Introduction to Computer Networks and Internet

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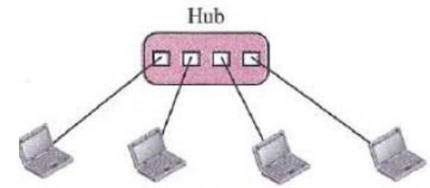
What is Data Communication?

- Data communications are the exchange of data between two devices via some form of transmission medium.

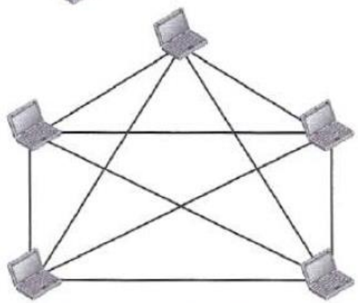
- **Fundamental characteristics**:
  - Delivery: The system must deliver data to the correct destination.
  - Accuracy: The system must deliver the data accurately.
  - Timeliness: The system must deliver data in a timely manner.
  - Jitter: Jitter refers to the variation in the packet arrival time.
- **Components:**
  - Message
  - Sender
  - Receiver
  - Transmission medium
  - Protocol

What is Network?

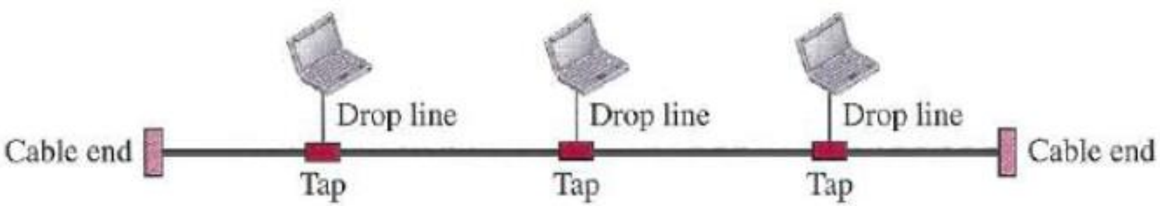
- A network is the interconnection of a set of devices capable of communication.



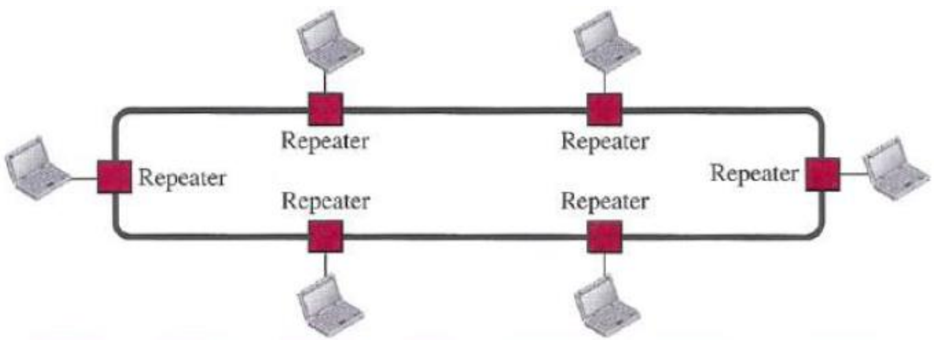
- **Network Criteria:**
  - *Performance:* Throughput, Delay
  - *Reliability:* frequency of failure
  - *Security:* protecting from unauthorized access



- **Type of Connection**
  - Point-to-Point
  - Multipoint

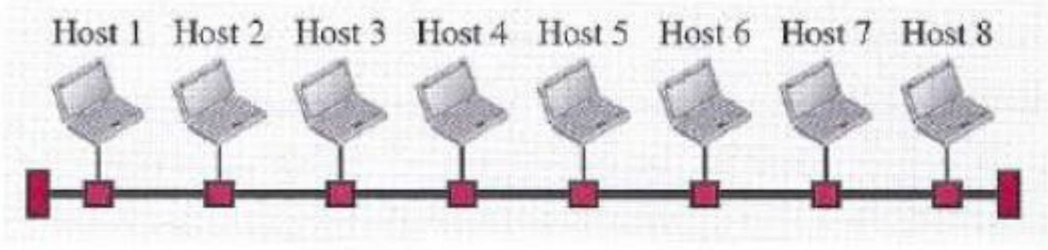


- **Physical Topology**
  - Mesh
  - Star
  - Bus
  - Ring

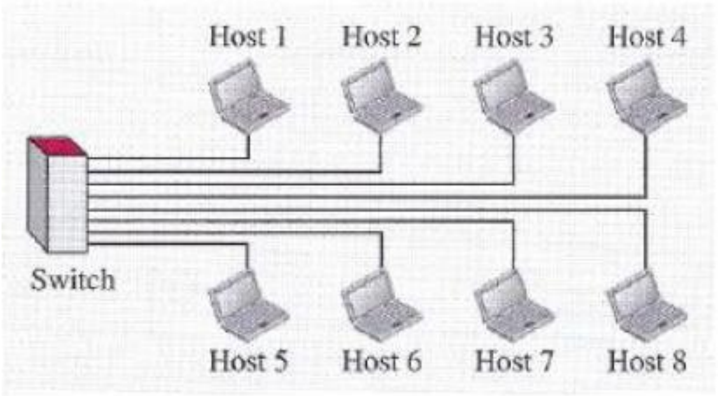


Network Types

- Local Area Networks (LAN)

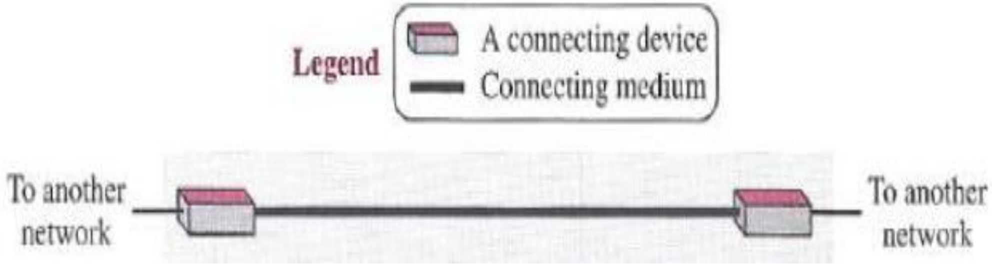


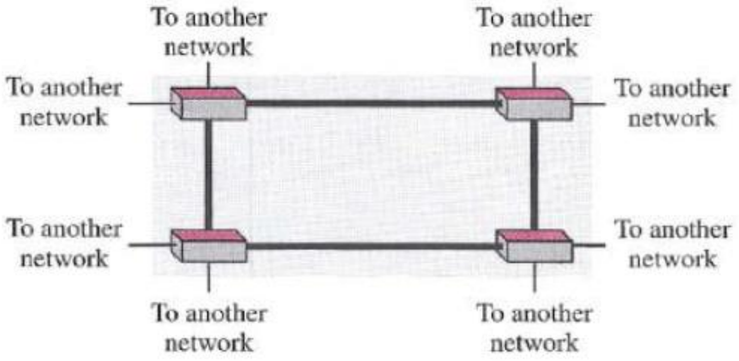
a. LAN with a common cable (past)



b. LAN with a switch (today)

- Wide Area Networks (WAN)





What is Internet?

couple of ways to answer

1. we can describe the basic hardware and software components that make up the Internet

2. we can describe in terms of a networking infrastructure that provides services to distributed applications

End systems are connected together by a network of communication links and packet switches.

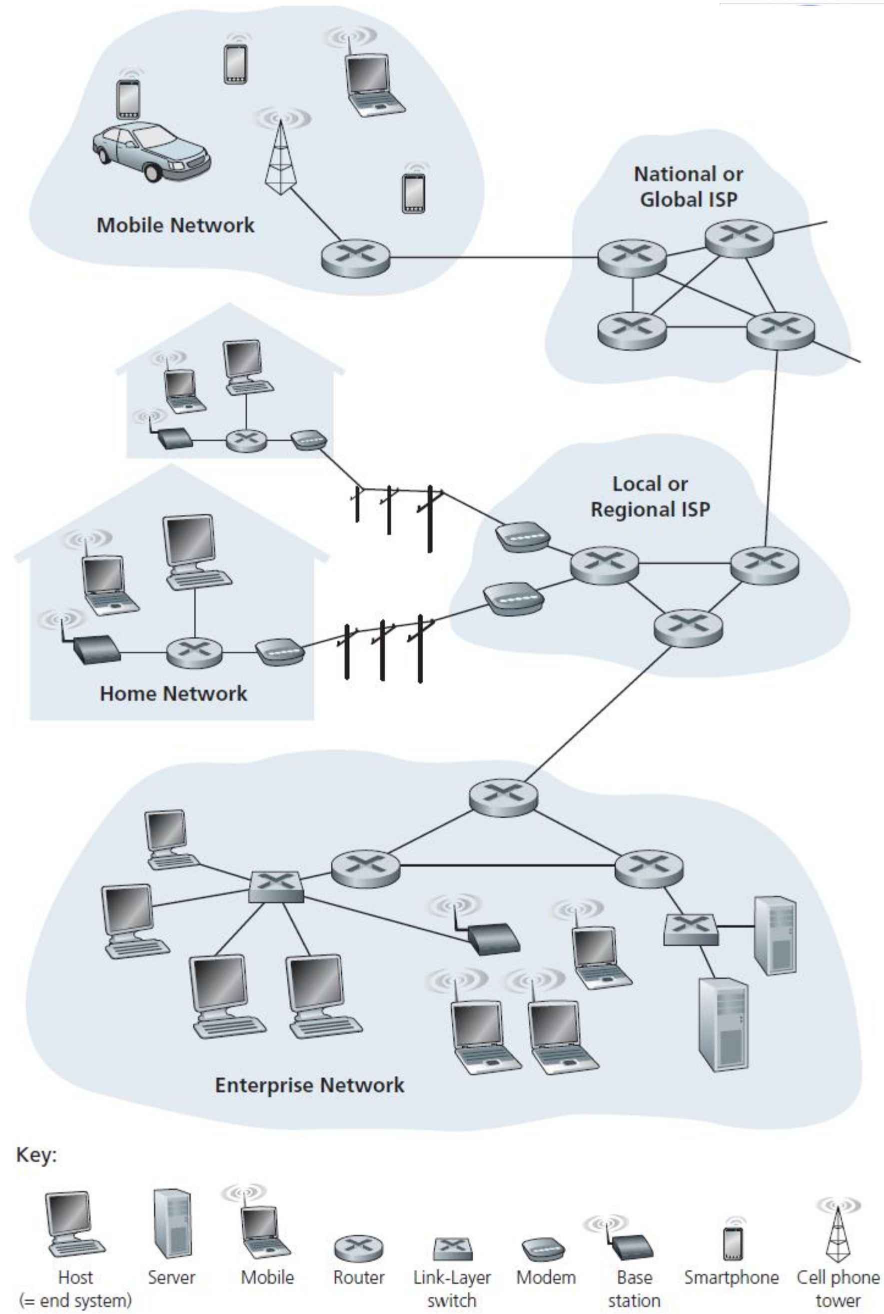


Figure 1.1 ♦ Some pieces of the Internet

Infrastructure view of Internet

- *an infrastructure that provides services to applications*
- *Applications: E-mail,* Web surfing, social networks, instant messaging, VoIP, video streaming, distributed games, peer-to-peer (P2P) file sharing, television over the Internet, remote login, etc.
- Suppose you have an exciting new idea for a distributed Internet application. How to transform the idea into actual Internet application?
- End systems attached to the Internet provide an Application Programming Interface (API) that specifies how a program running on one end system asks the Internet infrastructure to deliver data to a specific destination program running on another end system.
- This Internet API is a set of rules that the sending program must follow so that the Internet can deliver the data to the destination program.
- Ex. Alice wants to send a letter to Bob using the postal service. the postal service requires that Alice put the letter in an envelope; write Bob's full name, address, and zip code in the center of the envelope; seal the envelope; put a stamp in the upper-right-hand corner of the envelope; and finally, drop the envelope into an official postal service mailbox.

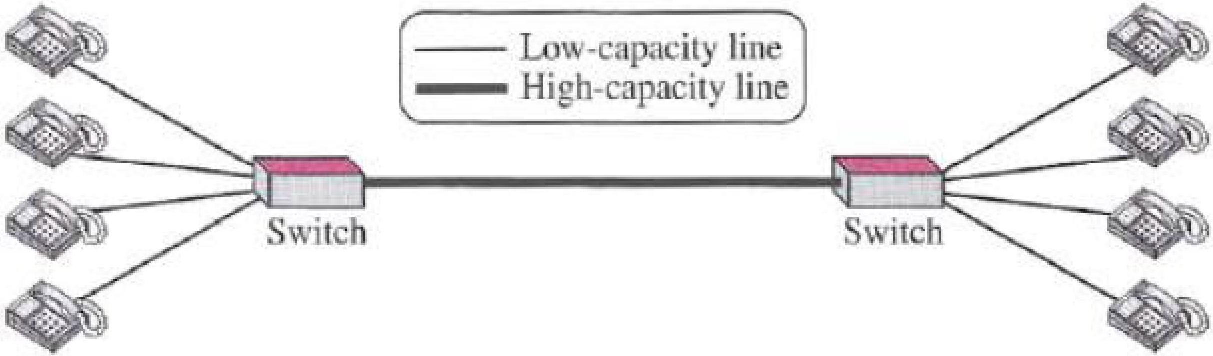
Switching

- An internet is a switched network in which a switch connects at least two links together.

- Common Types:
  - circuit-switched networks
  - packet-switched networks
    - Virtual circuit approach
    - Datagram approach

Circuit-switched Network

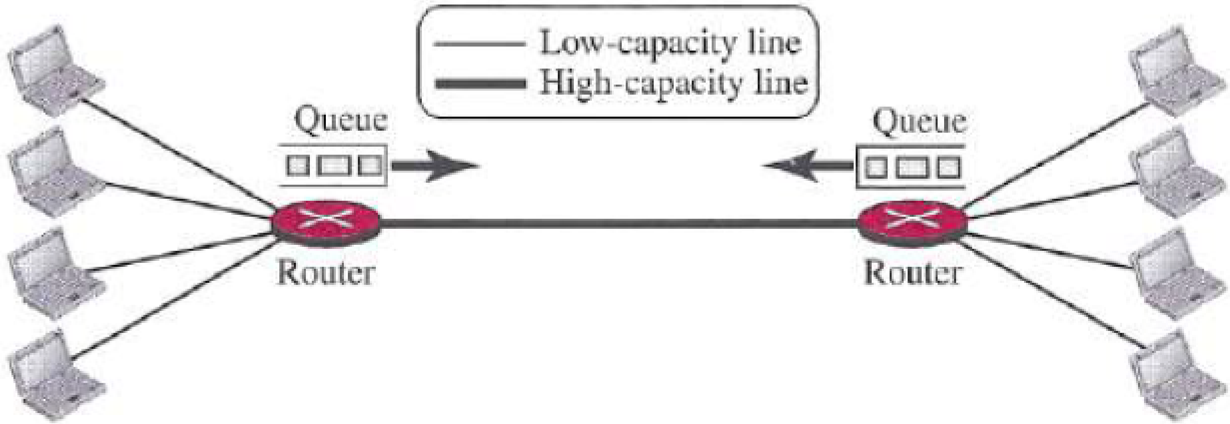
- a dedicated connection, called a circuit, is always available between the two end systems; the switch can only make it active or inactive.
  - E.g., Telephone Network



- Disadvantage:
  - Underutilization of link capacity
  - No storing / holding capacity

Packet-switched Network

- the communication between the two ends is done in blocks of data called packets.
  - E.g., Internet



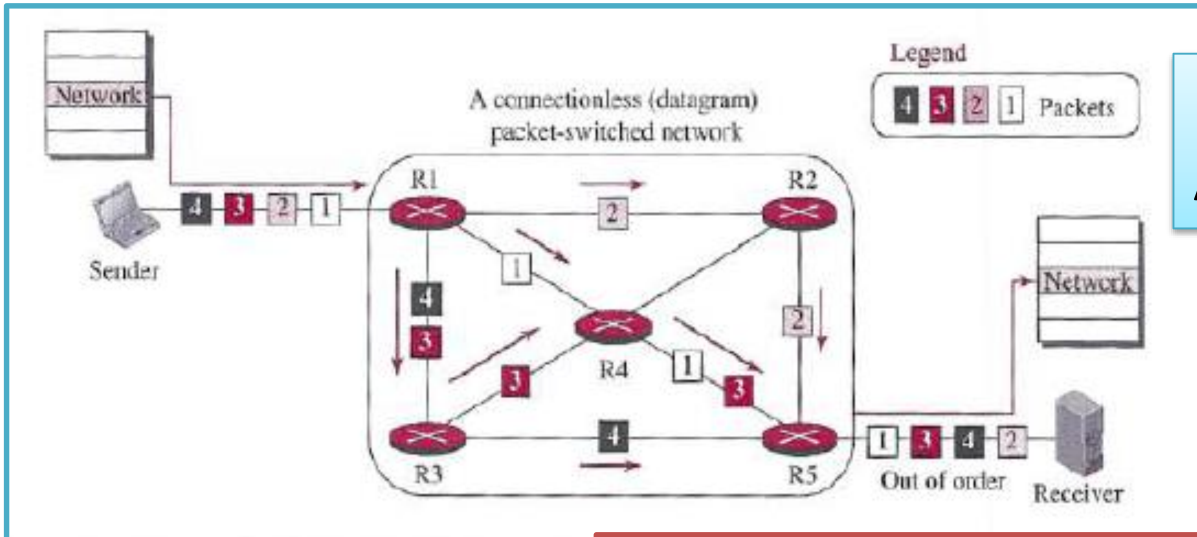
- Advantages:
  - Better utilization of link
  - Router can store and forward data packets

Approaches in Packet-switching

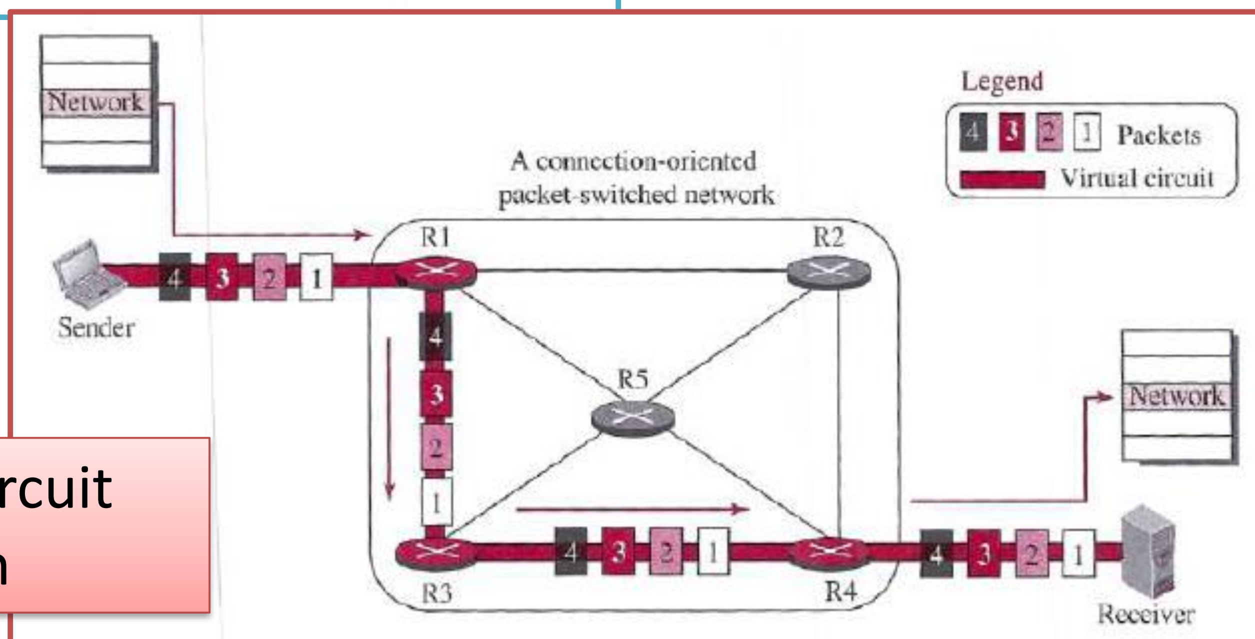
- Datagram approach
  - Connectionless service: each packet is treated independently
  - Packet forwarding decision is based on destination address

- Virtual-Circuit approach
  - Connection-Oriented service: exists relationship among all packets belonging to a message
  - Packet forwarding decision is based on label of the packet

Approaches in Figure



Datagram Approach



Virtual-circuit Approach

ISP

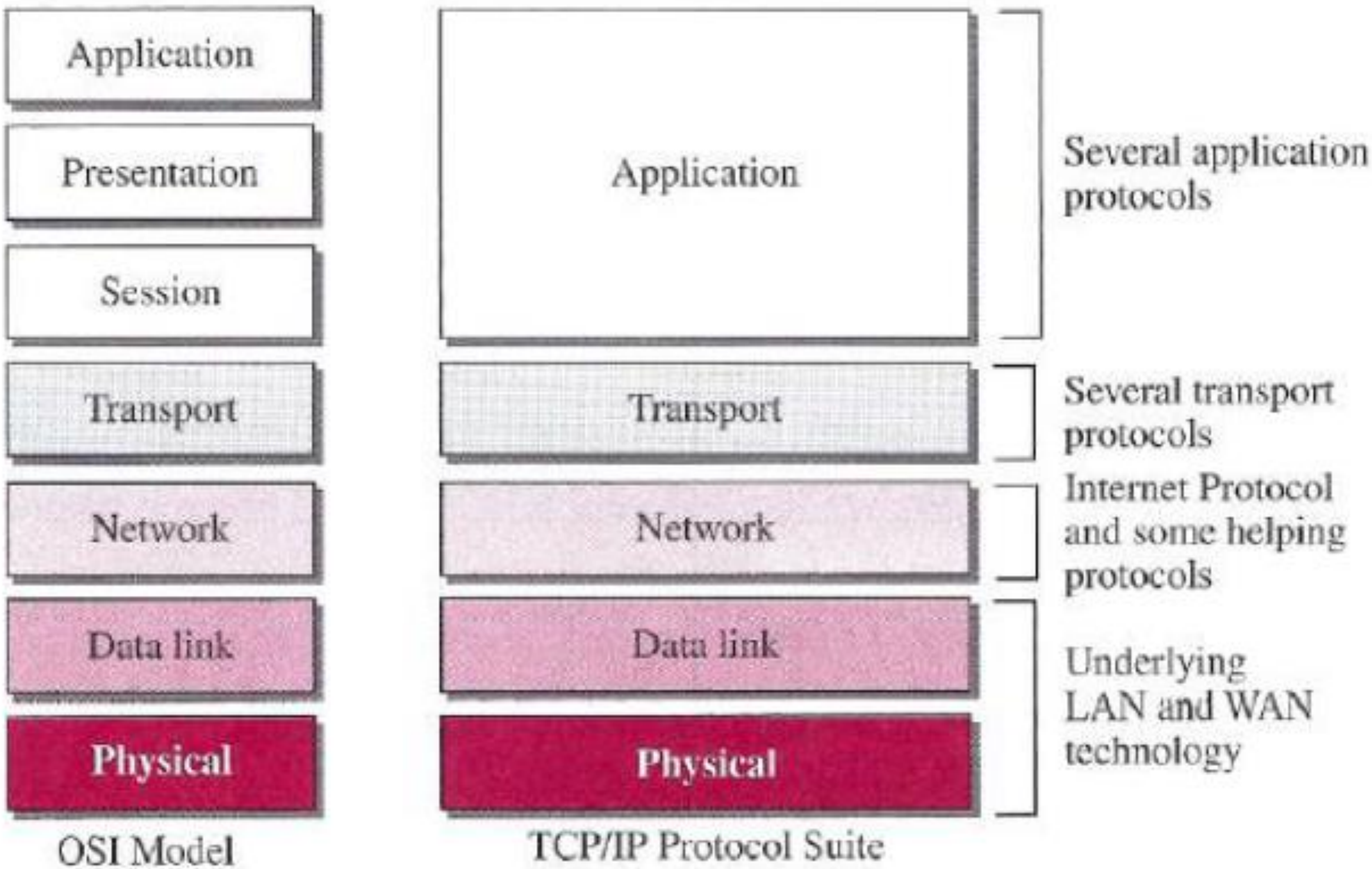
- End systems access the Internet through Internet Service Providers (ISPs)
  - residential ISPs such as local cable or telephone companies; corporate ISPs; university ISPs; and ISPs that provide WiFi access in airports, hotels, coffee shops, and other public places.
- Each ISP is in itself a network of packet switches and communication links.

- types of network access to the end systems
  - residential broadband access: cable modem or DSL
  - high-speed LAN access
  - wireless access
  - 56 kbps dial-up modem

How to define Network Operations?

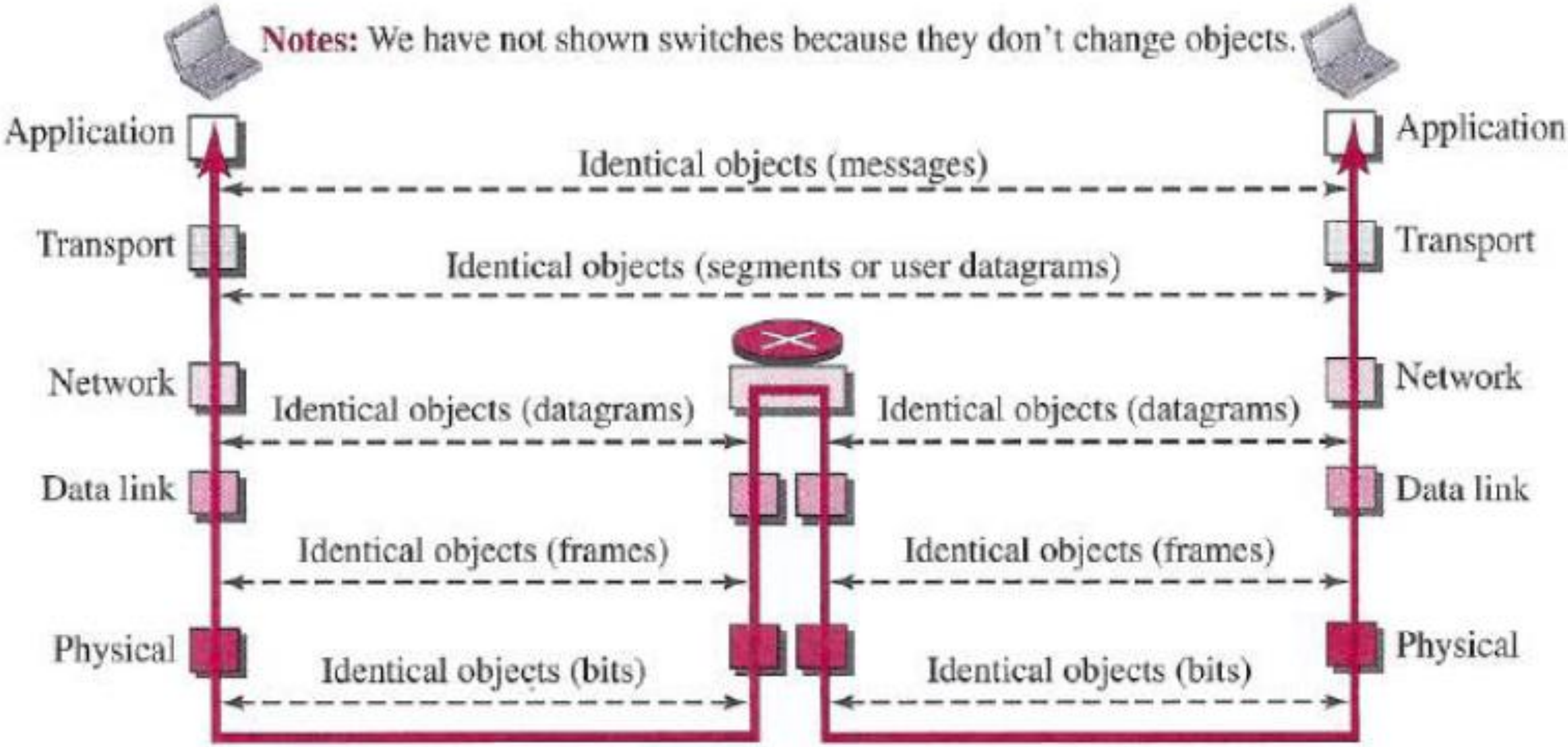
- Ans: Protocol
- Protocol controls the sending and receiving of information within the Internet
- Protocol defines the rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively.
- For simple communication (between 2 computer): One protocol is enough
- For complex communication (multiple computers): Modularization / Protocol Layering is essential
- Principles of Protocol Layering:
  - each layer performs two opposite tasks, one in each direction
  - Two objects under each layer at both sites should be identical

Protocol Layering



- *Allegory*:: Please Do Not Touch Steve's Pet Alligator

TCP/IP Protocol Suite



Application Layer

- The application layer consists of what most users think of as programs.
- Although each application is different, some applications are so useful that they have become standardized.
- **File transfer (FTP)**: Connect to a remote machine and send or fetch an arbitrary file. FTP deals with authentication, listing a directory contents, ASCII or binary files, etc.
- **Remote login (telnet)**: A remote terminal protocol that allows a user at one site to establish a TCP connection to another site, and then pass keystrokes from the local host to the remote host.
- **Mail (SMTP)**: Allow a mail delivery agent on a local machine to connect to a mail delivery agent on a remote machine and deliver mail.
- **Web (HTTP)**: Base protocol for communication on the World Wide Web.

Presentation and Session Layers

- Presentation layer:
  - This layer is concerned with Syntax and Semantics of the information transmitted
  - Service: Encoding / Decoding, Abstract data structures and conversion among them, etc.
- Session layer:
  - This layer allows users on different machines to establish session between them.
  - Service: dialogue control, token management, synchronization, etc.

Transport Layer

- The transport layer provides end-to-end communication between processes executing on different machines.
  - Connection establishment
  - Segmentation
  - Quality of Services: throughput, delay, protection, priority, reliability, etc.
  - Flow control
  - Congestion control
  - Etc.

Network Layer

- The network layer provides an end-to-end communication between machines belonging to different/same network.

  - Routing
  - Internetworking
  - Interface between the host and the network
  - Logical Addressing
  - Fragmentation
  - Etc.

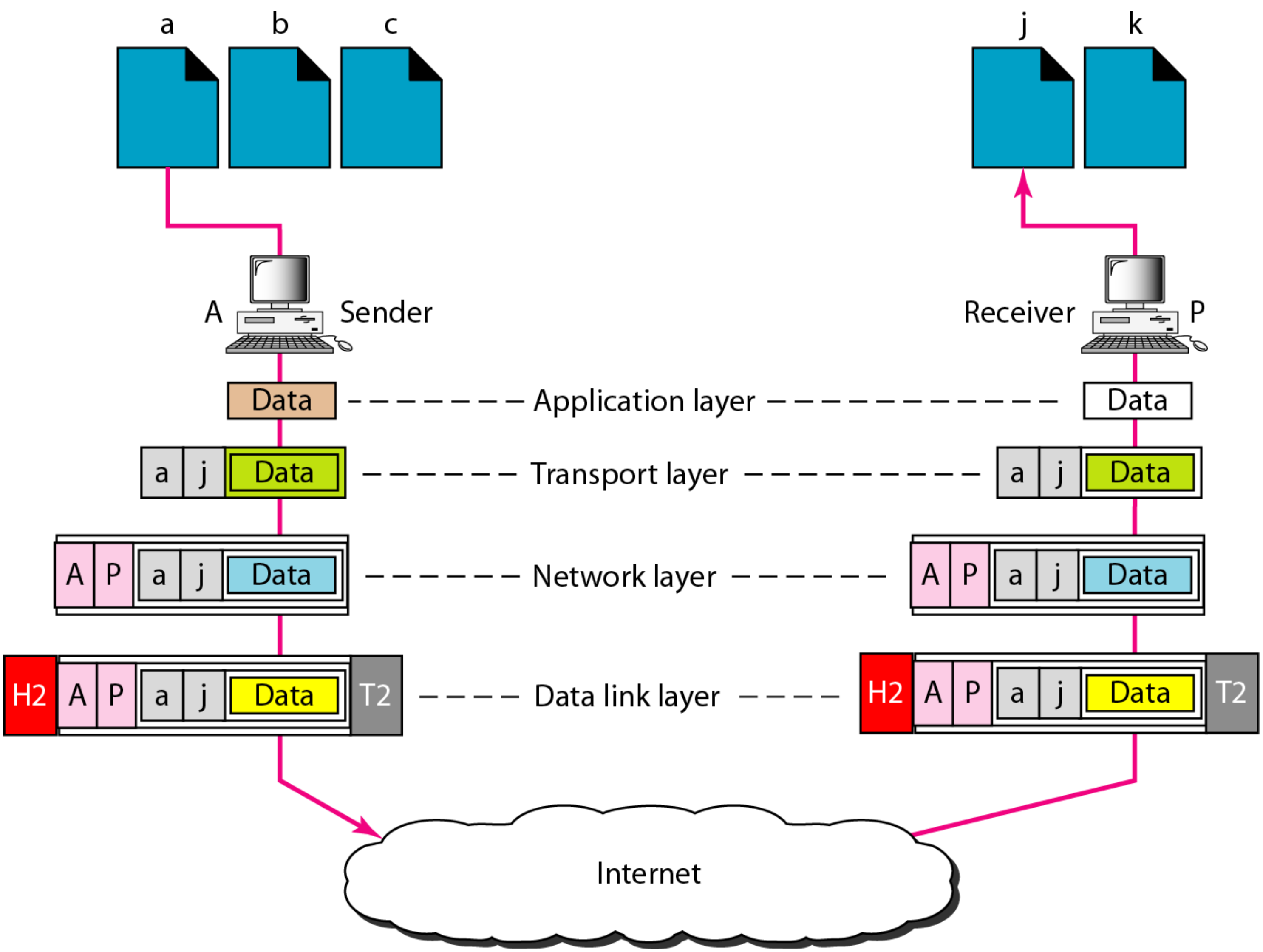
Datalink Layer

- provides reliable, efficient communication between adjacent machines connected by a single communication channel.
  - Framing
  - Reliable delivery
  - Acknowledged delivery
  - Error control
  - Flow control
  - Etc.

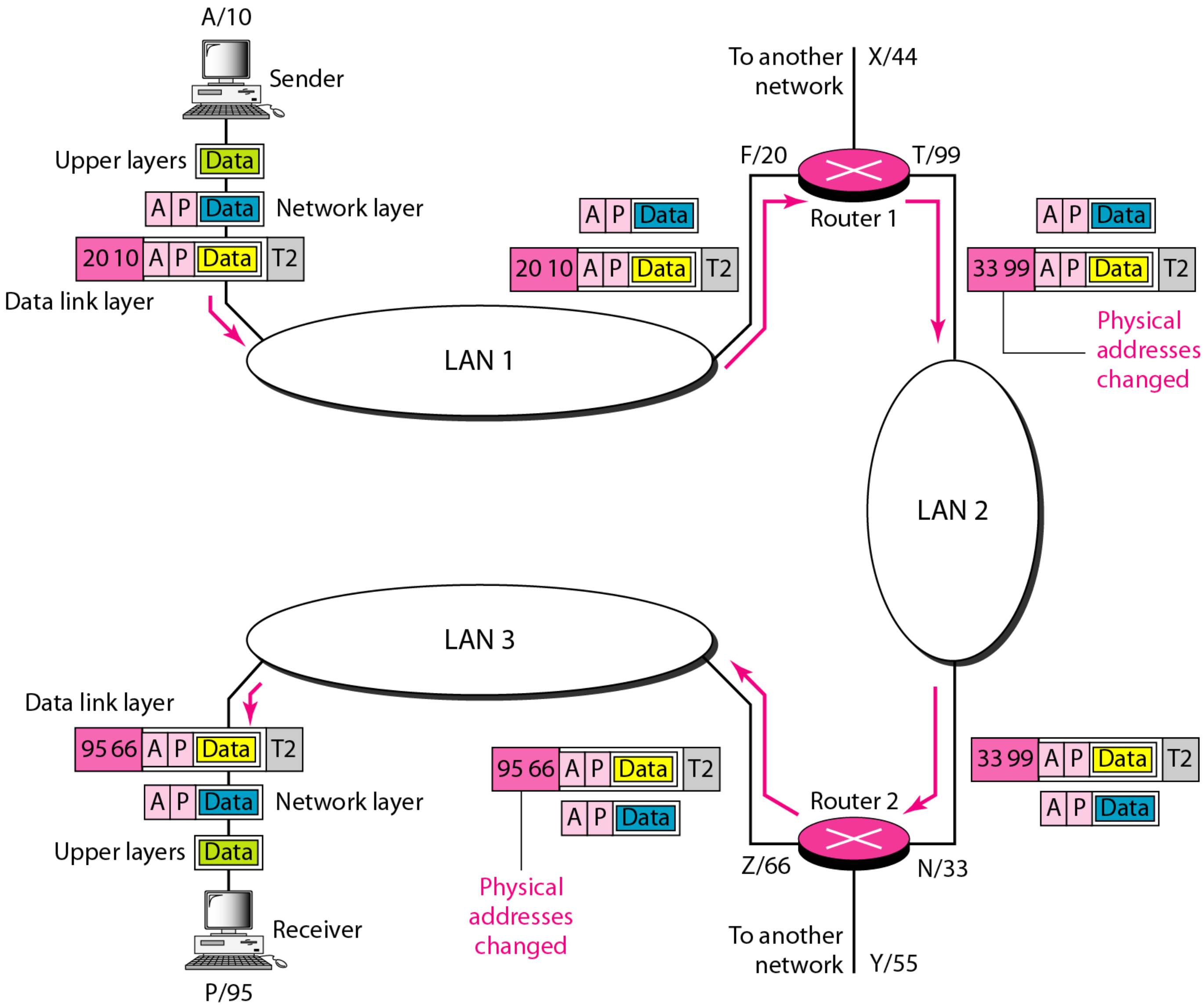
Physical Layer

- This layer is concerned with transmission of raw bits over a communication channel.
  - Deals with physical transmission
  - Establishing and breaking of connection
  - Signal Level, Data rate
  - Etc.

Example of Data Delivery



Example of Data Delivery



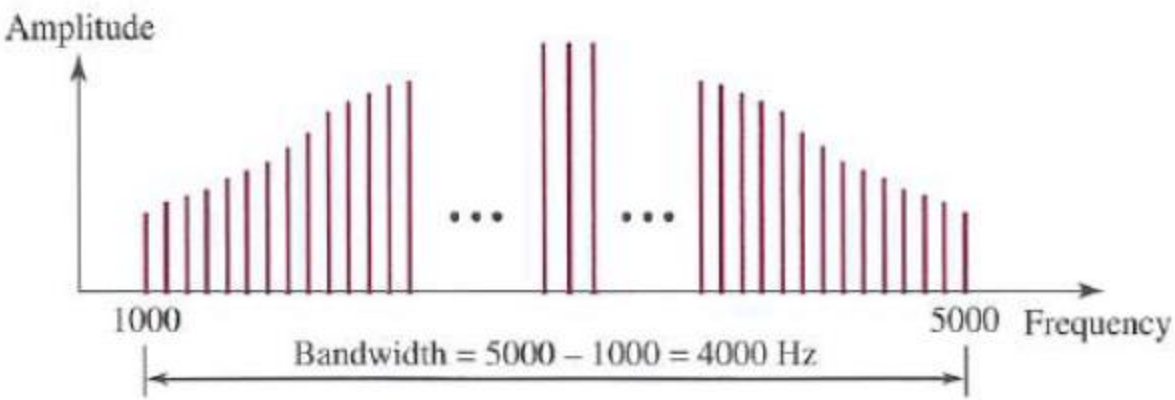
Performance Metrics

- Bandwidth
- Latency (delay)
- Bandwidth-delay product
- Throughput

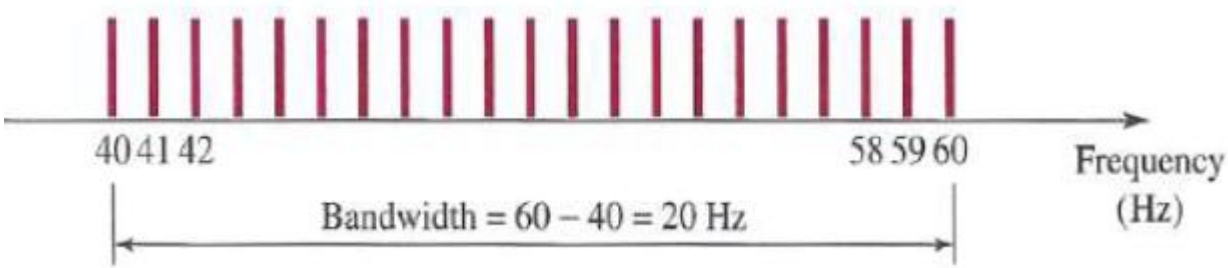
- Bandwidth:
  - Number of bits transmitted per second
  - Difference between the highest and lowest frequencies contained in that signal

Bandwidth (in Hertz)

- For Analog Signal

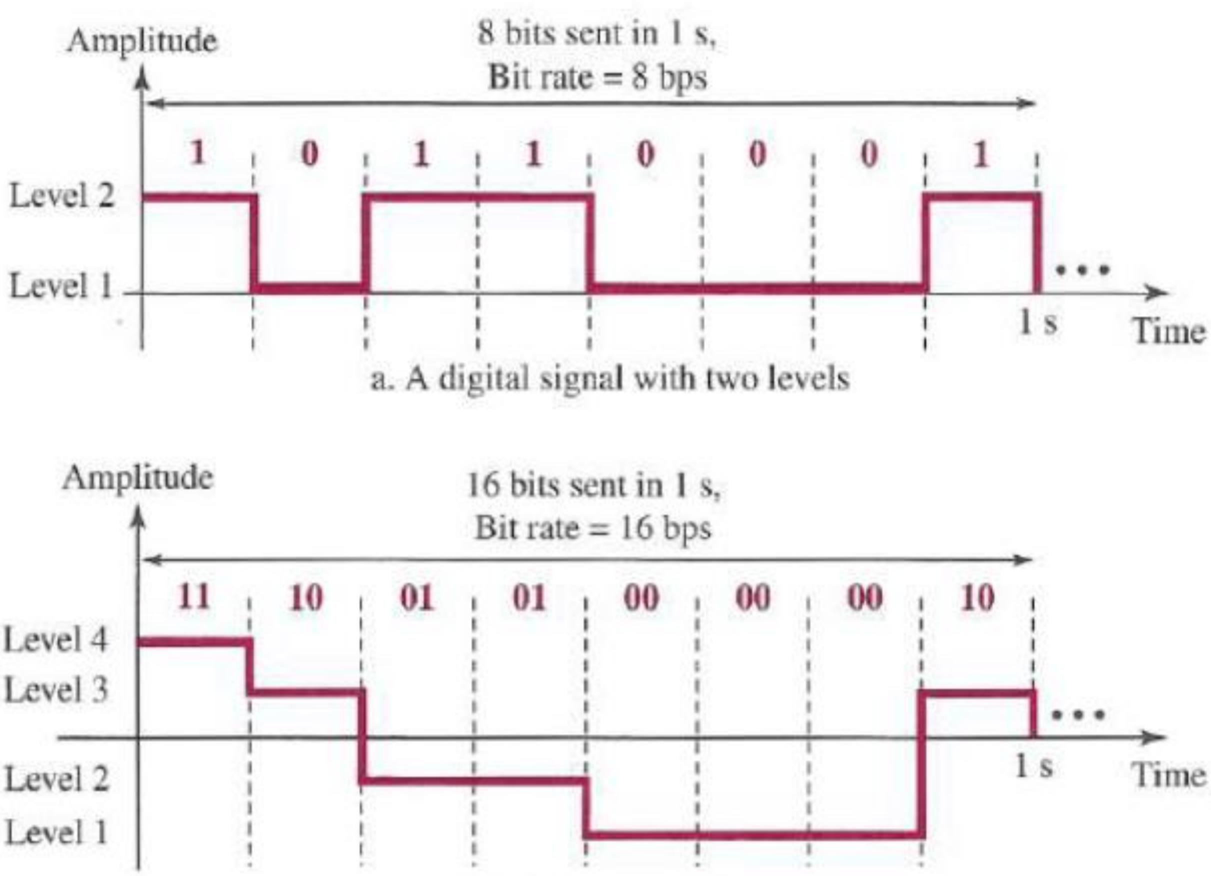


a. Bandwidth of a periodic signal



Bandwidth (in Bits per Second)

- For Digital Signal



a. A digital signal with two levels

b. A digital signal with four levels

Latency or Delay

- The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.
  - Latency = propagation time + transmission time + queuing time (+ processing delay)
  - Processing delay= time needed to process the message by devices
  - Queuing delay = the time needed for each intermediate device to hold the message before it can be processed
  - Transmission delay = Message size / Datarate
  - Propagation delay = Distance / (Propagation Speed)
    - Speed of Light in:
      - Vacuum 3×10^8 m/s
      - Copper 2.3×10^8 m/s
      - Fiber 2×10^8 m/s
  - Round Trip Time: roughly two times of Latency

Example

- A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?
- Solution:
  - Throughput = (12,000 x 10,000) / 60 = 2 Mbps

- What are the propagation time and the transmission time for a 5-MB (megabyte) message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 x 10^8 m/s.
- Solution:
  - Propagation time = (12,000 x 1000) / (2.4 x 10^8) = 50 ms
  - Transmission time == (5,000,000 x 8) /10^6 = 40 sec

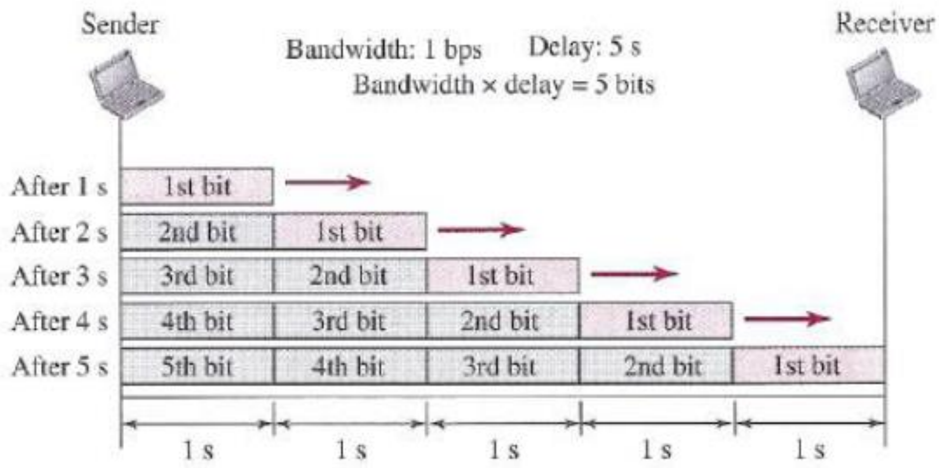
End-to-End Delay

- Total delay from source to destination
- suppose there are N -1 routers between the source host and the destination host
- suppose the network is uncongested (so that queuing delays d_{que} are negligible)

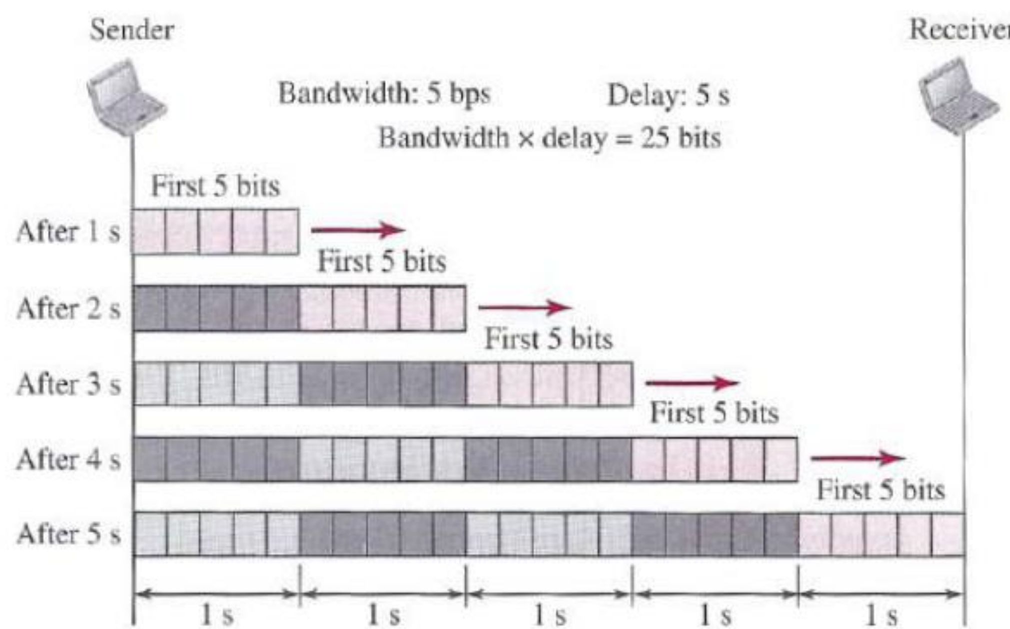
$$d_{\text{end-end}} = N\,(d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}})$$

- Queuing Delay:
  - Unlike the other three delays, the queuing delay can vary from packet to packet.
- When is the queuing delay large and when is it insignificant?
  - depends on the arrival rate of traffic at the queue, the transmission rate of the link, and the nature of the arriving traffic (periodic / bursty)

Bandwidth-Delay Product



The bandwidth-delay product is a measure of the number of bits a sender can transmit through the system while waiting for an ACK from the receiver.



Transmission of Digital Signal

- Digital signal is treated as composite analog signal

- Two different approaches:

  - Baseband Transmission: sending digital signal without changing to analog signal
    - Need dedicated medium as frequency starts from zero
    - Low-pass channel
    - Required bandwidth is proportional to the bit rate; approximately bitrate/2.

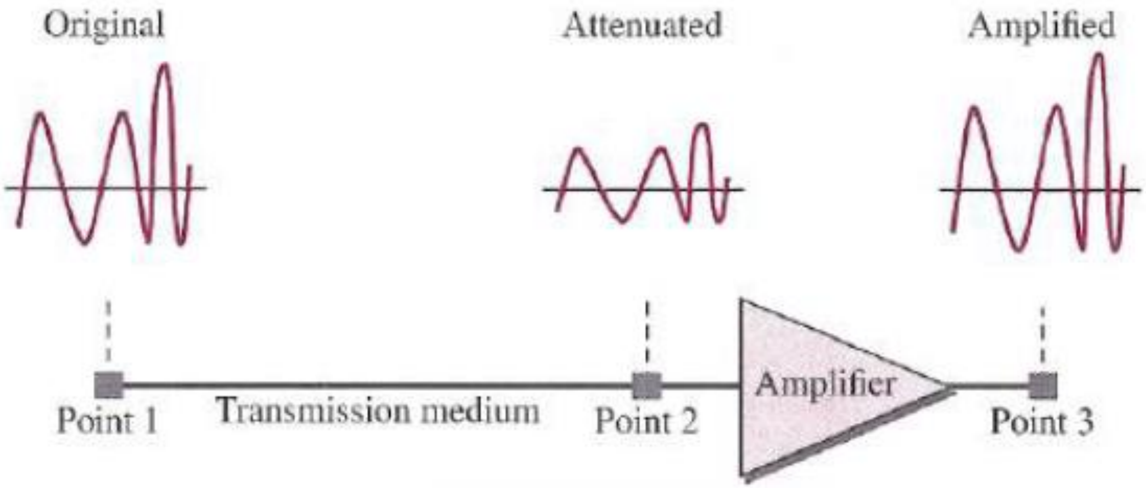
  - Broadband Transmission: changing the digital signal to analog signal for transmission
    - Need modulation & de-modulation
    - Bandpass channel

Transmission Impairment

- **Attenuation** means a loss of energy.
- **Distortion** means that the signal changes its form or shape.
- Several types of **noise**, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.
- Thermal noise: the random motion of electrons in a wire
- Induced noise: comes from sources such as motors and appliances
- Crosstalk: is the effect of one wire on the other.
- Impulse noise: is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

Decibel

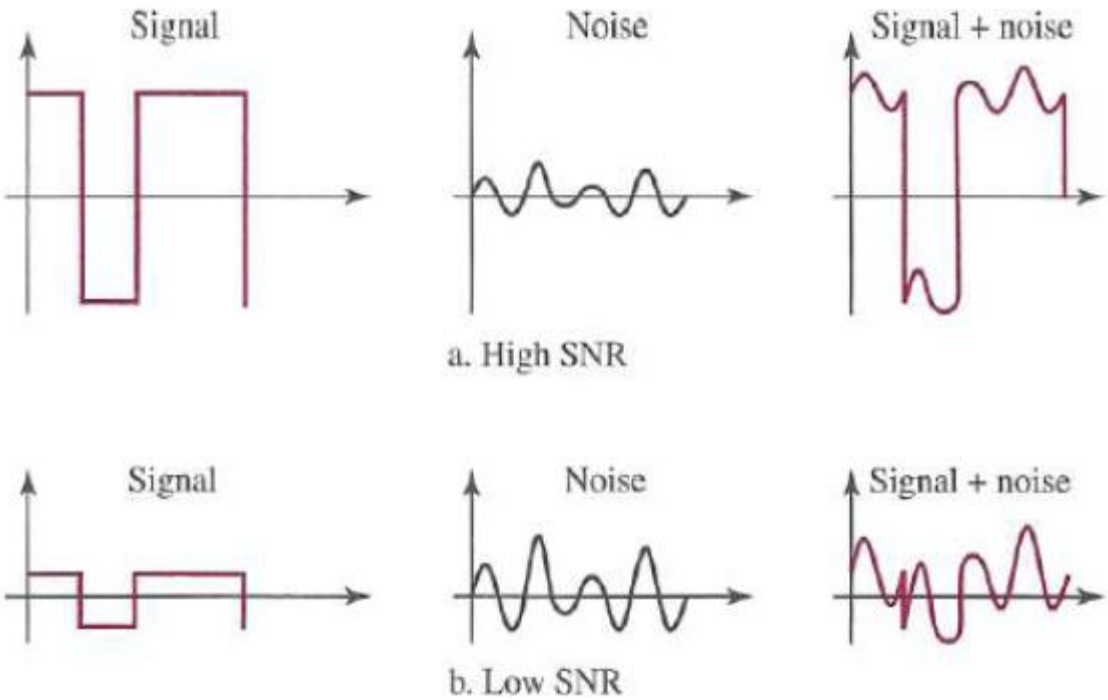
- The decibel (dB) measures the relative strengths of two signals or one signal at two different points.



$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

Signal-to-Noise Ratio (SNR)

- SNR is the ratio of the signal power to the noise power.



$$SNR_{dB} = 10 \log_{10} SNR$$

The values of SNR and SNR_{dB} for a noiseless channel are

$$SNR = (\text{signal power}) / 0 = \infty \longrightarrow SNR_{dB} = 10 \log_{10} \infty = \infty$$

Throughput (in Bits per Second)

- how fast we can actually send data through a network.
  - A link may have a bandwidth of B bps, but we can only send T bps through this link with $T < B$.
  - *Corollary*:: Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, if there is congestion on the road, this figure may be reduced to 100 cars per minute. The bandwidth is 1000 cars per minute; the throughput is 100 cars per minute.

Data Rate (in Bits per Second)

- how fast we can send data over a channel.
  - Bits per sec.

- Depends on:
  - Bandwidth available
  - Level of signals we use
  - Quality of the channel

Noiseless Channel: Nyquist Bit Rate

- Nyquist Capacity Theorem::
  - For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate.
  - **BitRate** = 2 x Bandwidth x $\log_2(L)$;

    where L is the number of signal levels used to represent data.

- Note: Increasing the levels of a signal may reduce the reliability of the system.

- Sampling Theorem: Any signal whose bandwidth is *B* can be completely recovered by the sampled data at rate *2B* samples per second.

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.

- the Shannon capacity determines the theoretical highest data rate for a noisy channel.
  - Capacity = Bandwidth x $\log_2(1+SNR)$

- 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:

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

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

Thanks!