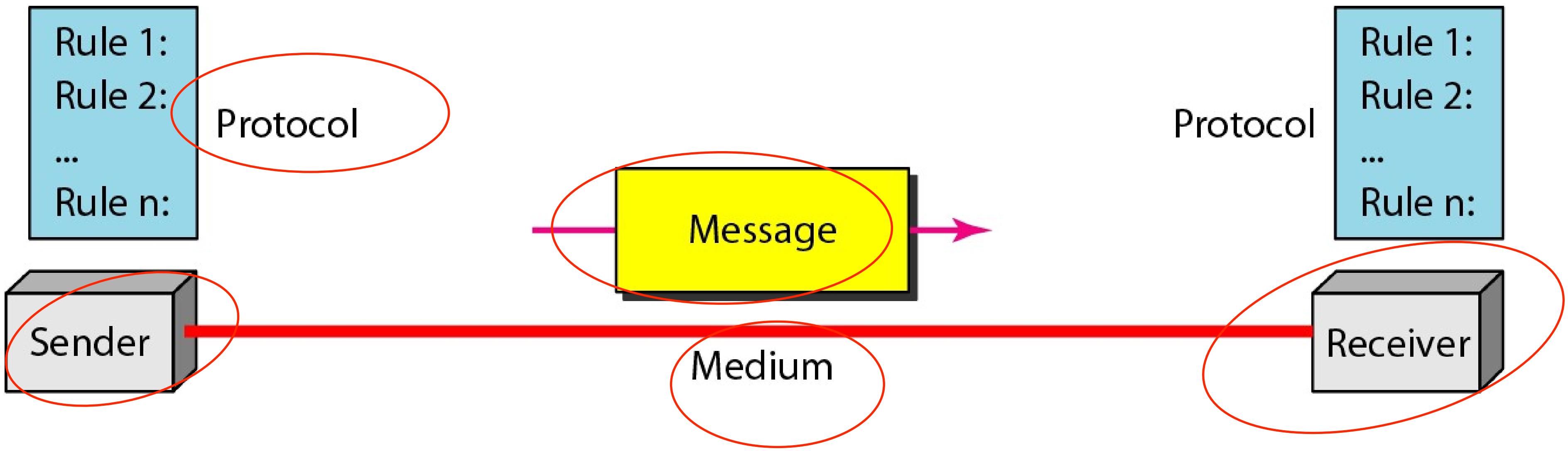
Basic Concepts

What is Data Communications

- The term telecommunication means communication at a distance.
- The word data refers to information presented in whatever form is agreed upon by the parties creating and using the data.
- Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable.

Five components of data communication

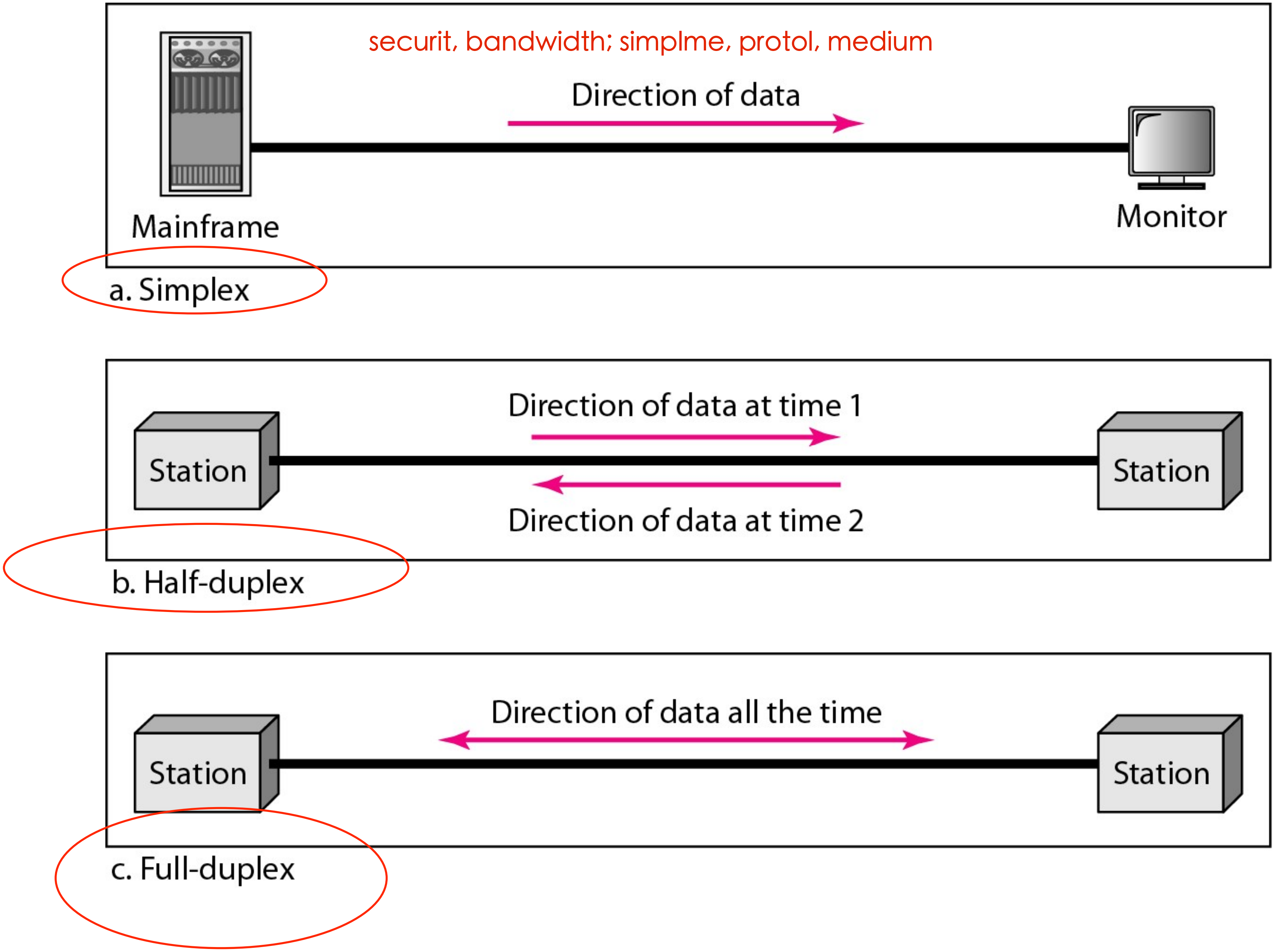
protocol: a set of rules: 1. signaling 2. encoding, decoding



What is a network protocol?

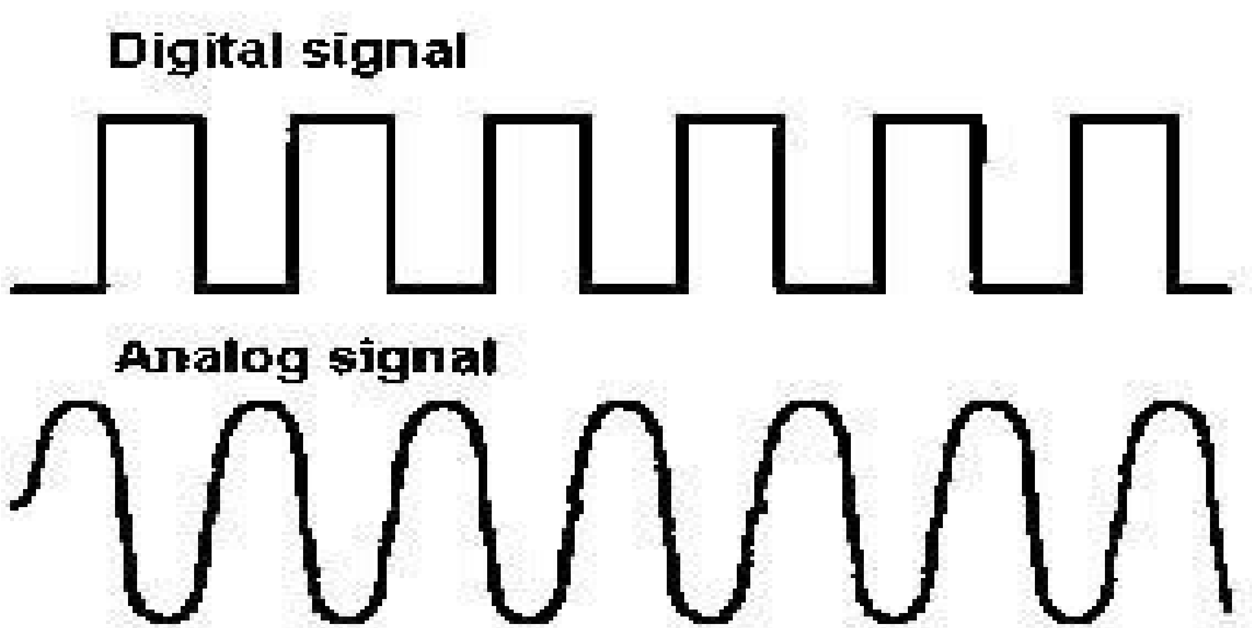
- Communication node is machine
- All communication activity in the Internet is controlled by protocols
- Protocols define formats, order of sending and receiving of messages, and the actions that the reception initiates

Data flow (simplex, half-duplex, and full-duplex)



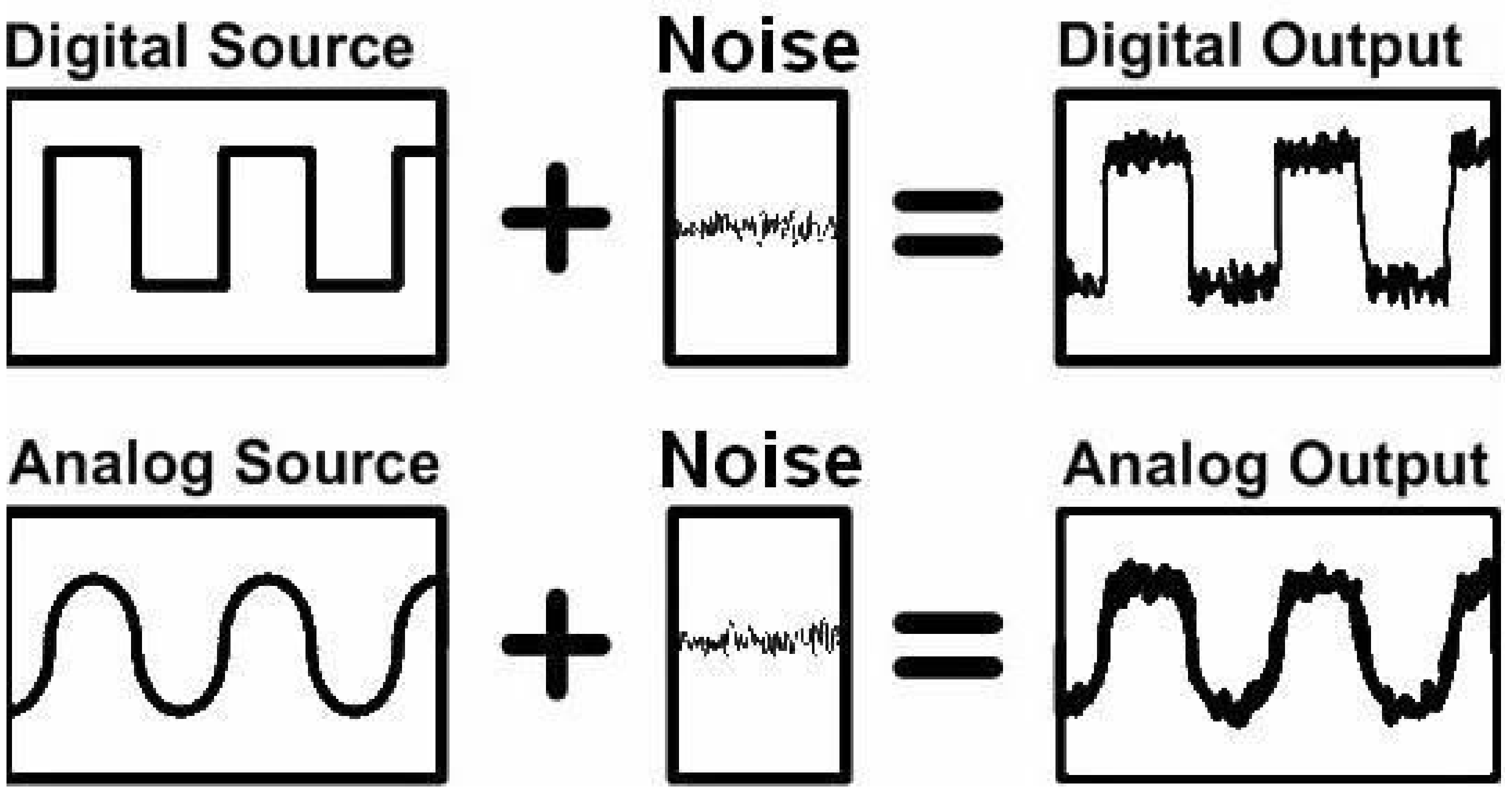
Fundamentals of Data and Signals

- Analog versus Digital
  - Analog signals are continuous electrical signals that vary in time.
  - Digital signals are non-continuous. They consist of pulses or digits with discrete levels or values. The value of each pulse is constant. Digital signals usually have two amplitude levels such as 1 or 0, HIGH or LOW.



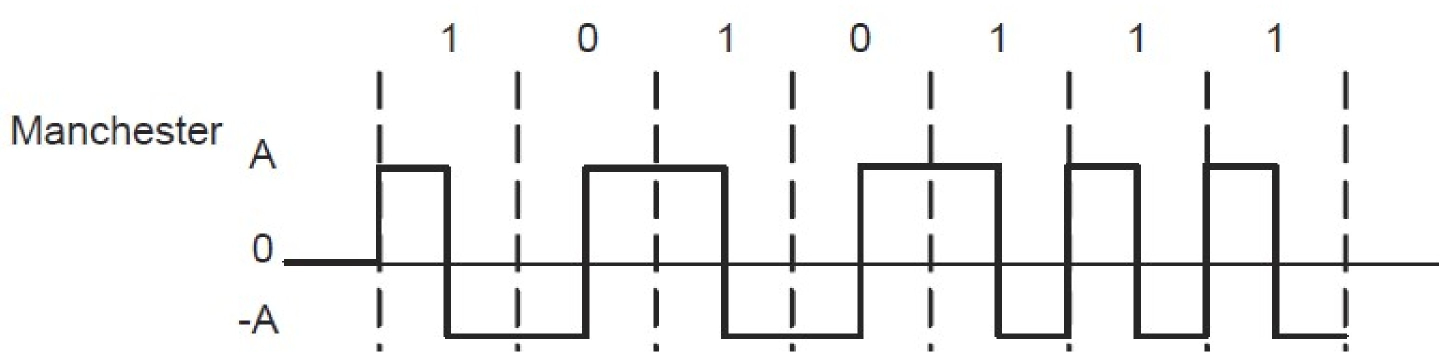
Advantages of Digital Signals

- Less sensitive to the interferences (e.g., noise, magnetic field)
- Easier for further processing (e.g., error correction, storage, etc.)



Transmitting digital data with digital signals: Digital Encoding Schemes

- Non-return to zero digital encoding scheme
  - **‘1’ bit** is sent as a high value and **‘0’ bit** is sent as a low value.
  - The receiver may lose synchronization because the data may contain long runs of consecutive bits with the same value [no changes in voltage].
- Manchester digital encoding scheme
  - The digital data is represented as: **‘0’ bit** by a voltage from low to high; **‘1’ bit** by a voltage from high to low.
  - Manchester encoding is a synchronous clock encoding technique to encode the clock and data of a synchronous bit stream.



Transmitting digital data with digital signals: Digital Encoding Schemes

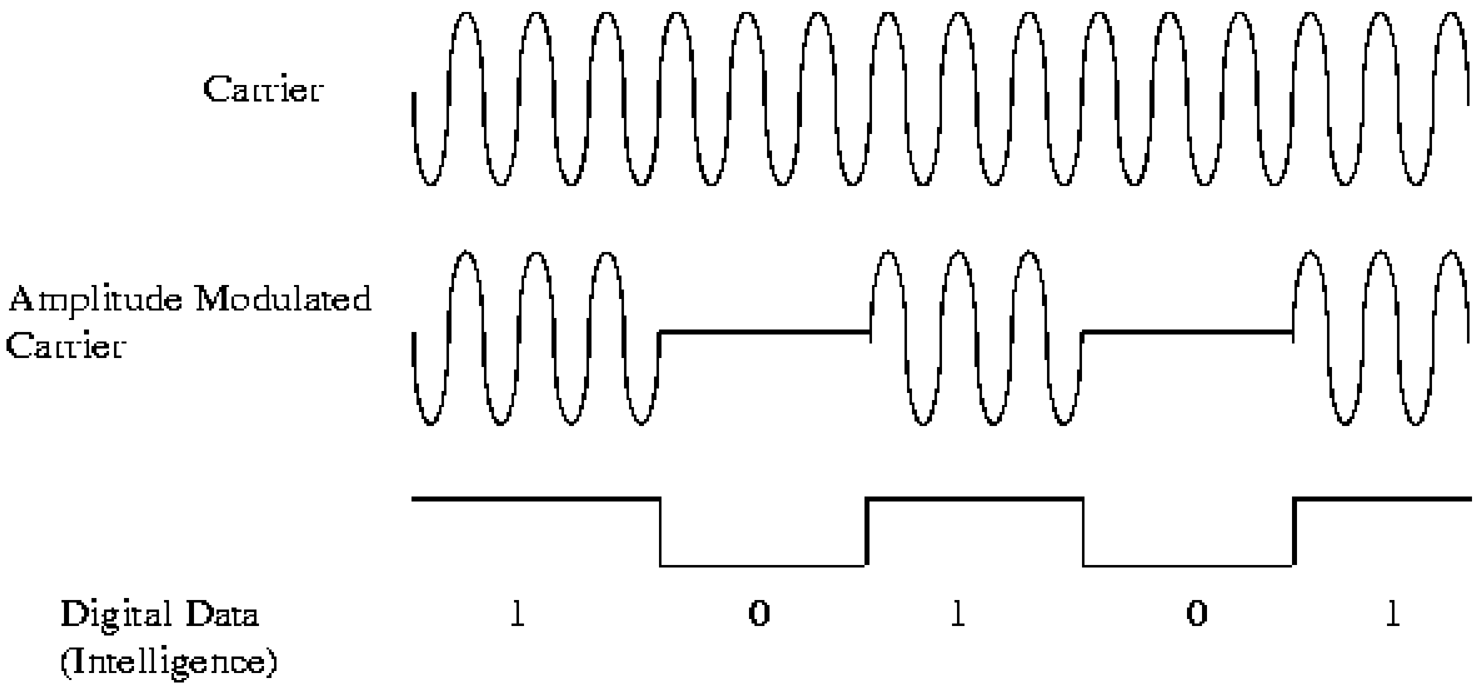
- 4B/5B digital encoding scheme
  - It produces a signal for a group of bits each time, rather than outputting a signal for each individual bit.
  - Each time, a **4-bit input data** (16 different bit patterns) is encoded as a **5-bit data** (32 different bit patterns).
  - By carefully choosing the 5-bit patterns which always contain two '1's even if the input data is all '0's, the clock synchronizations can be achieved.

Table of 4B/5B Conversion

Hex Digit	**4B**	**5B**
0	0000	11110
1	0001	01001
2	0010	10100
3	0011	10101
4	0100	01010
5	0101	01011
6	0110	01110
7	0111	01111
8	1000	10010
9	1001	10011
A	1010	10110
B	1011	10111
C	1100	11010
D	1101	11011
E	1110	11100
F	1111	11101

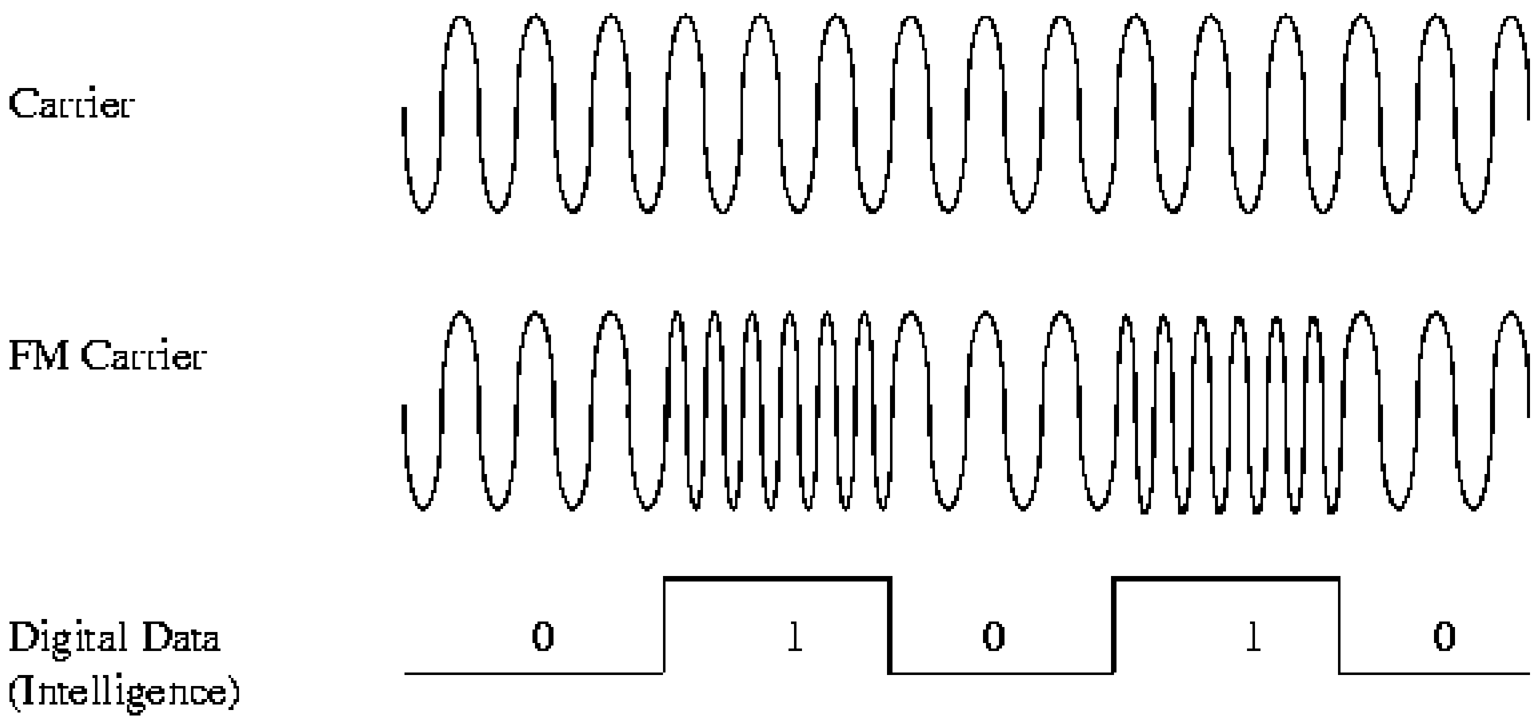
Transmitting digital data with analog signals: Digital Encoding Schemes

- **AM - Amplitude Modulation**
  - Amplitude Modulation modifies the amplitude of the carrier to represent 1s or 0s.
  - Example: A 1 is represented by the presence of the carrier for a predefined period of 3 cycles of carrier. Absence (or no carrier) indicates a 0.



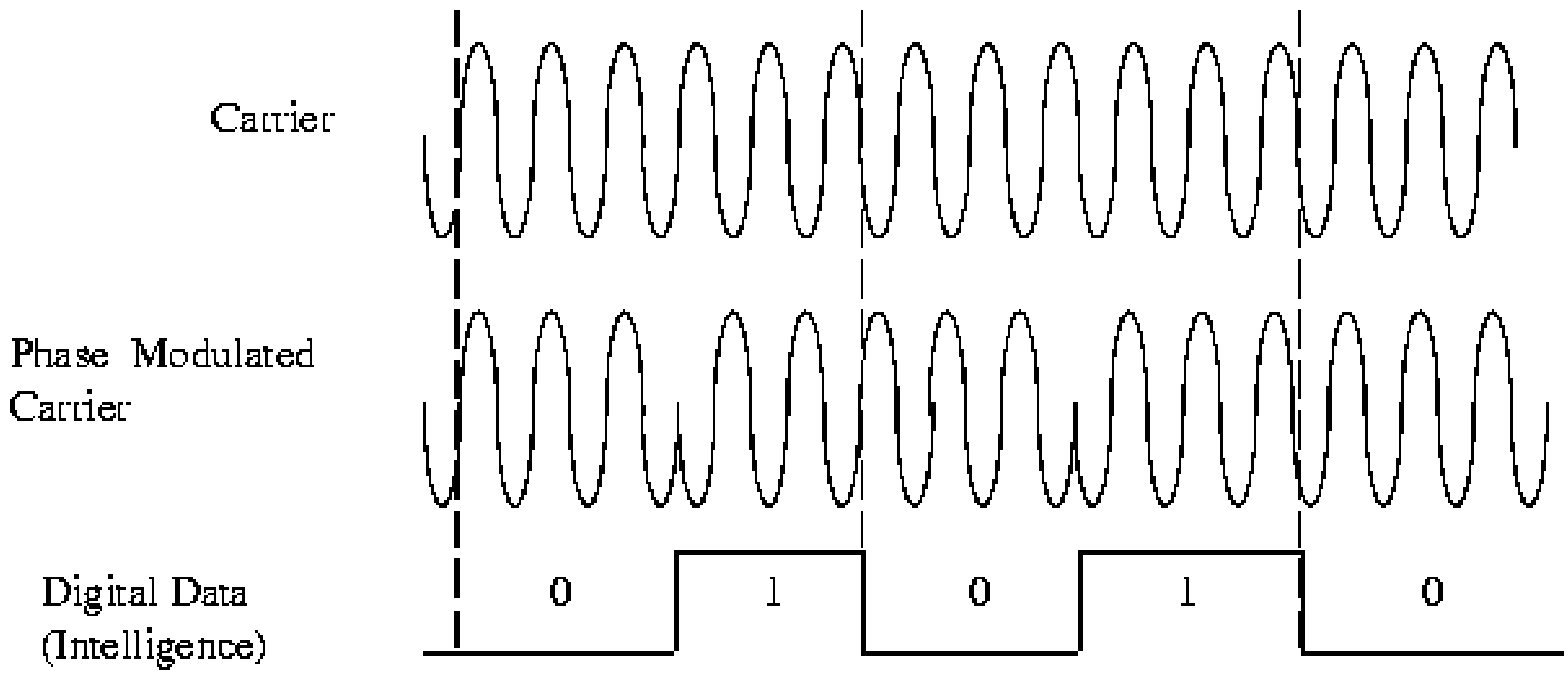
Transmitting digital data with analog signals: Digital Encoding Schemes

- **FM - Frequency Modulation**
  - Frequency Modulation modifies the frequency of the carrier to represent the 1s or 0s.
  - Example: A 0 is represented by the original carrier frequency and a 1 by a much higher frequency (the cycles are spaced closer together).



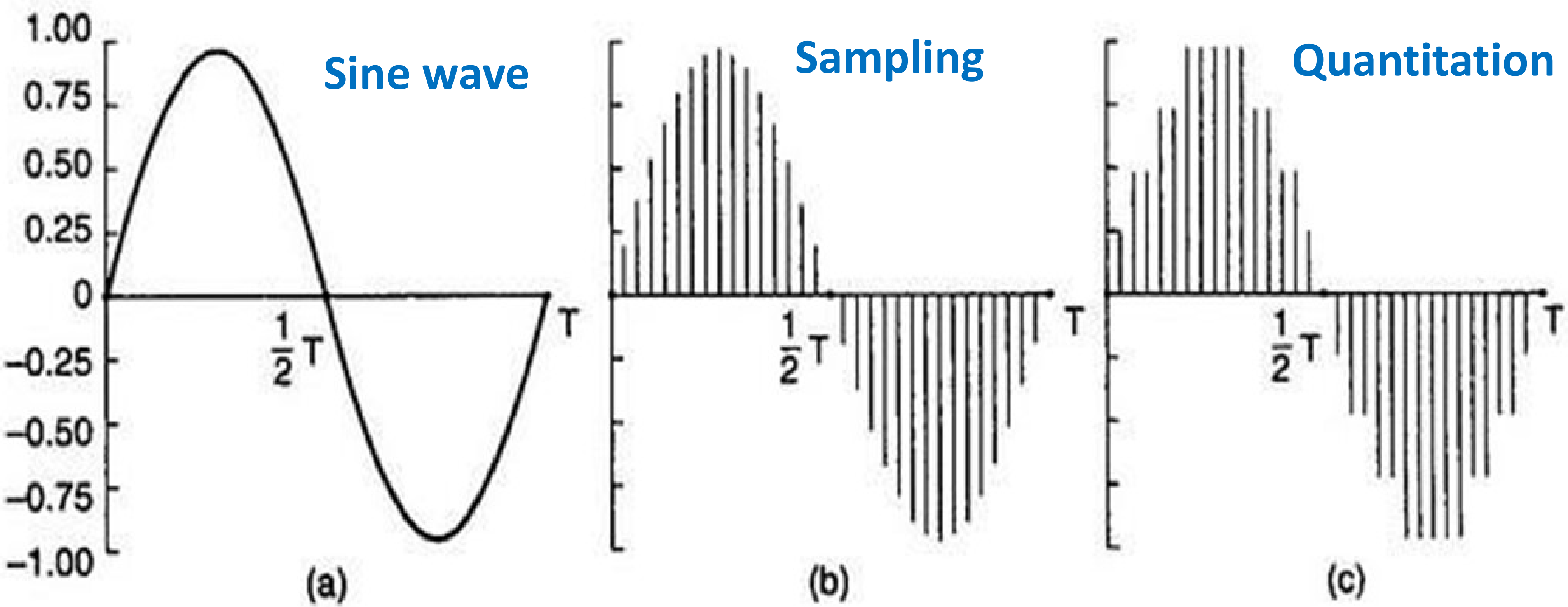
Transmitting digital data with analog signals: Digital Encoding Schemes

- **PM - Phase Modulation**
  - Phase Modulation modifies the phase of the carrier to represent a 1 or 0.
  - The carrier phase is switched at every occurrence of a 1 bit, but remains unaffected for a 0 bit. The bits are timed to coincide with a specific number of carrier cycles.



Convert Analog Signal to Digital Signal

- To digitize the analog signals, a common sampling technique called **Pulse Coding Modulation** is used.
- PCM samples the signal from 8 to 192 thousand times per second; each sample is represented by 8 to 24 bits.



Capacity of Communication Channel

- Nyquist's Theorem
  - Assumption: noise free in the channel
  - Formula: $\mathbf{B = 2F\,(\log_2 M)}$**,** where

    B = Bit Rate (bit/sec)
    F = Channel Bandwidth in Hertz
    M = Number of levels in a signal (two for binary)

Capacity of Communication Channel

- Shannon's Theorem
  - In reality, the signal may be corrupted by electrical noise.
  - Formula: $\mathbf{B = F\ [\log_2(1 + S/N)]}$, where

    B = Actual Bit Rate (bit/sec)
    F = Channel Bandwidth in Hertz
    S = Signal Power in watts
    N = Noise Power in watts

Signal-to-Noise Ratio

- The signal-to-noise ratio is often given in decibels.
- Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz.
- The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$B = F \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Computer Networks

- A network is a set of devices (often referred to as nodes) connected by communication links.
- A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

Network Hardware

- The computer networks can classified as the following 4 categories: Local loop, LANs, MANs and WANs.
- **Local Loop**: it refers to the “last mile” of analog phone line that goes from the Exchange Centre to your house.
  - Voice lines
  - Modem (56 kbps)
  - ISDN (Integrated Services Digital Network): 2 x 64 kbps digital lines
  - ADSL (Asymmetrical Digital Subscriber Line): up to 8 Mbps
  - Cable Modems (up to 30 Mbps)
  - Network cable

Network Hardware

- **Local Area Networks (LANs)**
  - LANs are privately-owned networks within a single building or campus of up to a few kilometers in size.
  - LANs run at speeds of 10Mbps to 10Gbps, have low delay, and make very few errors.
  - The topologies of LANs are various: Bus, Ring, Star, etc.

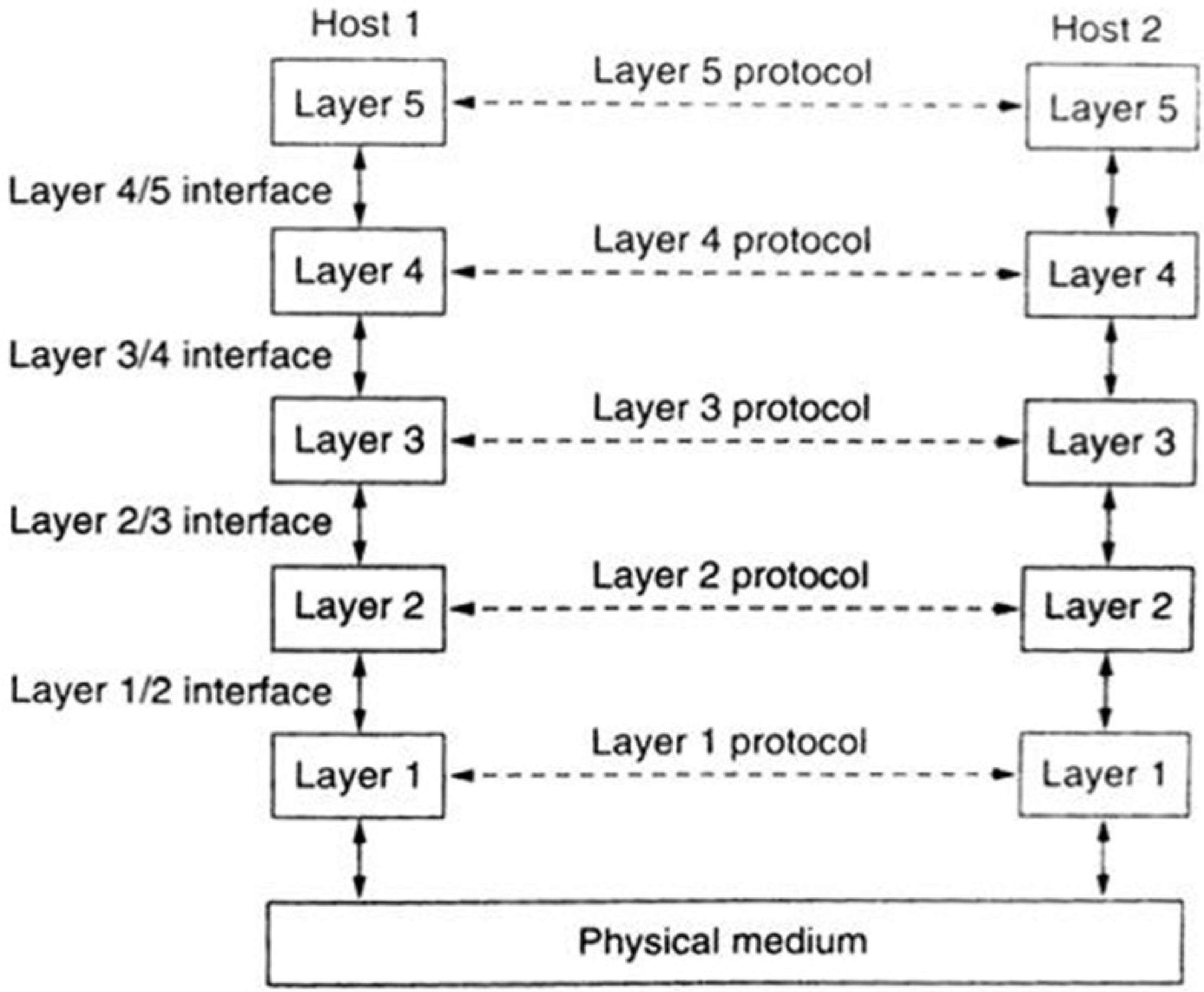
Network Hardware

- **MANs** (Metropolitan Area Network)
  - MANs are networks that connect LANs together within a city.
  - Example: cable television network
- **WANs (**Wide Area Networks**)**
  - WANs connect LANs together between cities. A WAN spans a large geographical area, often a country or continent.
- **Internetworks**
  - Many networks exists in the world with different hardware and software;
  - To communicate, it is better to connect different networks together.
  - A collection of interconnected networks is called an internetwork or internet (which is used in a generic sense, in contrast to the worldwide Internet).

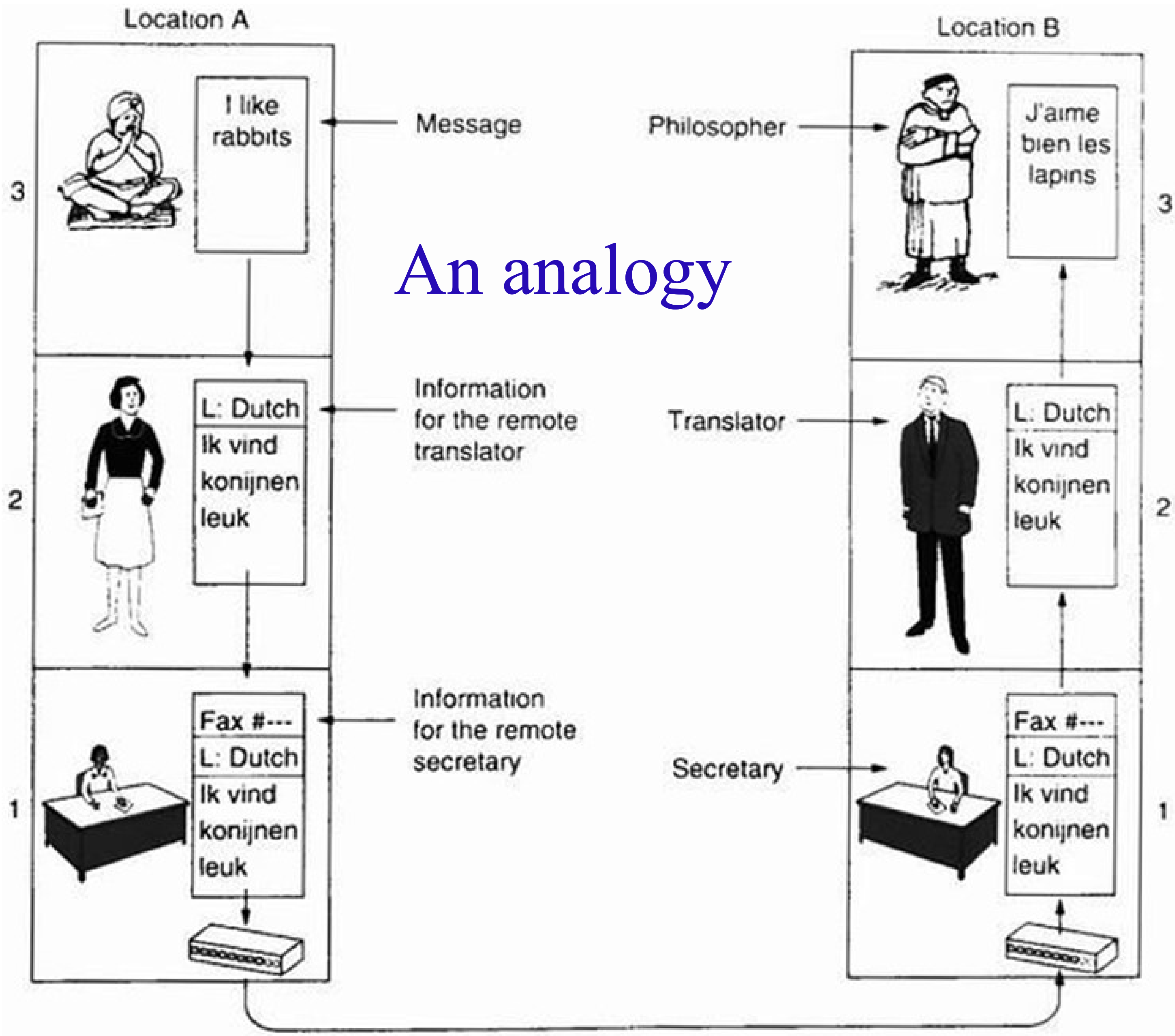
Network Software

- Protocol Hierarchies
  - To reduce the network design complexity, most networks are recognized as a stack of **layers** or **levels**, each one built upon the one below it.
  - Each layer offers certain services to the higher layers, shielding those layers from the details of how the offered services are implemented.
  - Between each pair of adjacent layers is an interface. The interface defines which primitives operations and services the lower layer makes available to the upper one.

Protocol Hierarchies: layers, protocols and interfaces



Protocol Hierarchies: layers, protocols and interfaces



Why Layering?

Management of complex systems:

- Modularisation simplifies
  - Design
  - Maintenance
  - Updating of a system
- Explicit structure allows
  - Identification of the individual parts
  - Relations among them
- Clear structure: layering
  - Layered reference model
  - Goal: different implementation of one layer fit with all implementations of other layers

Design Issues for the Layers

- **Addressing:** Every layer needs a mechanism for identifying senders and receivers.
- **Rules of data transfer:** simplex or duplex, no. of channels
- **Error control:** Both sender and receiver must agree on some sort of error-detecting and error-correcting codes.
- **Sequence:** The protocol must provide solution for receiver to reassemble the messages properly.
- **Flow control:** The protocol should provide a mechanism for sender and receiver to regulate the transmission rate.
- **Routing:** A mechanism must be provided to choose a route when there are multiple paths between source and destination.

Connection-Oriented and Connectionless Services

- **Connection-oriented services:** To establish a connection, the sender, receiver and the subnet conduct a negotiation about parameters to be used, such as maximum message size, quality of service required, etc.
  - The **Quality of Service** can be characterized in terms of Data Loss Rate, Delay Jitter, Data Rate, etc.
  - Application Example: File transfer
- **Connectionless service:** Each message carries the full destination address, and each one is routed through the system independent of all the others. No negotiation is needed between sender and receiver.

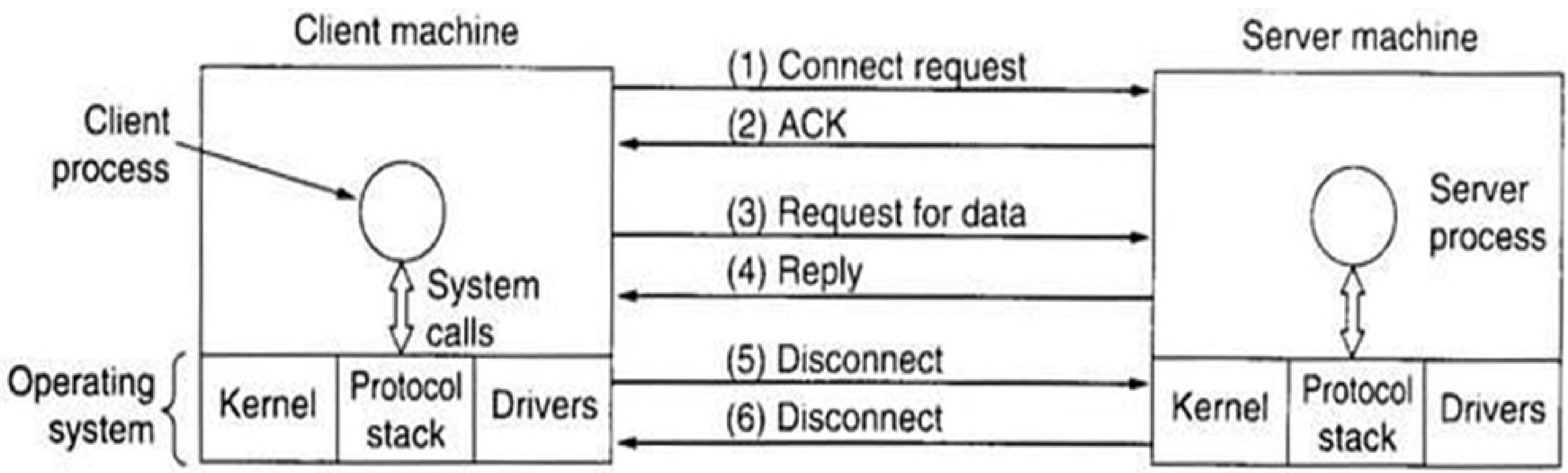
Service Primitives

- A service is formally specified by a set of **primitives** (operations) available to a user process to access the service. These primitives tell the service to perform some action or report on an action taken by a peer entity.
- Example: service primitives that might be provided to implemented a reliable byte stream in a client-server environment:

Primitives	**Meaning**
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

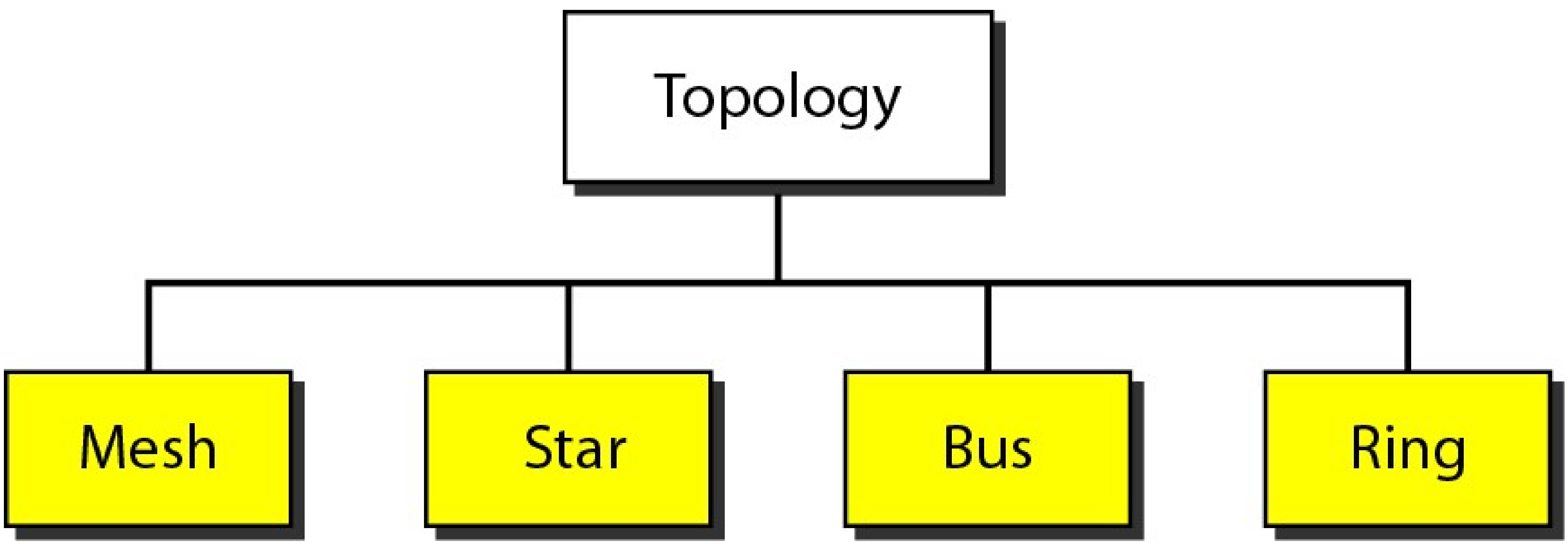
Service Primitives

Example: Client-server interactions



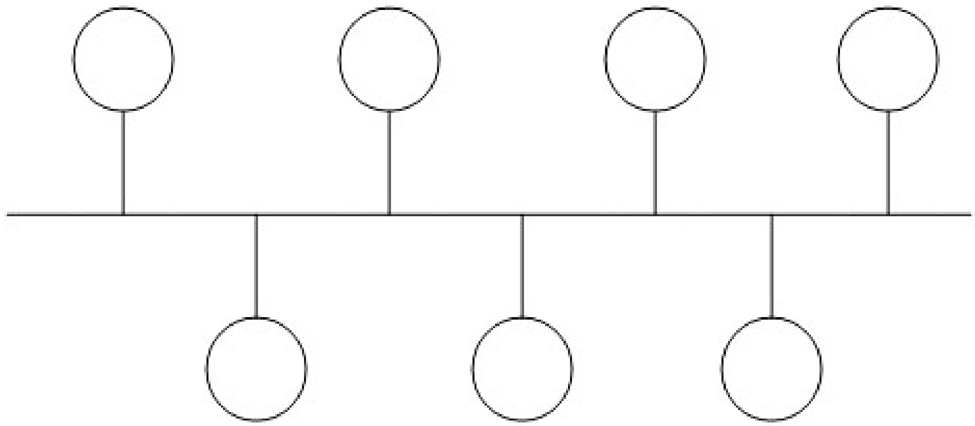
Network Topologies and Categories

- Network Topology refers to the layout of a network.
- Different configurations of network cable, computers and devices form different topologies.



Network Topologies and Categories

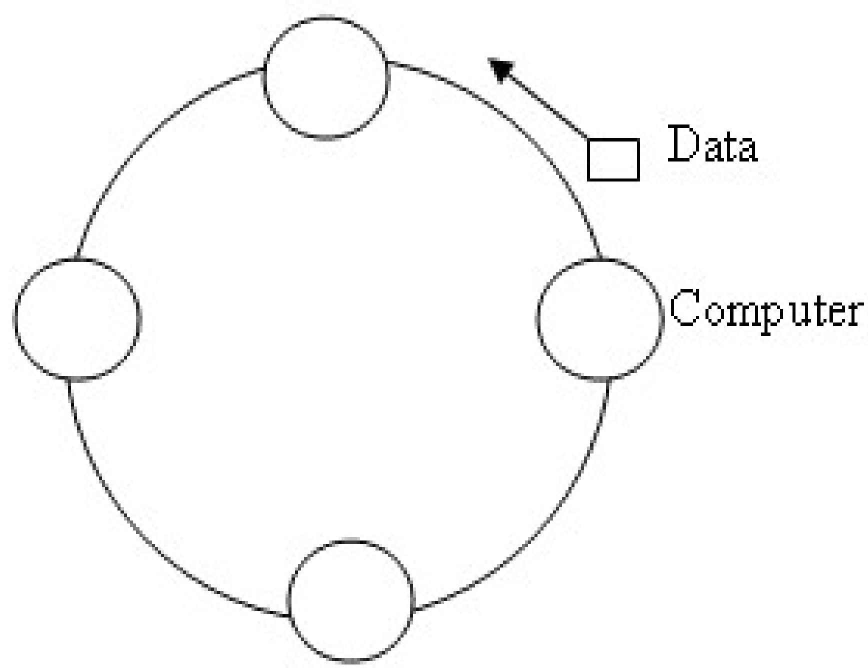
- Bus topology: All devices are connected to a common backbone.



- Advantages
  - Easy to connect a computer or peripheral to a linear bus.
  - Requires less cable length than a star topology.
- Disadvantages
  - Entire network shuts down if there is a break in the main cable.
  - Terminators are required at both ends of the backbone cable.
  - Difficult to identify the problem if the entire network shuts down.
  - Not meant to be used as a stand-alone solution in a large building.

Network Topologies and Categories

- Ring topology: In a ring network, every device has exactly two neighbors for communication purposes.
- All messages travel through a ring in the same direction (either "clockwise" or "counterclockwise").

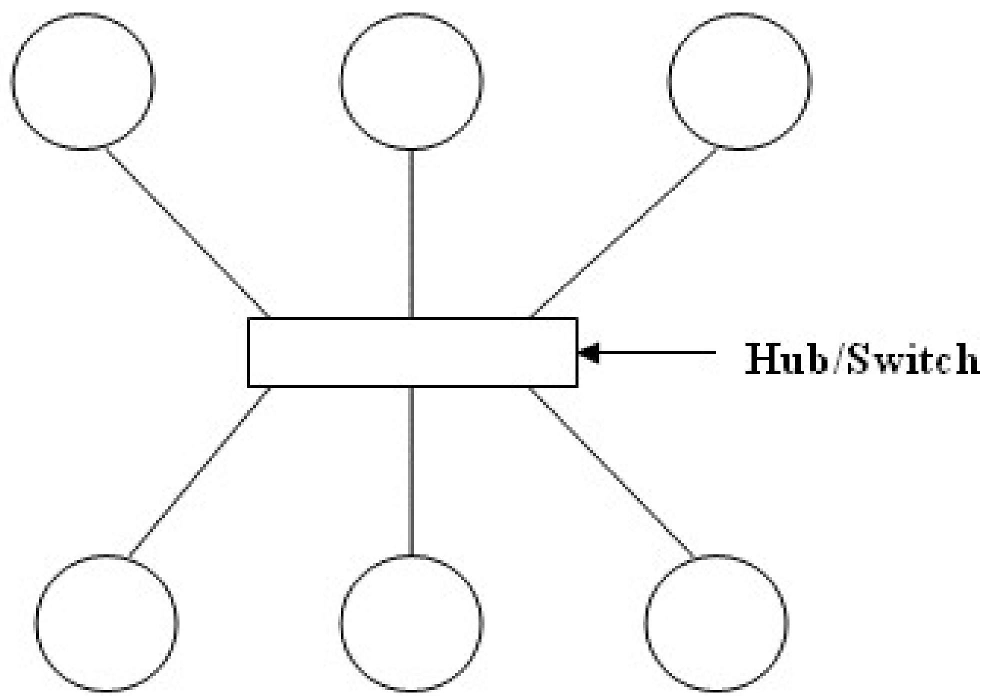


Network Topologies and Categories

- Star topology
  - A star topology is designed with each node (file server, workstations, and peripherals) connected directly to a central network hub or concentrator.
  - Data on a star network passes through the hub or concentrator before continuing to its destination.
  - The hub or concentrator manages and controls all functions of the network.
  - It also acts as a repeater for the data flow.
  - Advantages
    - Easy to install and wire.
    - No disruptions to the network then connecting or removing devices.
    - Easy to detect faults and to remove parts.

Network Topologies and Categories

- Disadvantages
  - Requires more cable length than a linear topology.
  - If the hub or concentrator fails, nodes attached are disabled.
  - More expensive than linear bus topologies because of the cost of the concentrators.

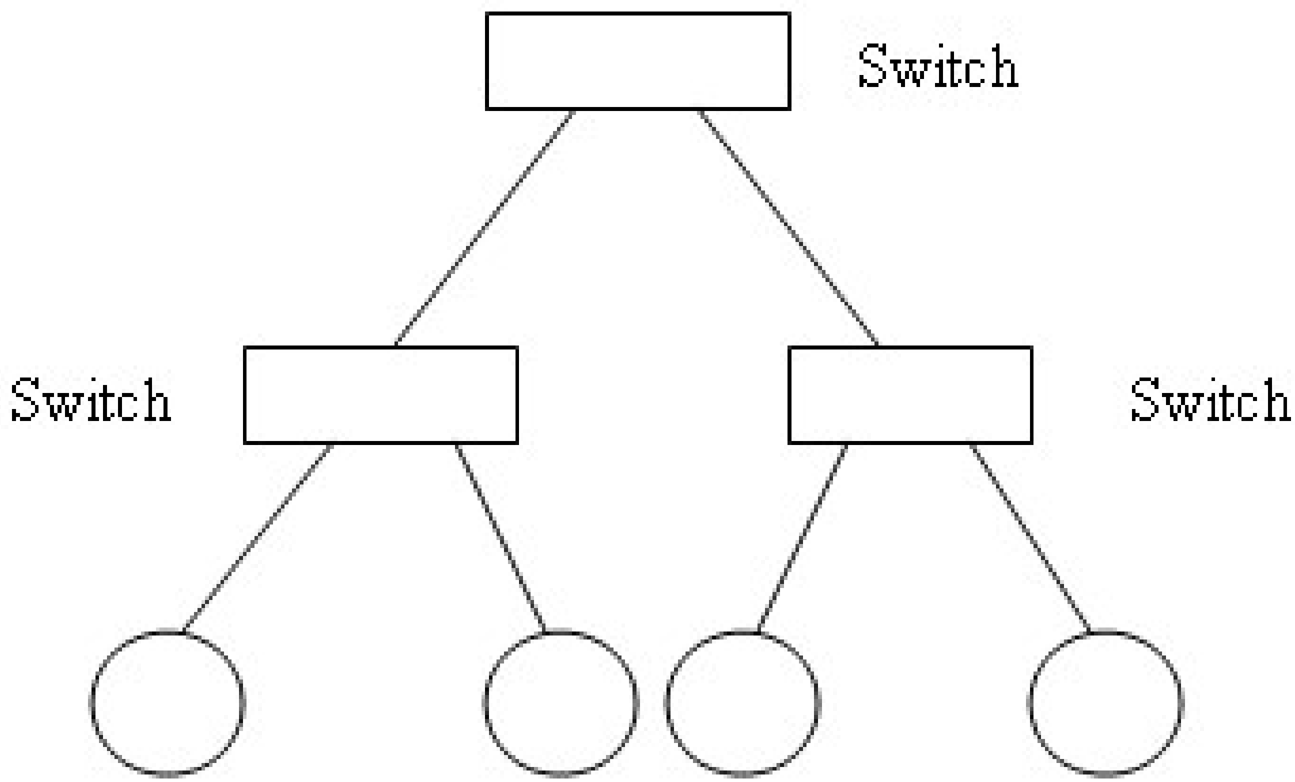


Network Topologies and Categories

- Tree topology
  - A tree topology combines characteristics of star and/or linear bus topologies.
  - Tree topologies allow for the expansion of an existing network. For example, enabling schools to configure a network for labs.
  - Advantages
    - Point-to-point wiring for individual segments.
    - Supported by several hardware and software venders.
  - Disadvantages
    - Overall length of each segment is limited by the type of cabling used.
    - If the backbone line breaks, the entire segment goes down.
    - More difficult to configure and wire than other topologies.

Network Topologies and Categories

Tree Topology

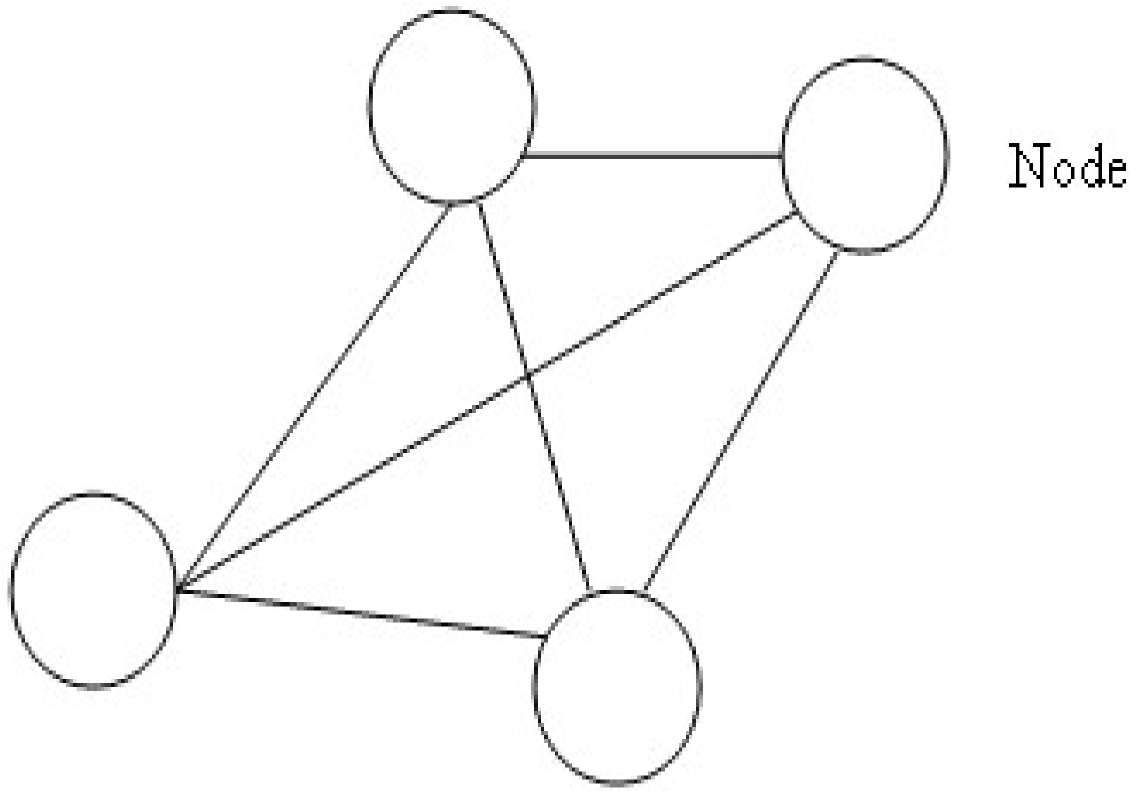


Network Topologies and Categories

- Mesh topology
  - A Mesh topology consists of a network where every device on the network is physically connected to every other device on the network.
  - Advantages
    - It provides a great deal of performance and reliability.
  - Disadvantages
    - However the complexity and difficulty of creating one increases geometrically as the number of nodes on the network increases.

Network Topologies and Categories

Mesh topology



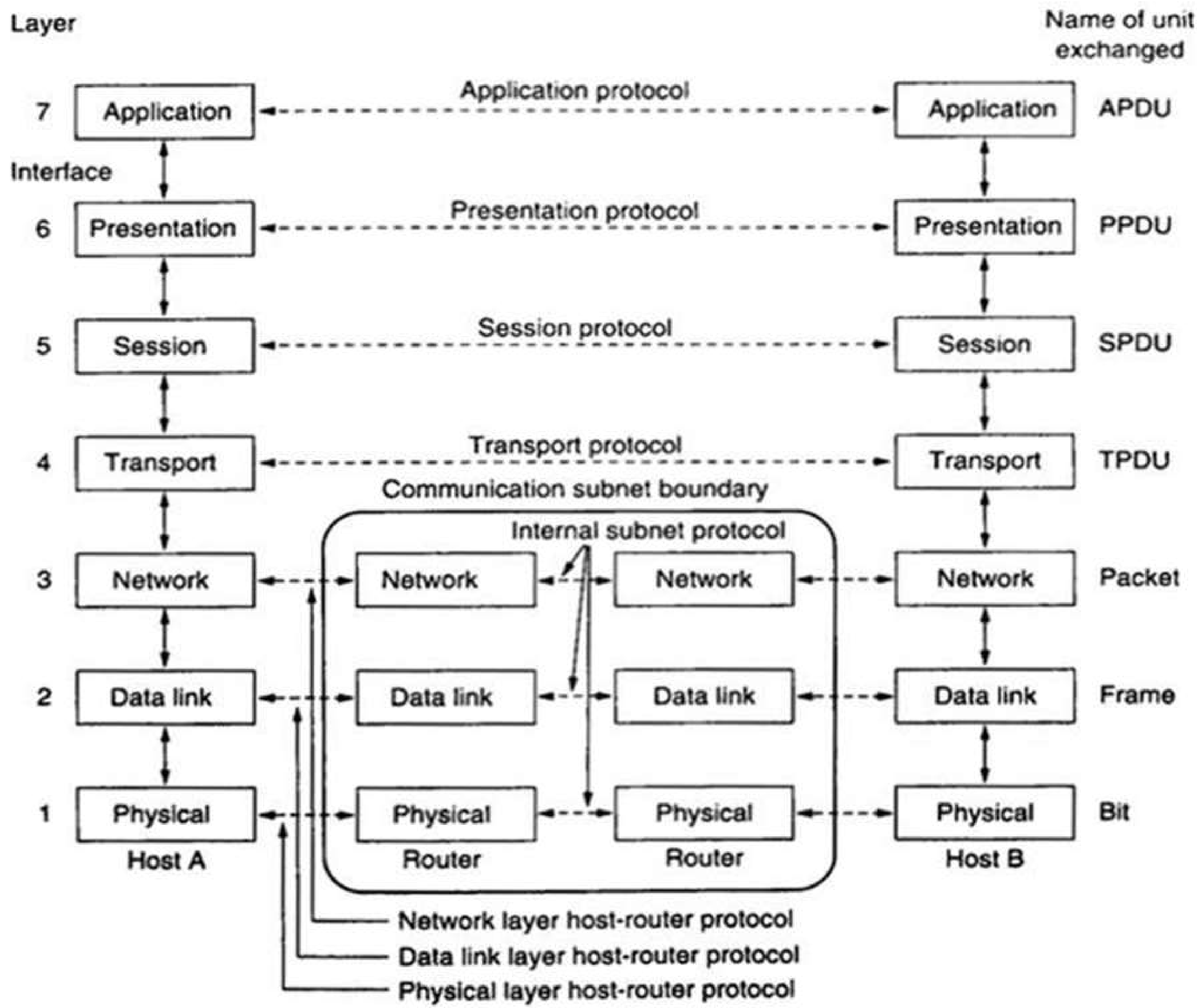
Reference Models and Standards

- Open System Interconnection (OSI) Model has seven layers.
  - **Physical Layer:** It is concerned with transmitting raw bits over a communication channel. This layer deals with the issues including mechanical, electrical, timing interfaces, and the physical transmission medium.
  - **Data Link Layer:** It is to transform a raw transmission facility into a line that appears free of undetected transmission errors to the network layer.
  - **Network Layer:** It controls the operation of the subnet. It routes packets from source to destination. The routing algorithm can be static or dynamic.

Reference Models and Standards

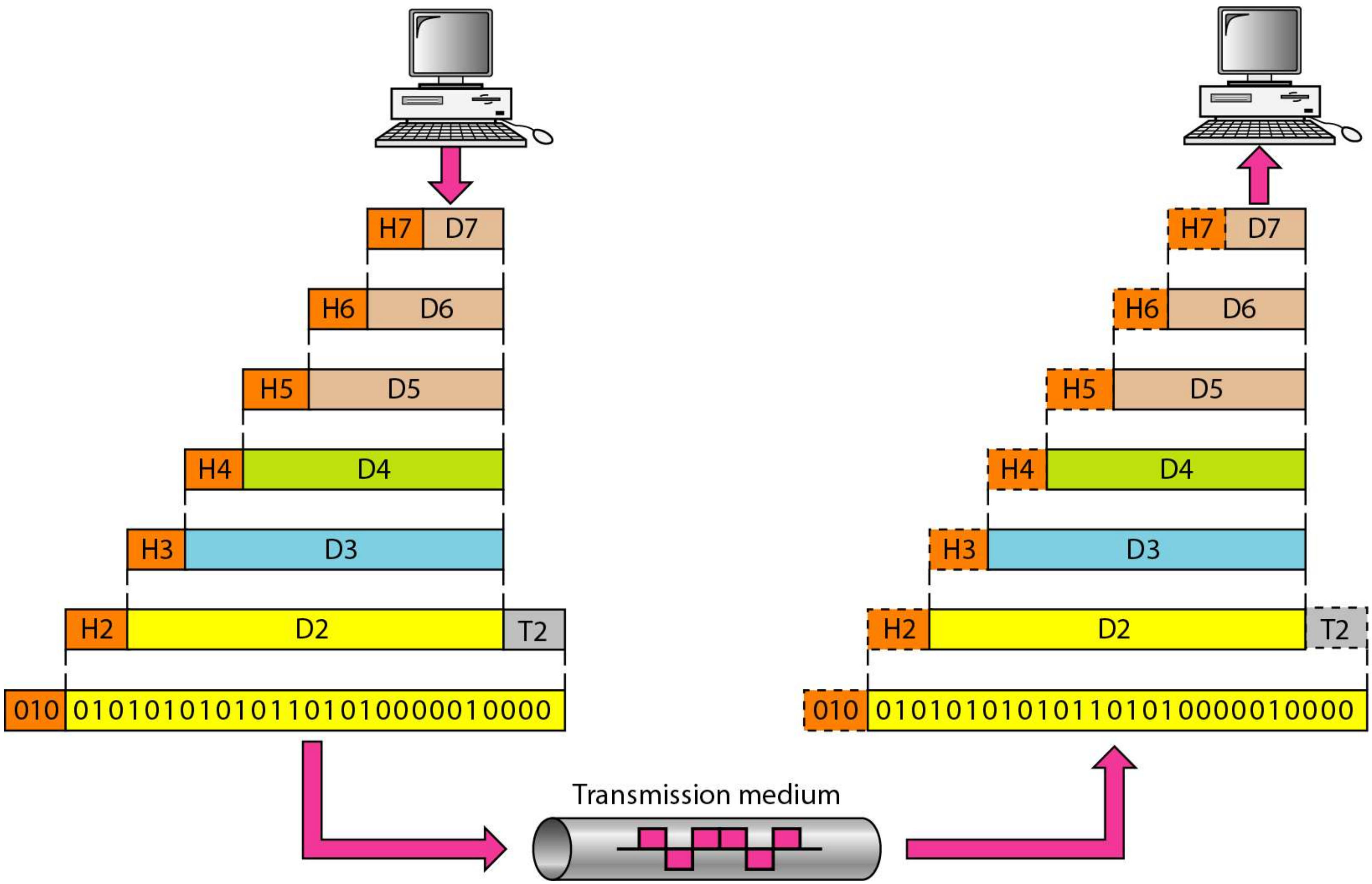
- **Transport Layer:** It is to accept data from above, split it up into smaller units if need be, pass these to the network layer, and ensure that the pieces all arrive correctly at the other hand.
- **Session Layer:** It allows users on different machines to establish sessions between them.
- **Presentation Layer:** It is concerned with the syntax and semantics of the information transmitted.
- **Application Layer:** It contains a variety of protocols that are commonly needed by users, such as HTTP, Email, etc.

OSI Reference Model

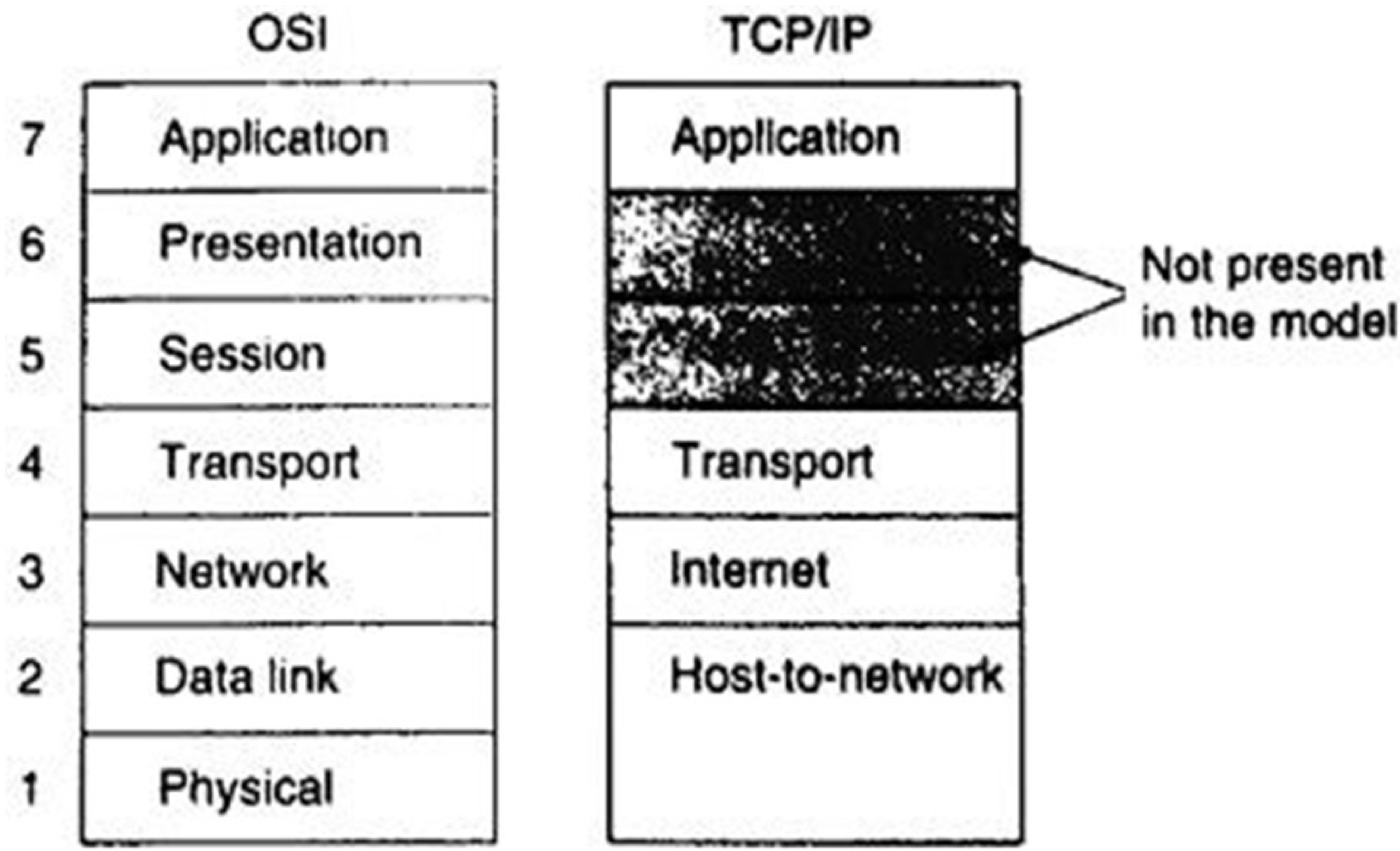


OSI Reference Model

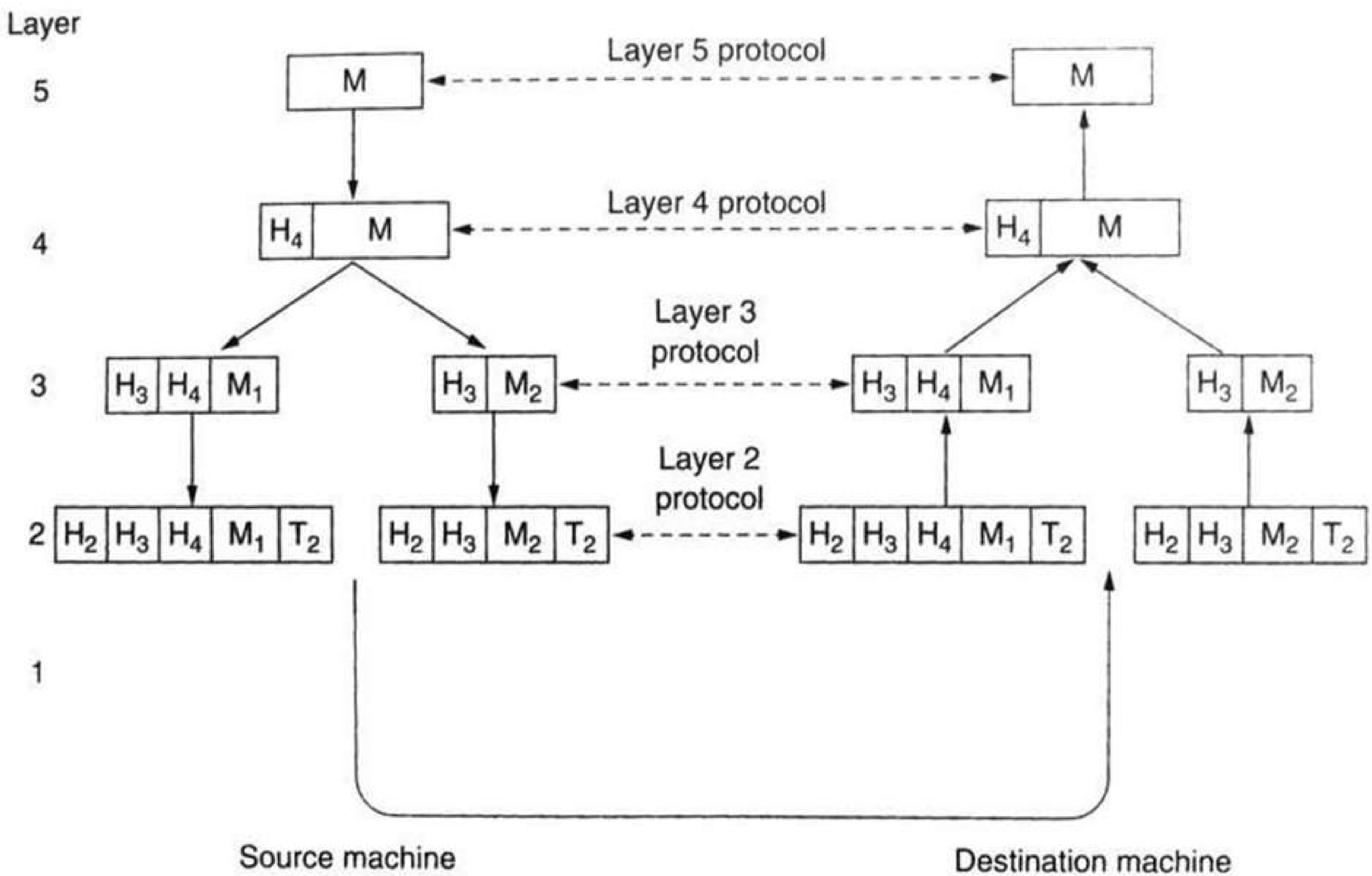
- An exchange using the OSI model



The TCP/IP Reference Model



Information Flow for the TCP/IP Model



Protocols and Networks in the TCP/IP Model