CS348: Computer Networks

Introduction to Computer Networks and Internet

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Course Plan

- Syllabus: http://www.iitg.ac.in/cse/csecourses/?courseCode=CS348

- Class Time: Tuesday, Wednesday, Thursday, (3:00 p.m. – 3:55 p.m.)
- Room: 5001 (for CSE), 5102 (for M&C)

- Evaluation:
  - Attendance : 05%
  - Class Test/Quiz 1 : 15%
  - Mid-Sem Exam : 25%
  - Class Test/Quiz 2 : 15%
  - End-Sem Exam : 40%

- Text Book
  - Computer Networks: A Top Down Approach, by J.F. Kuros and K.W. Ross
  - Data and Computer Communications, by W. Stallings

- Reference Book
  - *Computer Networks: A Systems Approach*, by L.L. Peterson and B.S. Davie
  - Data Communications and Networking, by B.A. Forouzan

Data Communication System

- Data communications are
  - 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.

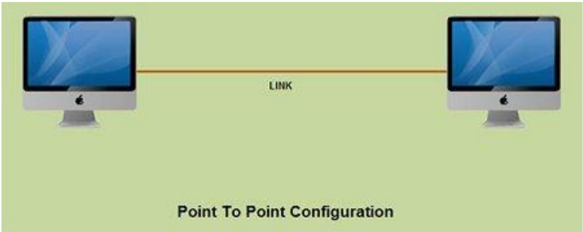
- **Components:**
  - Message / data
  - Sender & Receiver
  - Transmission medium
  - Protocols

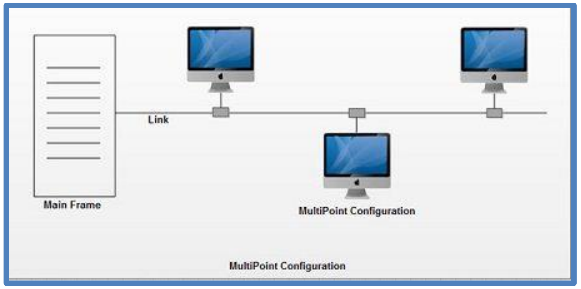
What is Computer Network?

- A network is the interconnection of a set of devices capable of communication.
- A computer network is defined as interconnected collection of autonomous computers who can exchange information.
- **Objectives of the computer networks:**
  - Efficient Resource sharing: provide all the program, data and hardware available to everyone on the network without regard to the physical location of the resource and the users
  - Communication: is a powerful communication medium
  - Reliability: achieved by replicating the files on two or more machines
  - Load balancing: provided means to increase system performance as the work load increases
  - Security: Only authorized user can access resource in a computer network

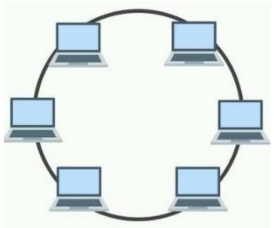
Network Topology

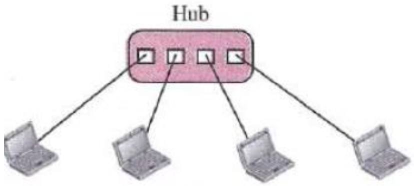
- **Type of Connection**
  - Point-to-Point: direct link between two devices
  - Multipoint: single link between three or more devices

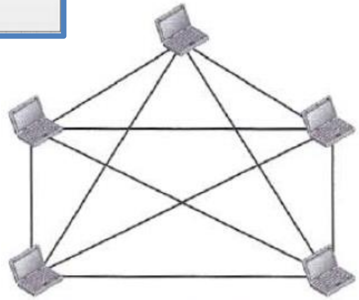


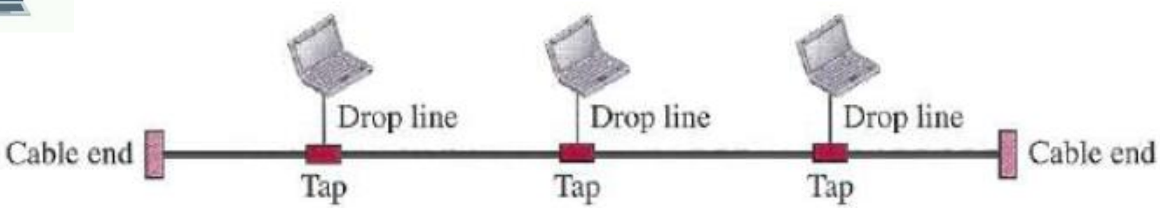


- **Physical Topology**
  - Bus
  - Star
  - Mesh
  - Ring



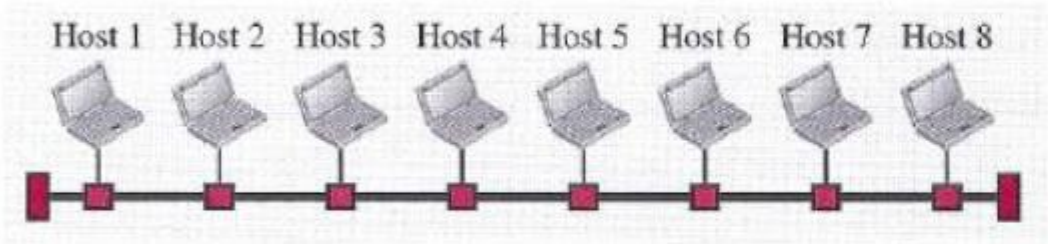




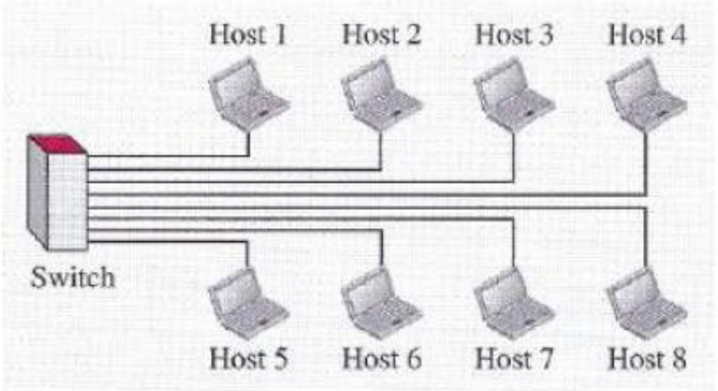


Network Types

- Local Area Networks (LAN)

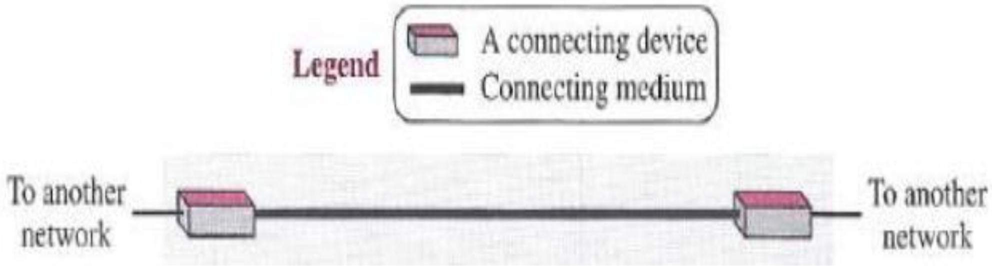


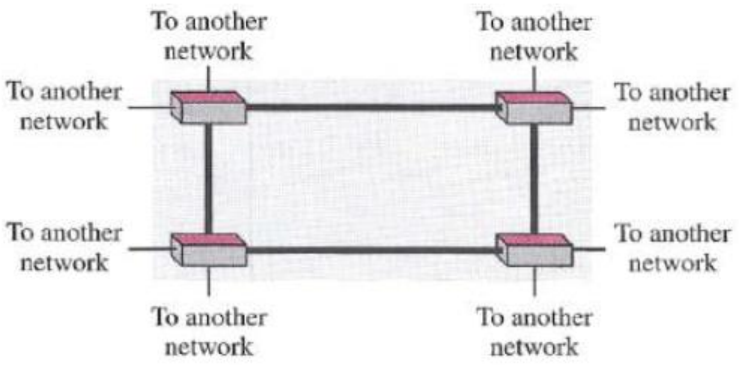
a. LAN with a common cable (past)



b. LAN with a switch (today)

- Wide Area Networks (WAN)





- Internet is arguably the largest WAN ever created by mankind

Internet

Ways to describe the **Internet**.

1. we can describe by 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.

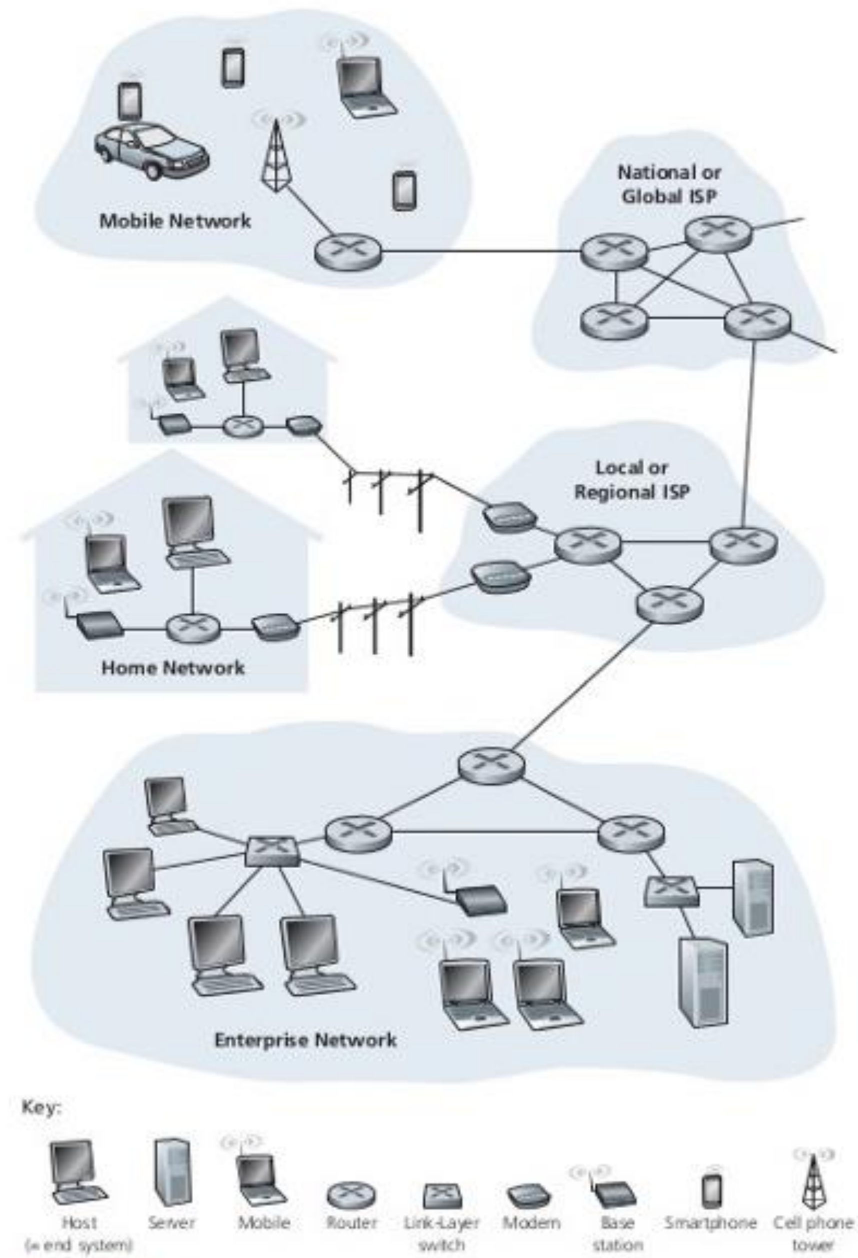


Figure 1.1 ♦ Some pieces of the Internet

Nuts-and-Bolts Description

- The Internet is a computer network that interconnects hundreds of millions of computing devices throughout the world.
- In Internet, all of these **edge devices** are called hosts / end systems.
- End systems are connected together by a network of communication links and packet switches.
  - two most prominent types of packet switch in today's Internet are routers and link-layer switches.
  - Link-layer switches are typically used in **access networks**, while routers are typically used in the **network core**.
- End systems access the Internet through Internet Service Providers (ISPs)
- End systems, packet switches, and other pieces of the Internet run protocols
- **Protocols** control the sending and receiving of information within the Internet.

Infrastructure View

- Internet is 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.
- End systems attached to the Internet provide an Application Programming Interface (API)
- API specifies how a program running on one end system asks the 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 process must follow so that the Internet protocol can deliver the data to the destination program.
- Example: postal service

Access Networks

- Access network—the network that physically connects an end system to the first router (also known as the "edge router")

- the applications and end systems at the "edge of the network"

- Types
  - residential access nets
    - DSL, Cable, FTTH, Dial-Up, and Satellite
  - enterprise access nets
  - mobile access nets

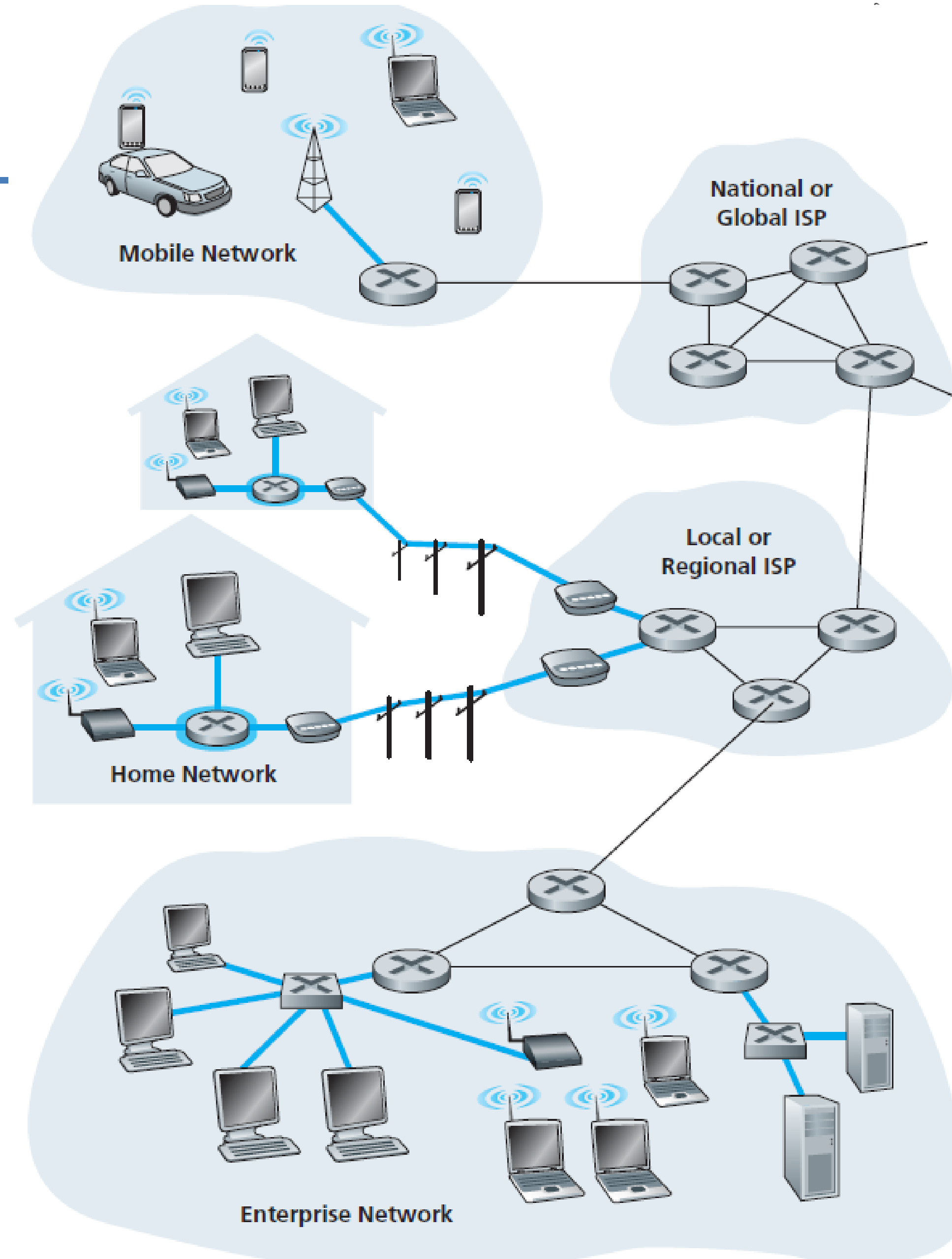
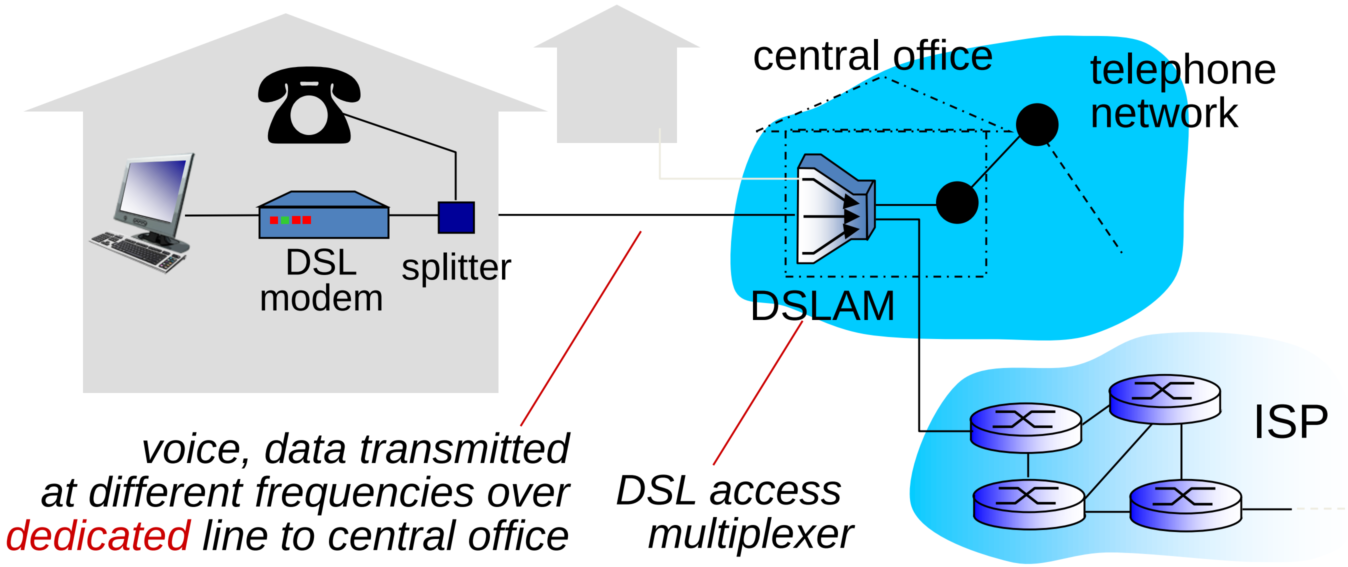


Figure 1.4 ♦ Access networks

Digital Subscriber Line (DSL)



Existing phone line:
0-4KHz ordinary telephone;

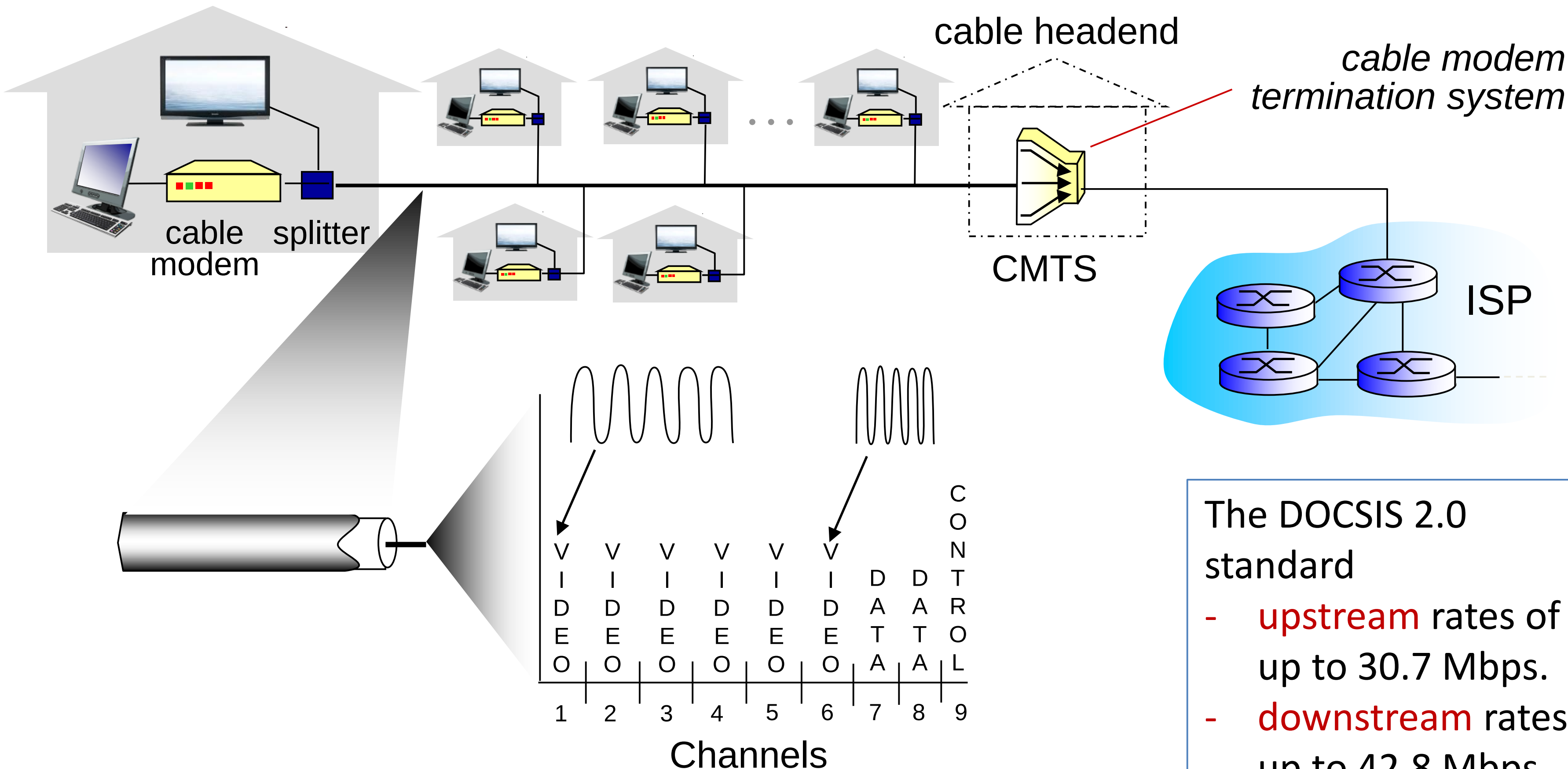
4-50KHz upstream data;

50KHz–1MHz downstream data

- use existing telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net

- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

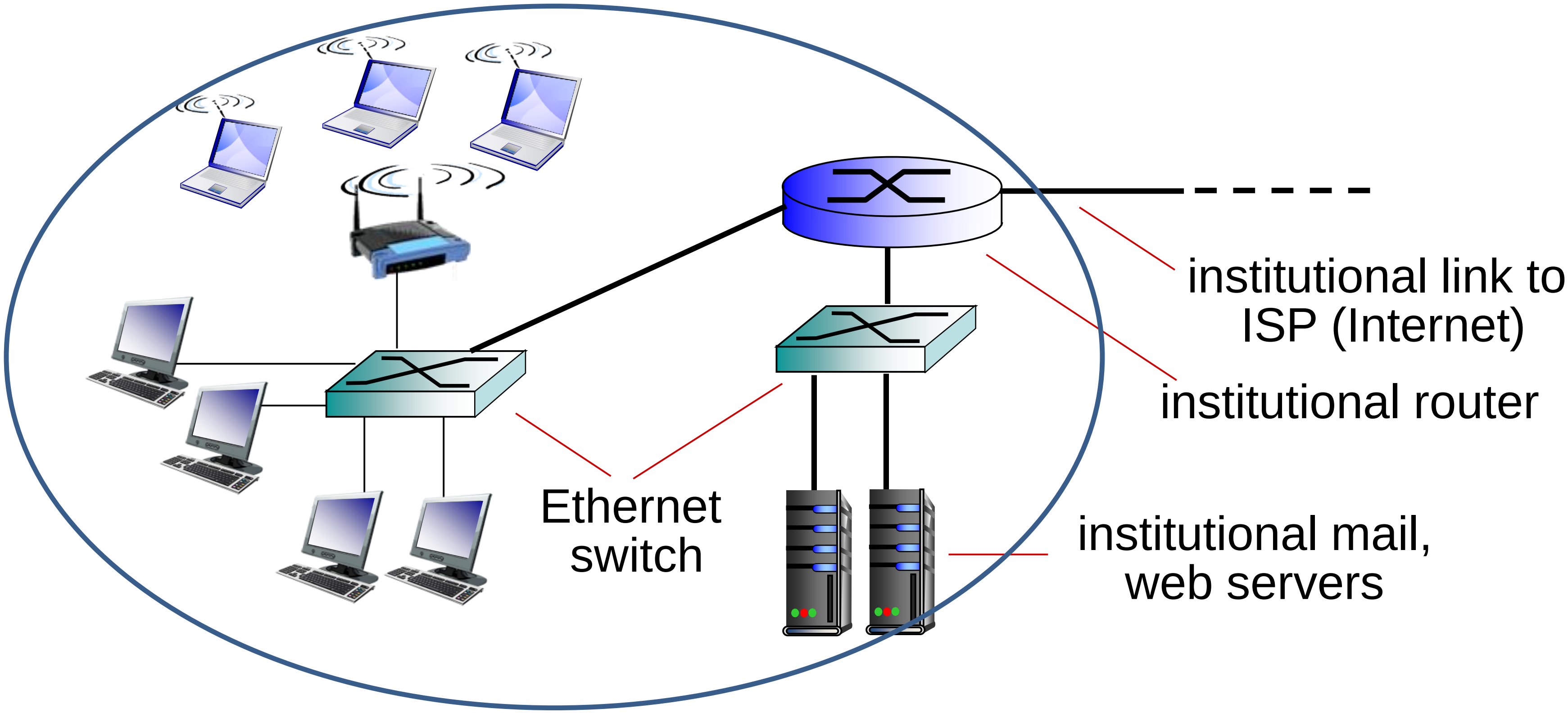
Cable network



The DOCSIS 2.0 standard
- upstream rates of up to 30.7 Mbps.
- downstream rates up to 42.8 Mbps

- use of the cable television company's existing cable television infrastructure.
- frequency division multiplexing (FDM): different channels transmitted in different frequency bands

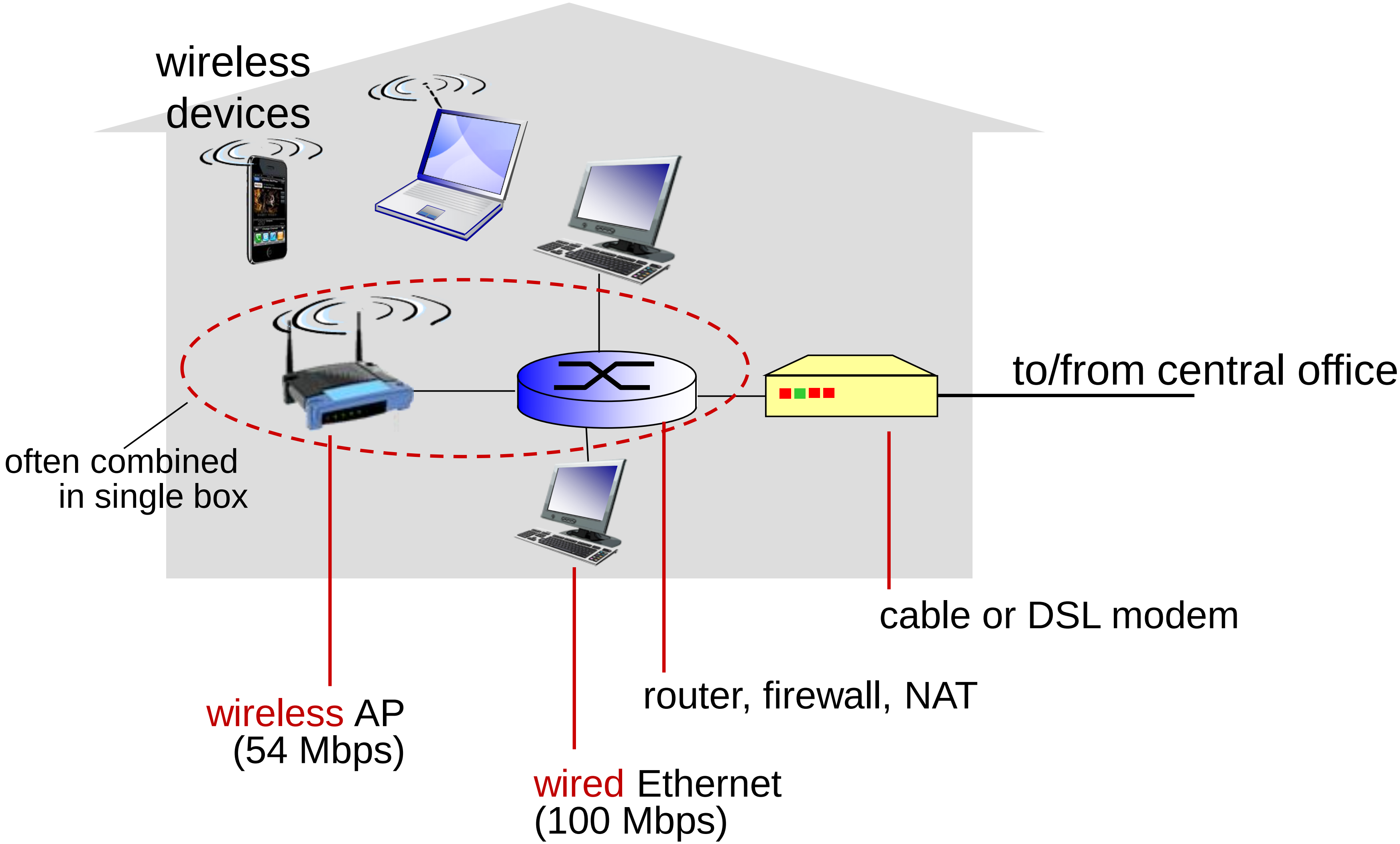
Ethernet



- typically used in companies, universities, etc

- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

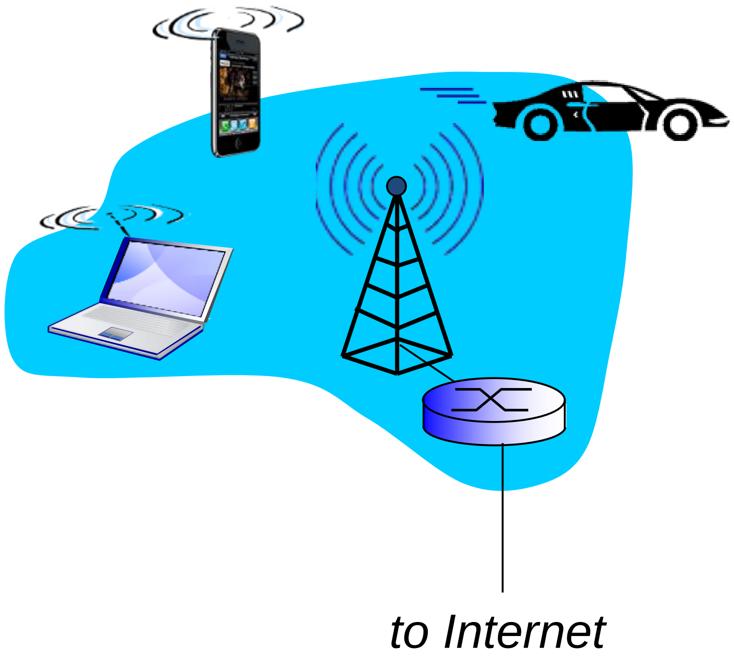
WiFi



wireless devices
to/from central office
often combined in single box
cable or DSL modem
router, firewall, NAT
wireless AP (54 Mbps)
wired Ethernet (100 Mbps)

3G and LTE

- Unlike WiFi, a user need only be within a few tens of kilometers (as opposed to a few tens of meters) of the base station.
- 3G provides packet-switched wide-area wireless Internet access at speeds in excess of 1 Mbps
- Long-Term Evolution (LTE) can potentially achieve rates in excess of 10 Mbps.



The Network Core

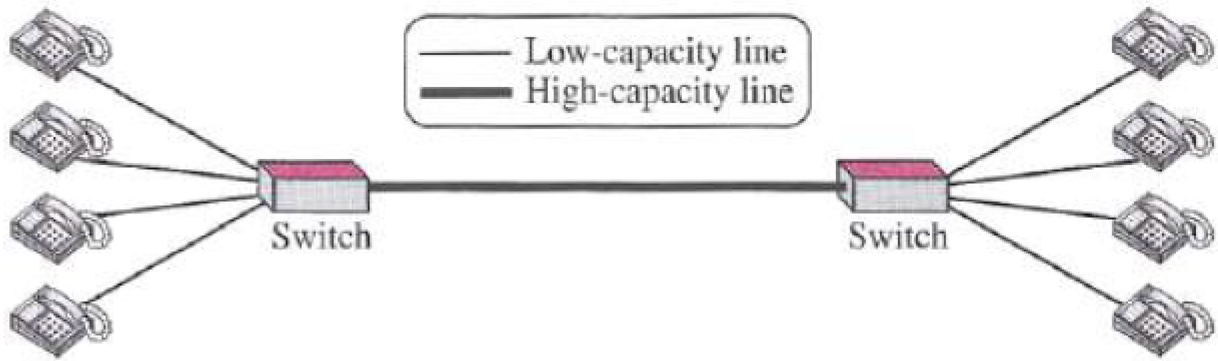
- The network core is the
  - mesh of packet switches, and
  - links that interconnects the Internet's end systems.

- 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

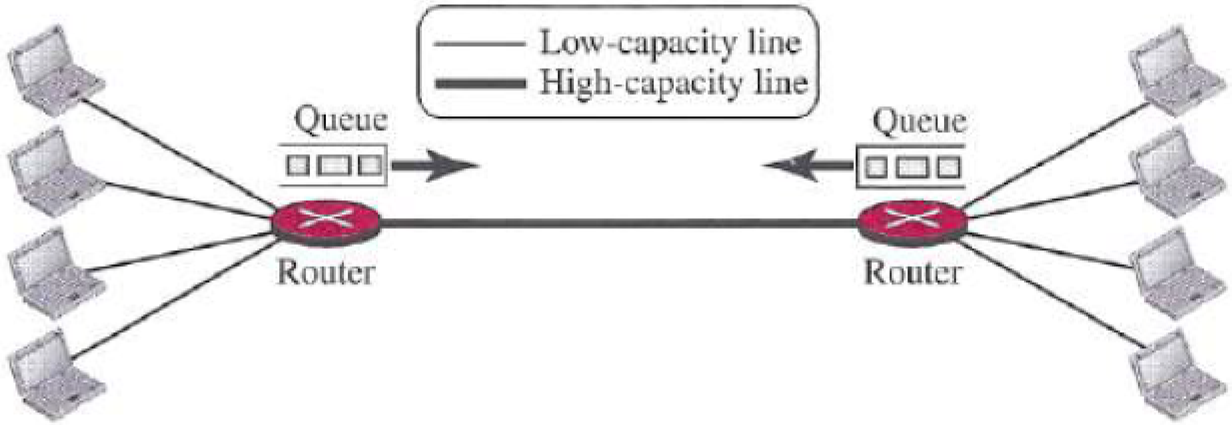
- a dedicated connection, called a circuit, is always available between the two end systems; the switch can only make it active or inactive.
  - E.g., Telephone Network



- 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



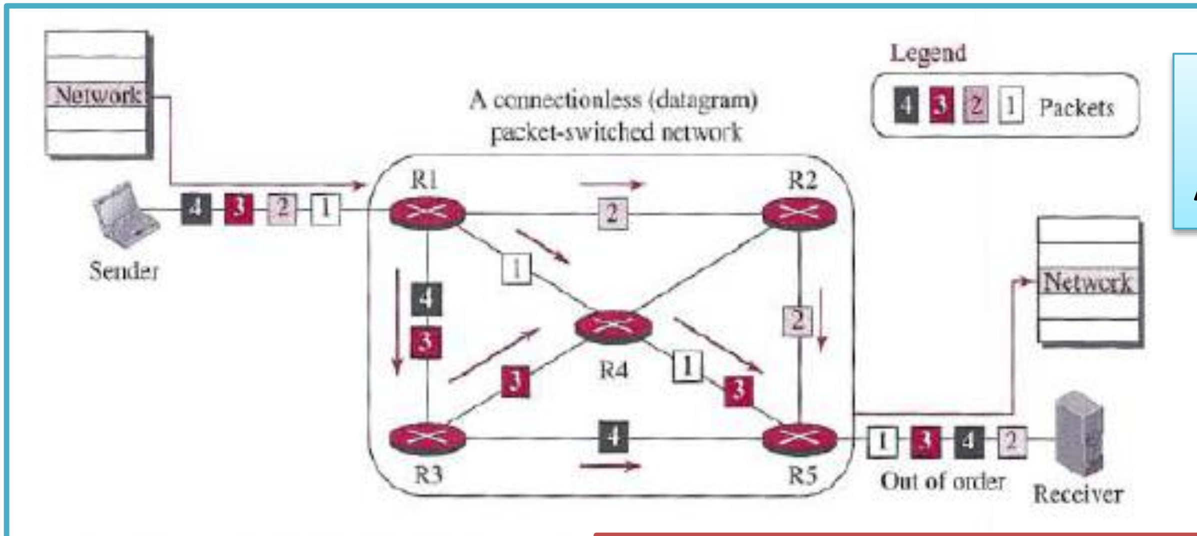
- Advantages:
  - Better utilization of link
  - Router can store and forward data packets

Approaches in Packet-switching

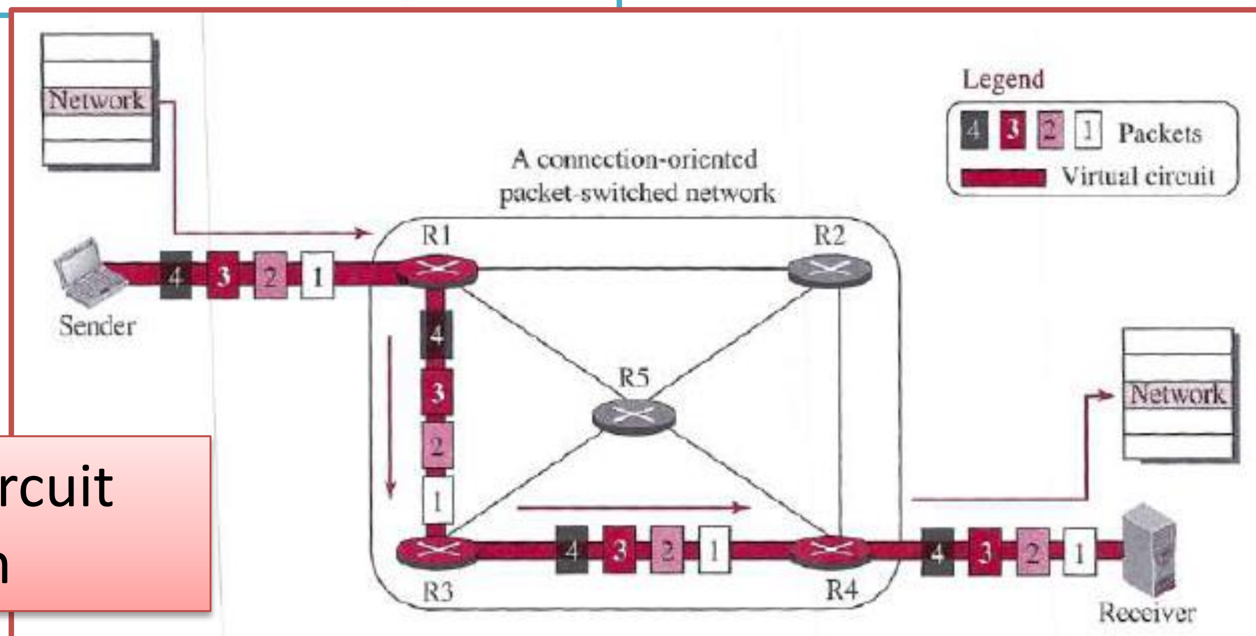
- Datagram approach
  - Connectionless service: each packet is treated independently
  - Packet forwarding decision is based on destination address

- 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

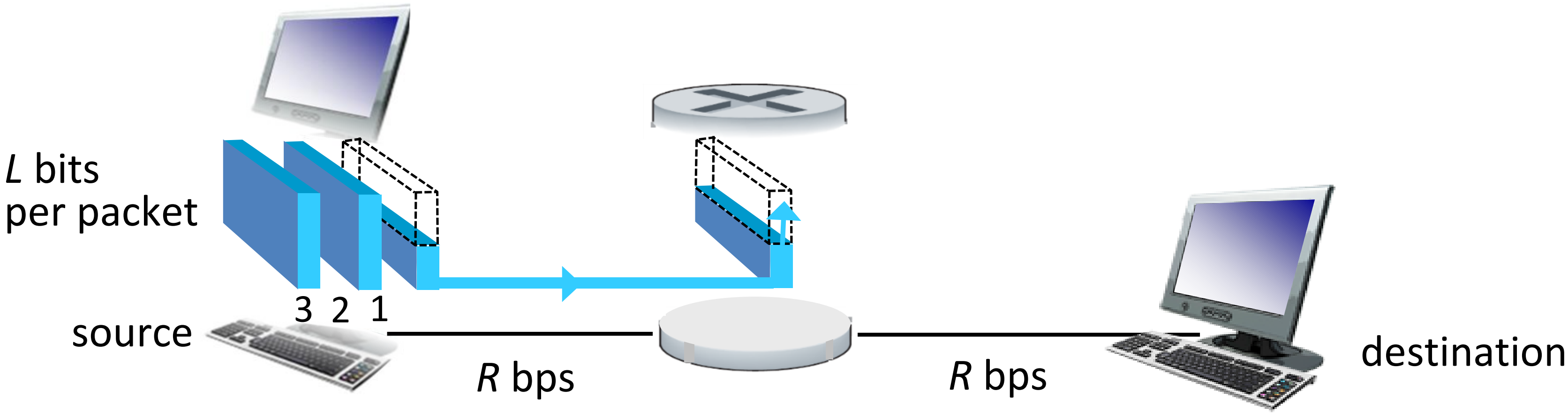


Datagram Approach



Virtual-circuit Approach

Packet-switching: store-and-forward



- Assume one router in between source and destination
- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2\ L/R$ (assuming no propagation and other delay)

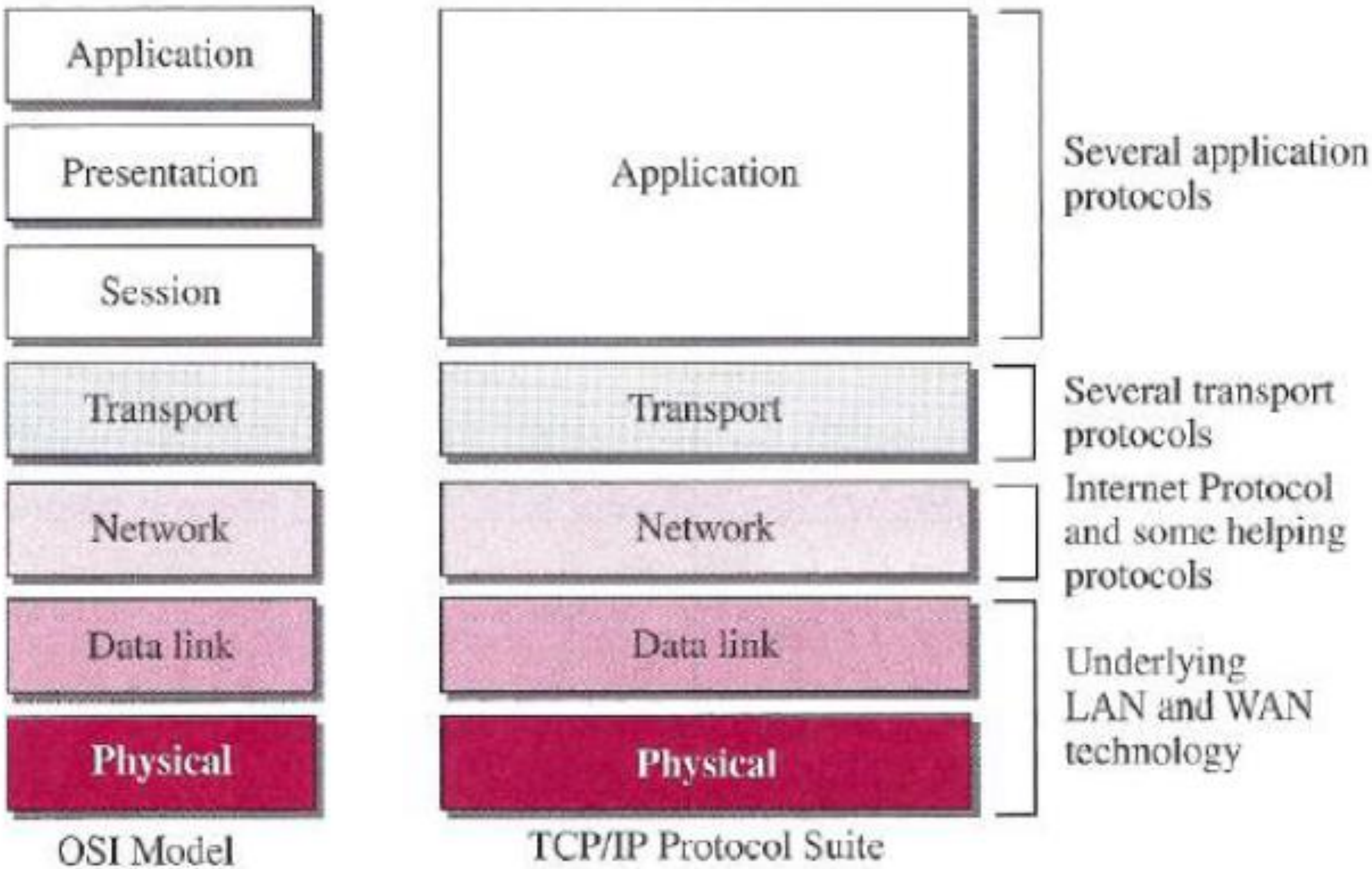
- In general sending one packet from source to destination over a path consisting of N links each of rate R, the end-to-end delay $= NL/R$

- What the delay would be for P packets sent over a series of N links?

How to define Network Operations?

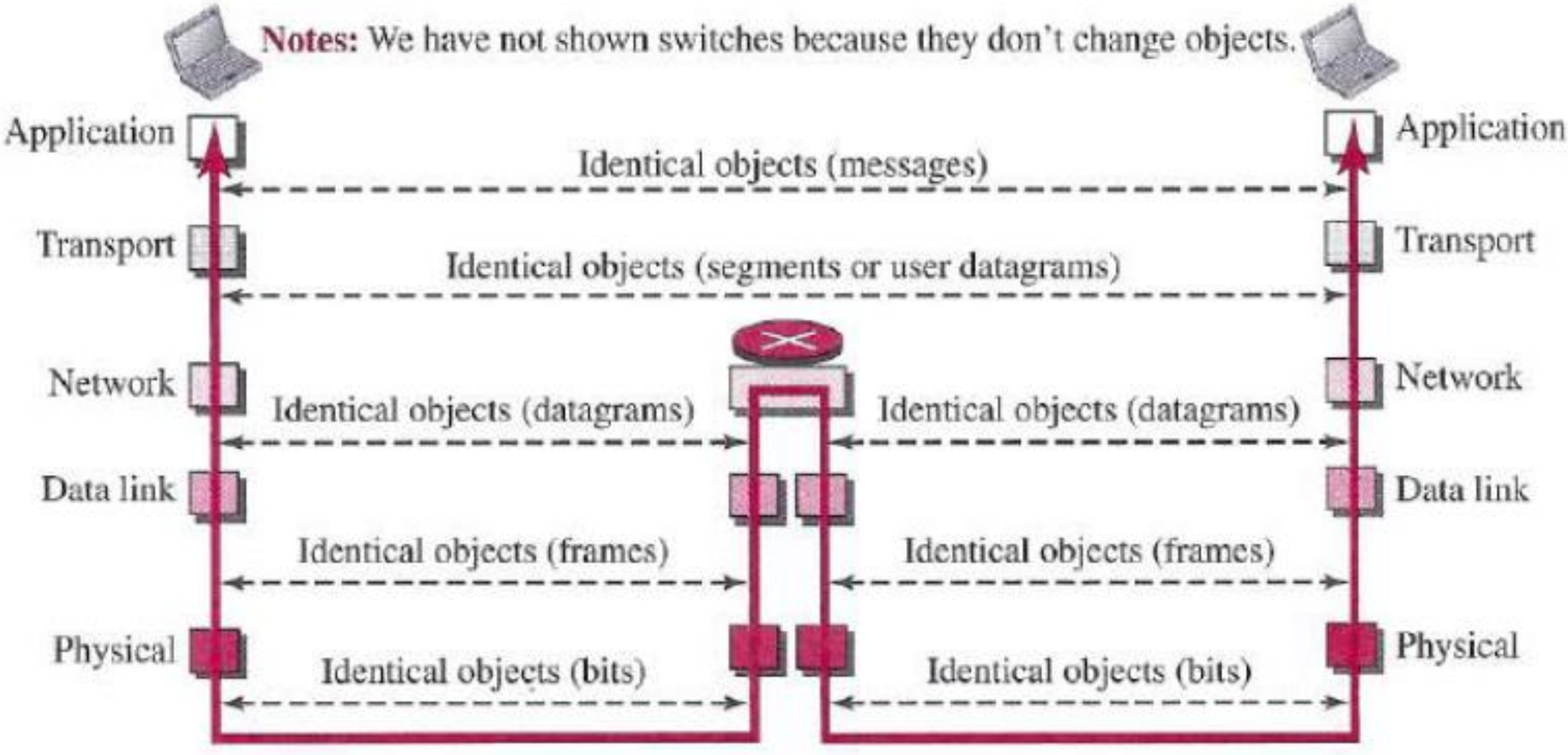
- Ans: **Protocol**
- Protocol controls the sending and receiving of information within the Internet
- Protocol defines the rules that both the **sender** and **receiver** and all **intermediate devices** need to follow to be able to communicate effectively.
- For simple communication (between 2 computer): 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

- 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

- Provides an end-to-end communication between machines belonging to different (or same) network.

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

Datalink Layer

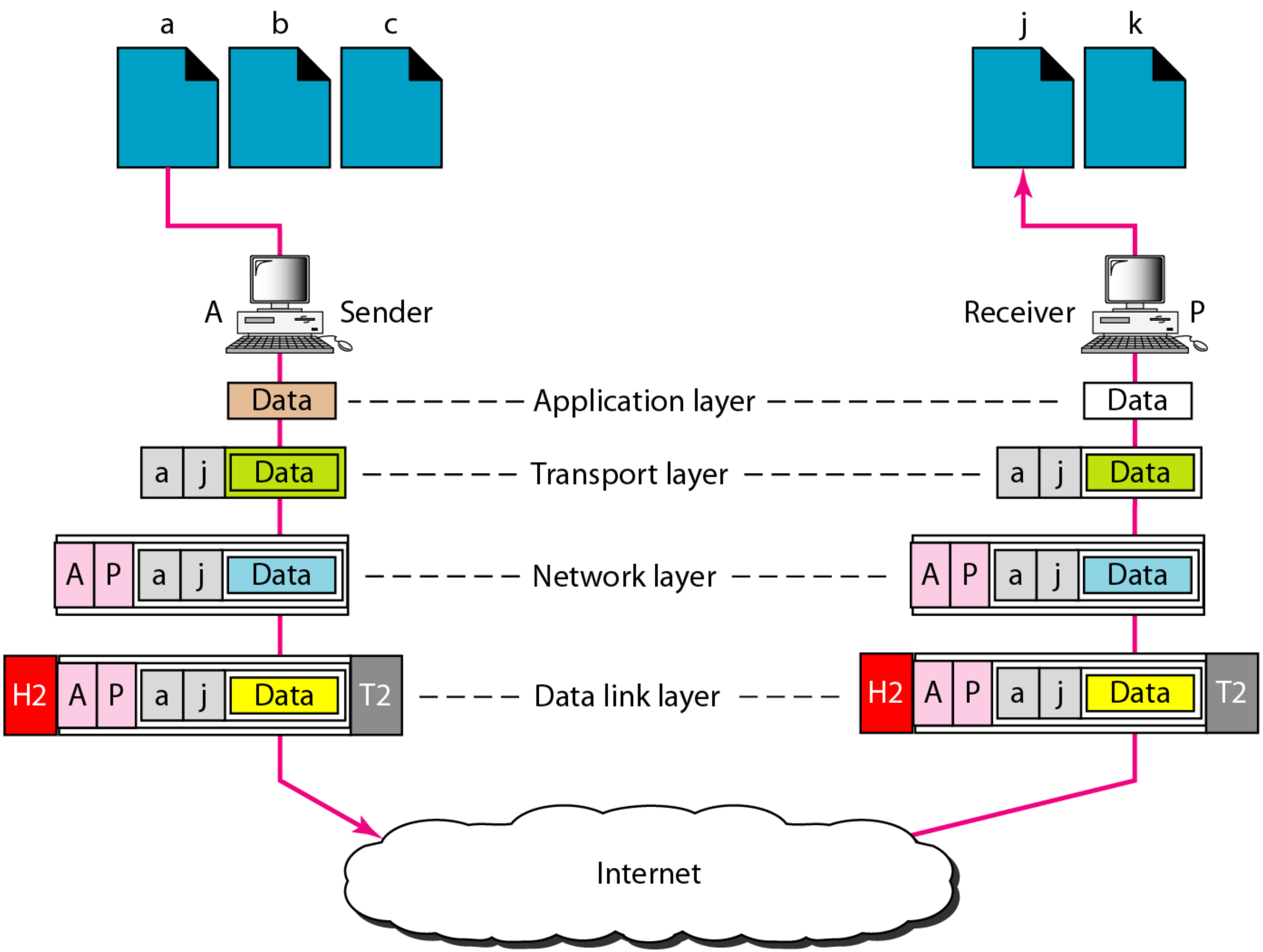
- Provides reliable, efficient communication between adjacent machines connected by a single communication channel.

  – Framing
  – Reliable delivery
  – Acknowledged delivery
  – Error control
  – Flow control
  – Etc.

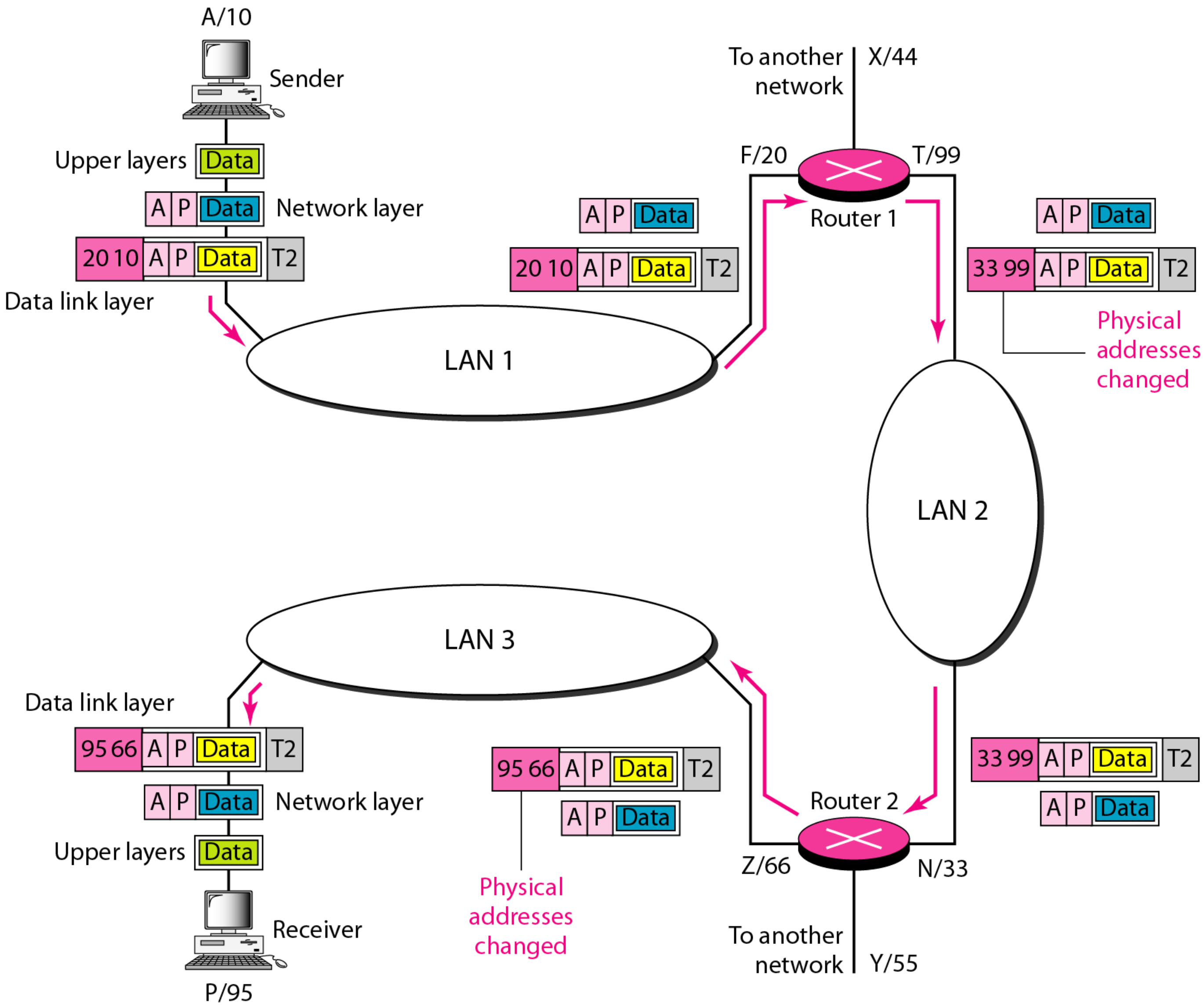
Physical Layer

- 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

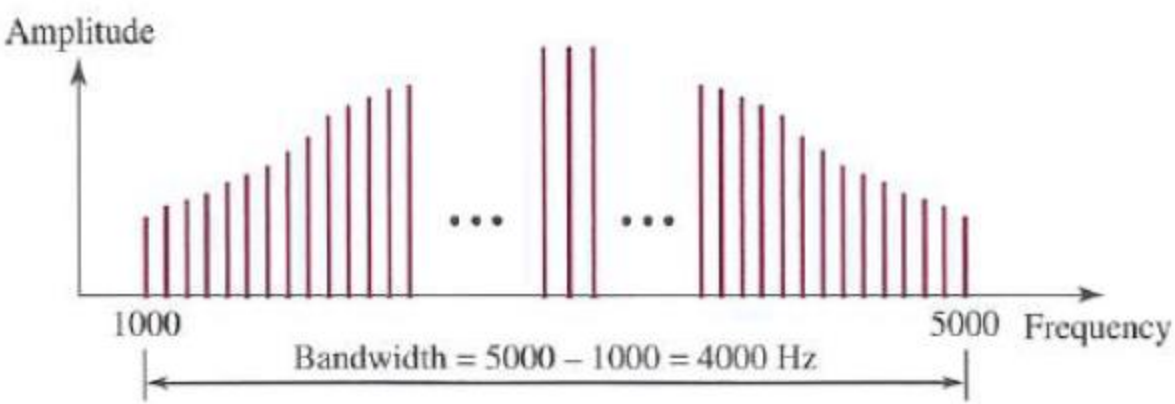


Performance Metrics

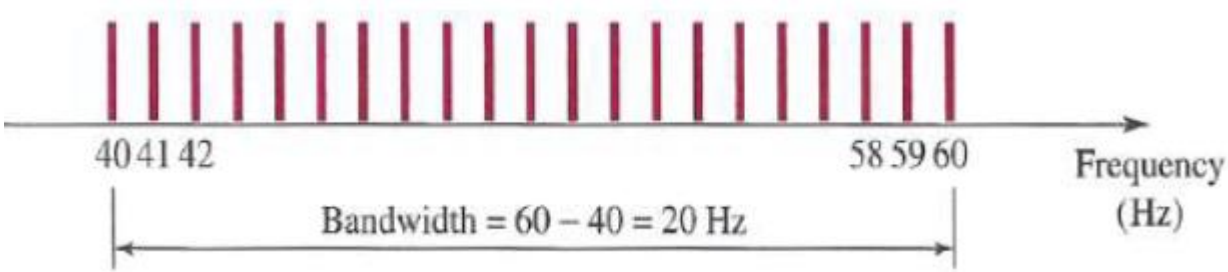
- Bandwidth
- Latency (delay)
- Bandwidth-delay product
- Throughput
- Datarate

Bandwidth (in Hertz)

- For Analog Signal : Difference between the highest and lowest frequencies contained in that signal

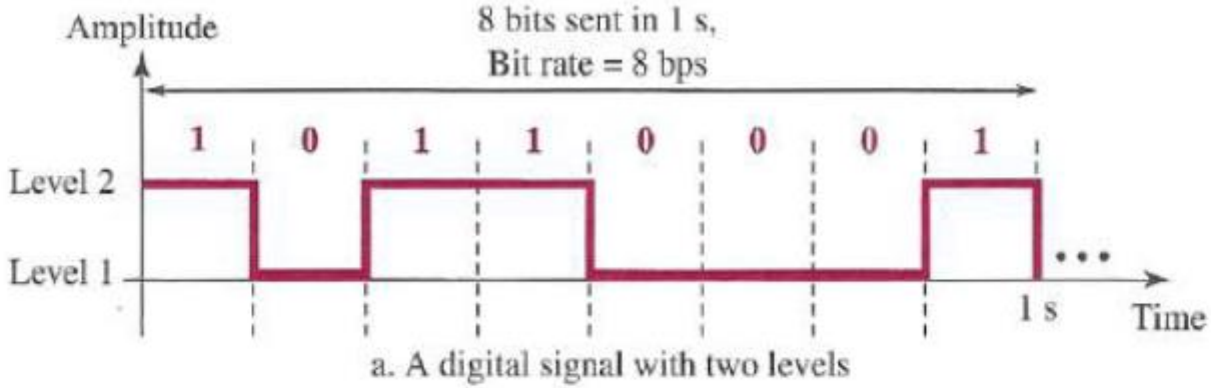


a. Bandwidth of a periodic signal

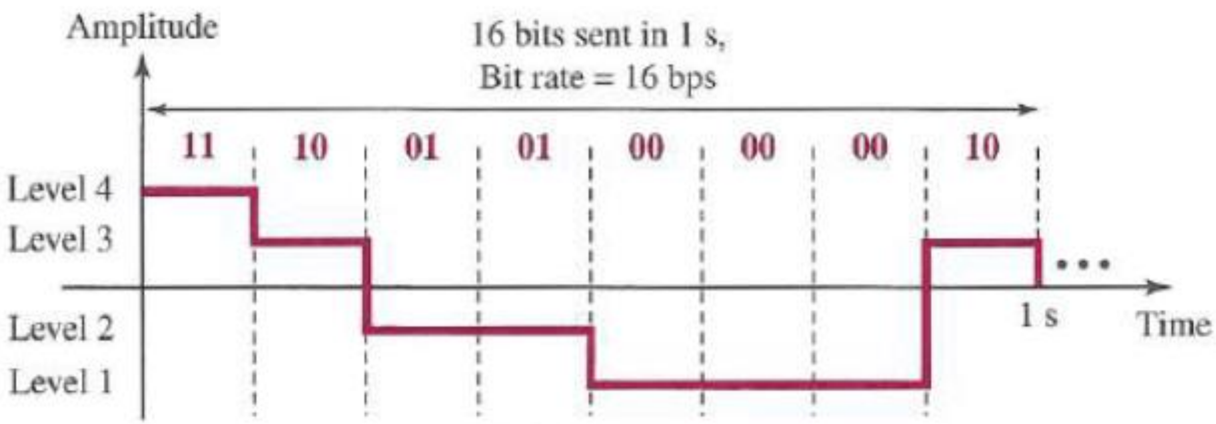


Bandwidth (in Bits per Second)

- For Digital Signal : amount of data that can be transmitted in a fixed amount of time, i.e. number of bits transmitted per second



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 or Delay = 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 10^4 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 if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and light travels in wire at 2.4×10^8 m/s.
- Solution:
  - Propagation time = $(12,000 \times 1000) / (2.4 \times 10^8)$ = 50 ms
  - Transmission time == $(5\text{x } 10^6 \times 8) / 10^6$ = 40 sec

End-to-End Delay

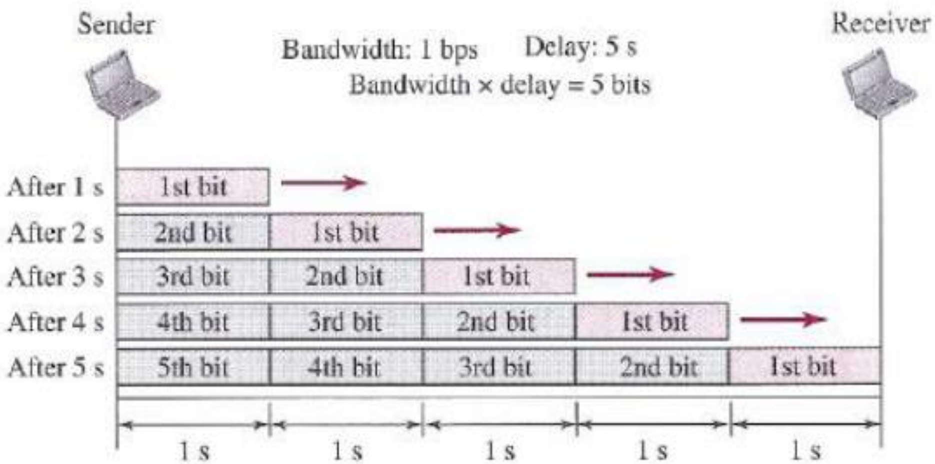
- Total delay from source to destination
- suppose there are N -1 routers between the source host and the destination host
- suppose the network is uncongested (so that queuing delays d_{que} are negligible)

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

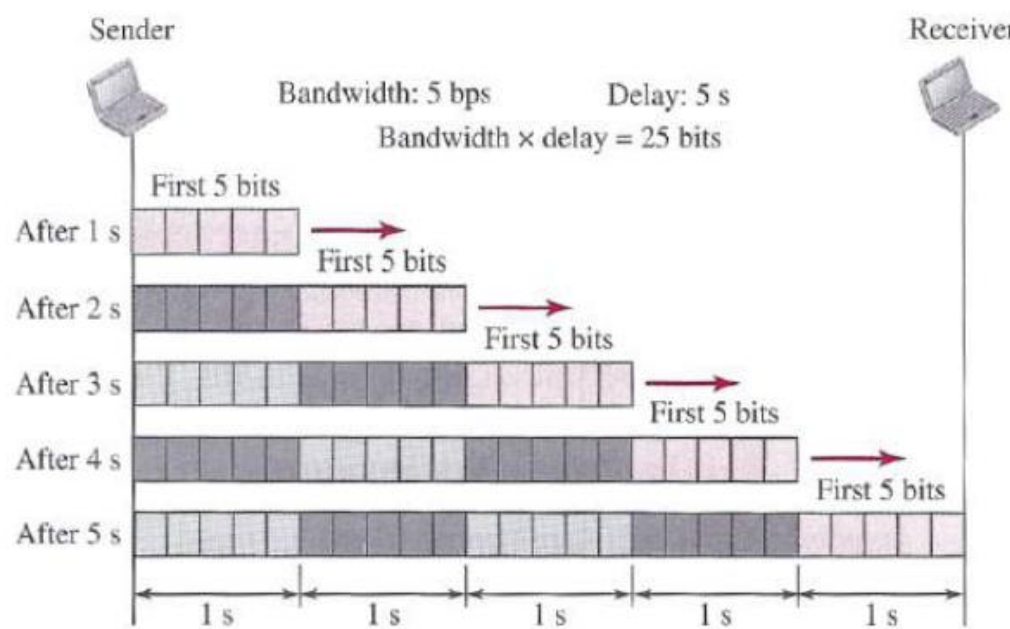
- Queuing Delay:
  - Unlike the other three delays, the queuing delay can vary from packet to packet.

- Queuing delay - when large and when insignificant?
  - depends on
    - (1) arrival rate of traffic at the queue,
    - (2) transmission rate of the link,
    - (3) nature of the arriving traffic (periodic / bursty)

Bandwidth-Delay Product



The bandwidth-delay product is a measure of the maximum number of bits a sender can transmit before 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

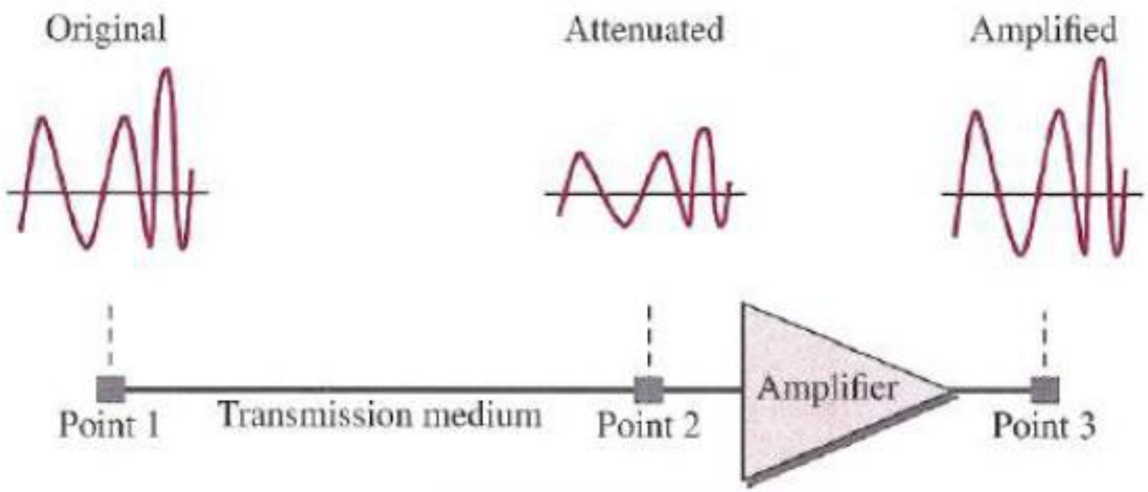
- **Attenuation** means a loss of energy.

- **Distortion** means that the signal changes its form or shape.

- Several types of **noise** may corrupt a 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

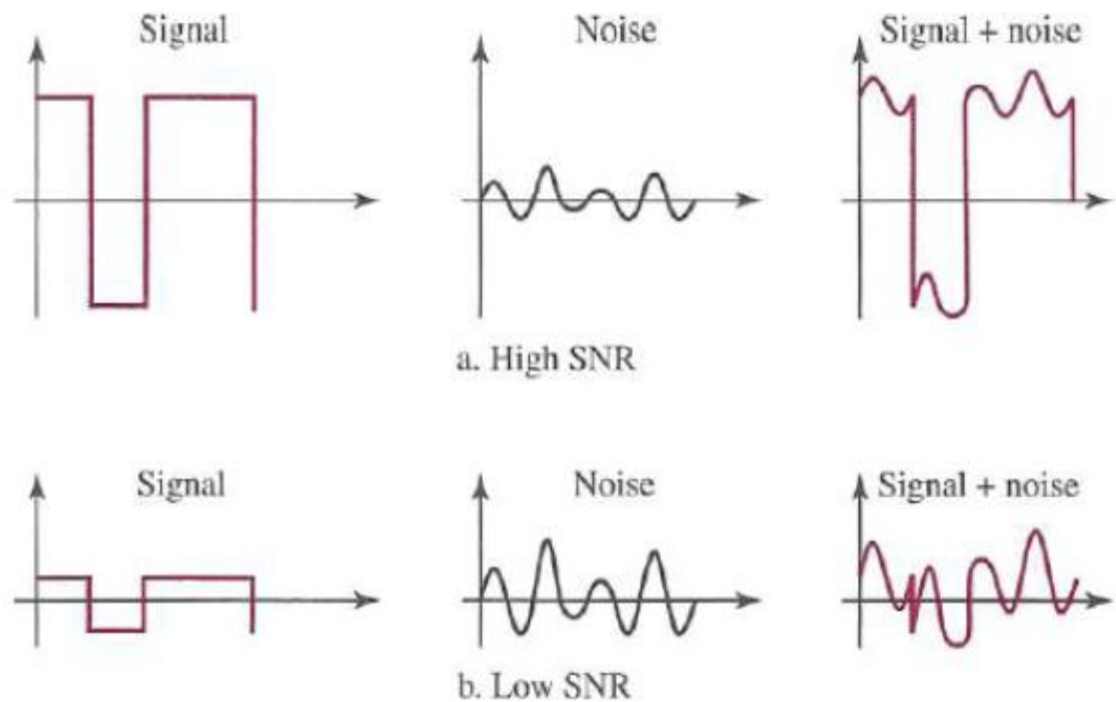
- The decibel (dB) measures the relative strengths of two signals or one signal at two different points.



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

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 and Data rate

- Throughput (in bps): 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 bps): how fast we can send data over a channel.
  - 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!