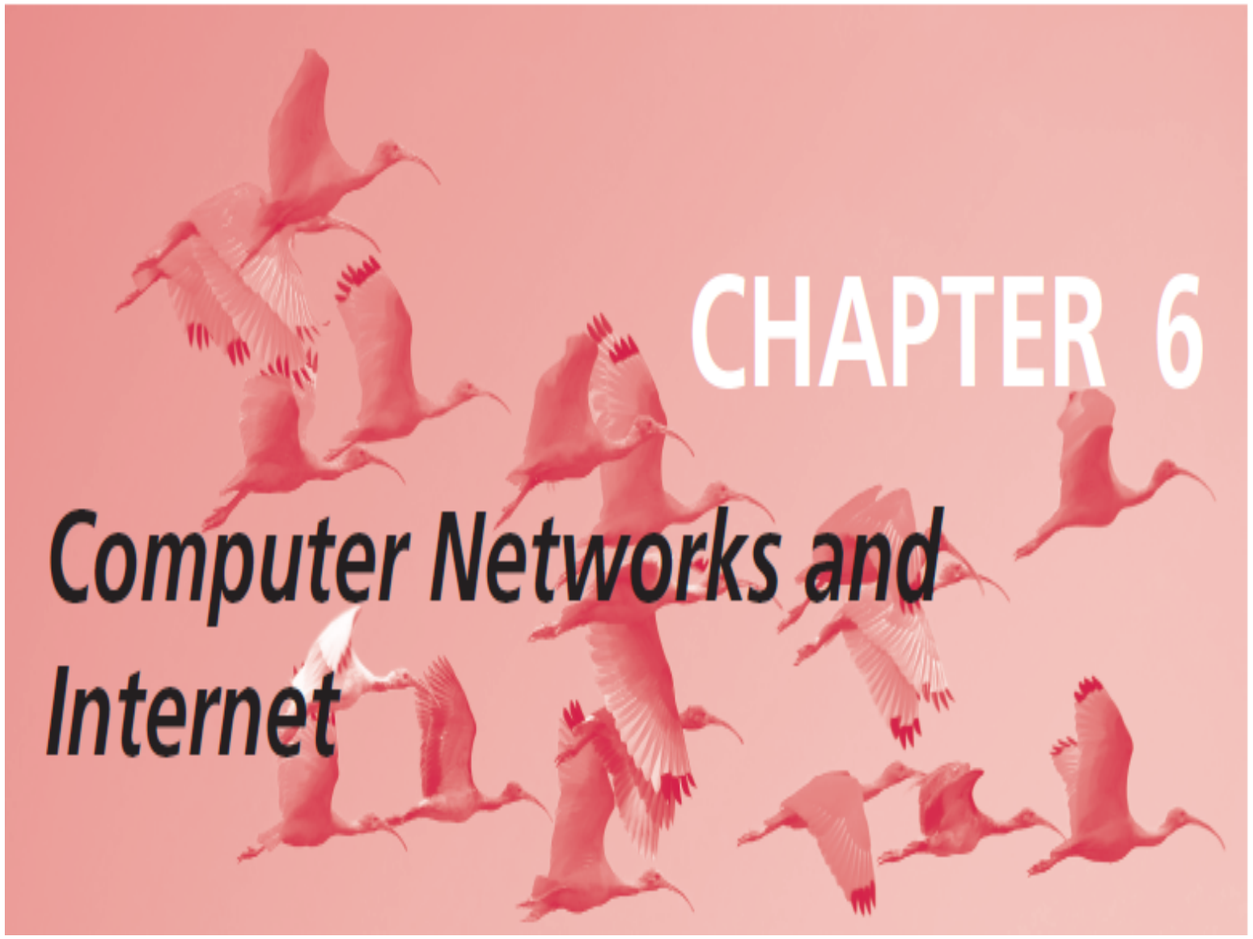


CHAPTER 6

Computer Networks and Internet

Objectives:

- To describe local and wide area networks (LANs and WANs).
- To distinguish an Internet from the Internet.
- To describe the TCP/IP protocol suite as the network model in the Internet.
- To define the layers in the TCP/IP protocol suite and their relationship.
- To describe some applications at the application layer.
- To describe the services provided by the transport-layer protocols..

Objectives (continued):

- To describe the services provided by the network-layer protocols
- To describe different protocols used at the data-link layer.
- To describe the duties of the physical layer.
- To understand how computer throughput can be improved using pipelining.
- To describe the different transmission media used in computer networking.

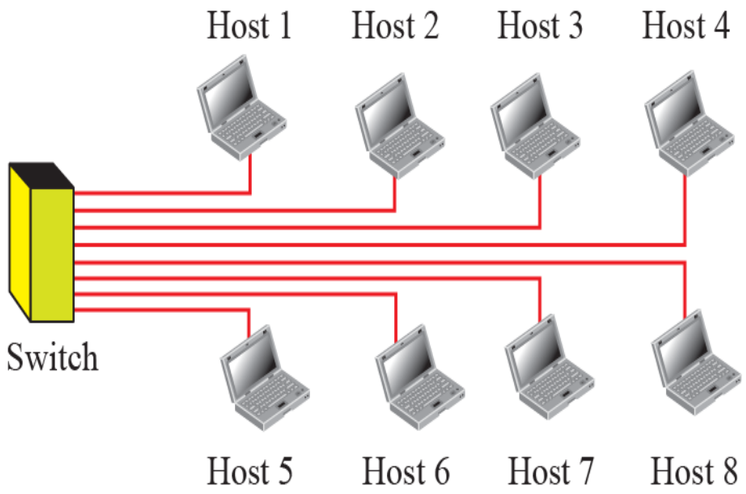
6.1 OVERVIEW

Although the goal of this chapter is to discuss the Internet, a system that interconnects billions of computers in the world, we think of the Internet not as a single network, but as an Internetwork, a combination of networks. Therefore, we start our journey by first defining a network. We then show how we can connect networks to create small Internetworks. Finally, we show the structure of the Internet and open the gate to study the Internet in the rest of this chapter.

A network is the interconnection of a set of devices capable of communication. In this definition, a device can be a host (or an end system as it is sometimes called) such as a large computer, desktop, laptop, workstation, cellular phone, or security system. A device in this definition can also be a connecting device such as a router which connects the network to other networks, a switch which connects devices together, a modem (modulator-demodulator) that changes the form of data, and so on. These devices in a network are connected using wired or wireless transmission media such as cable or air. When we connect two computers at home using a plug-and-play router, we have created a network, although very small.

A local area network (LAN) is usually privately owned and connects some hosts in a single office, building, or campus.

Figure 6.1: Example of a LAN



We see two distinct examples of WANs today: point-to-point WANs and switched WANs as shown in Figure 6.2.

Figure 6.2: A point-to-point and a switched WAN

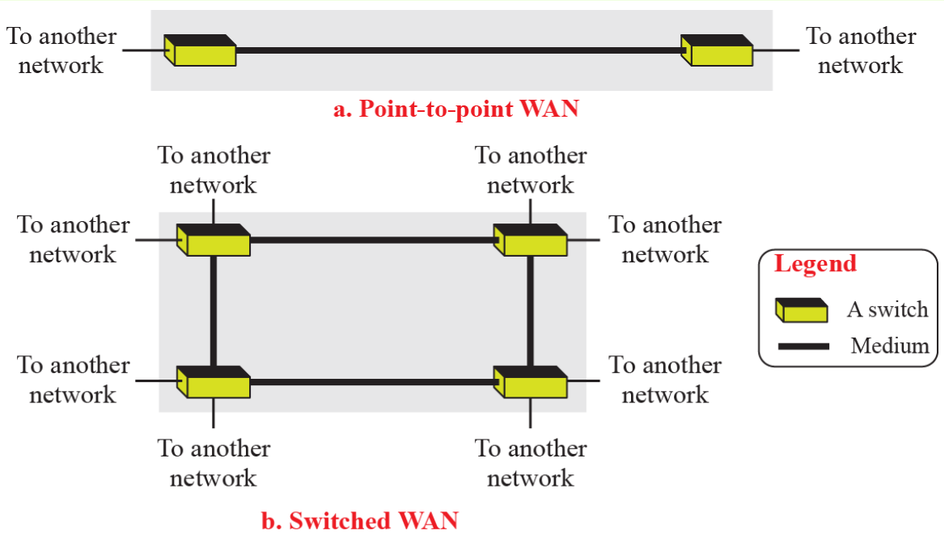
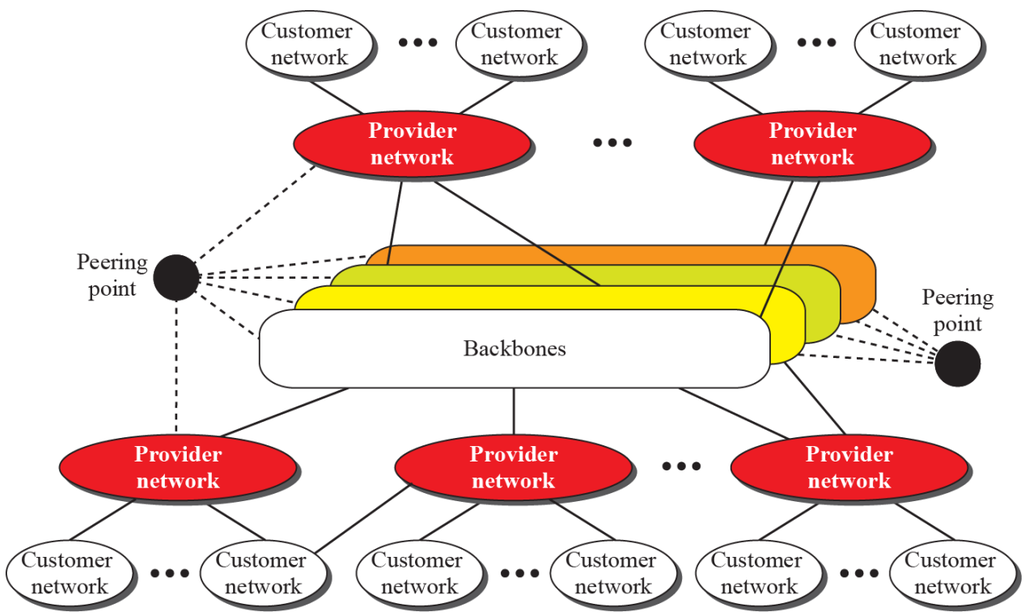


Figure 6.3: An Internetwork made of LANs and WANs

The Internet

As we discussed before, an Internet (note the owercase i) is two or more networks that can communicate with each other. The most notable Internet is called the Internet (uppercase I), and is composed of thousands of interconnected networks. Figure 6.4 shows a conceptual (not geographical) view of the Internet.
Backbones and provider networks are also alled Internet Service Providers (ISPs).

Figure 6.4: The Internet today



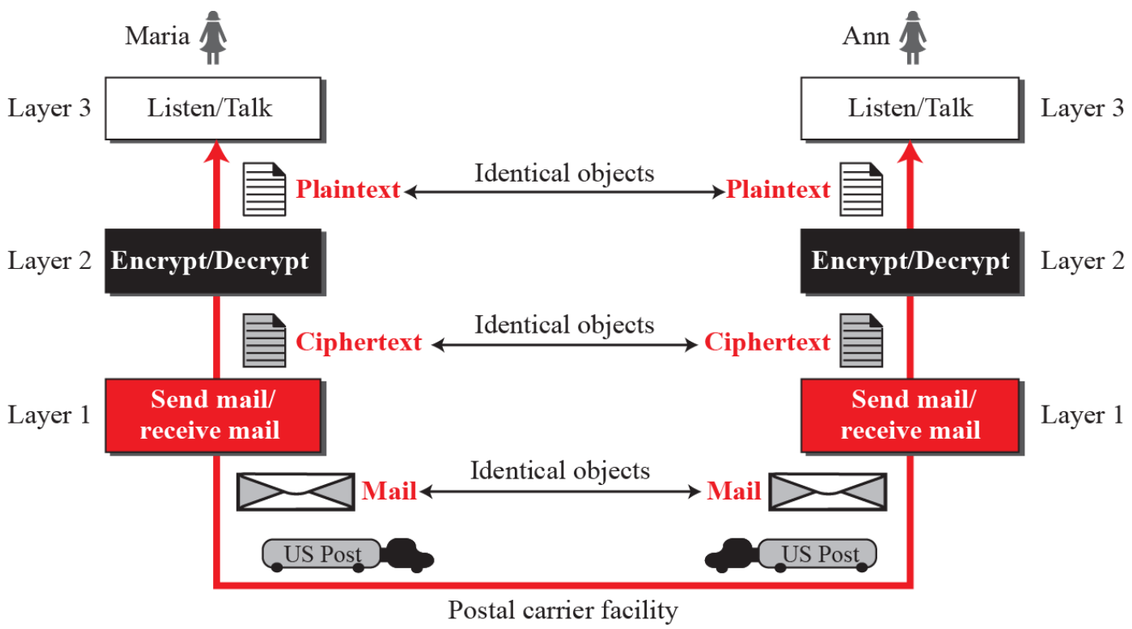
Hardware and softwar

For communication to happen, we need both hardware and software. This is similar to a complex computation in which we need both a computer and a program. In the next section, we show how these combinations of hardware and software are coordinated with each other using protocol layering.

Protocol layering

A word we hear all the time when we talk about the Internet is protocol. A protocol defines the rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively.

Figure 6.5: A three-layer protocol

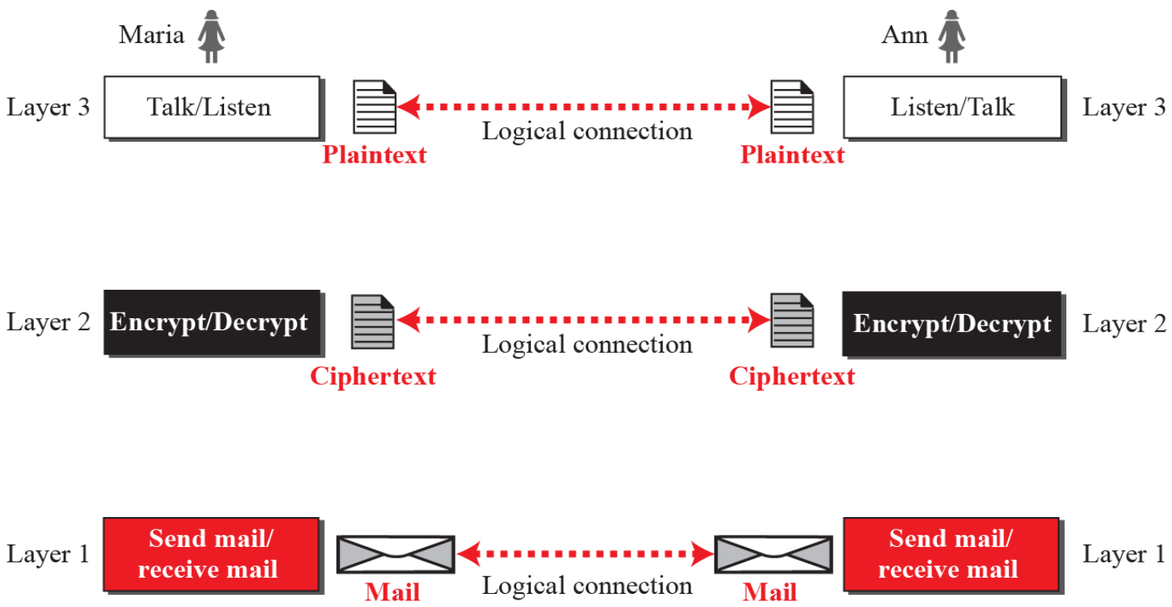


Principles of protocol layering

Logical connections

After following the above two principles,we can think about logical connection between each layer as shown in Figure 6.6. This means that we have layer-to-layer communication.

Figure 6.6: Logical connection between peer layers



TCP/IP protocol suite

Now that we know about the concept of protocol layering and the logical communication between layers in our second scenario, we can introduce the TCP/IP (Transmission Control Protocol/Internet Protocol). TCP/IP is a protocol suite (a set of protocols organized in different layers) used in the Internet today.

Figure 6.7: **Layers in the TCP/IP protocol suite**

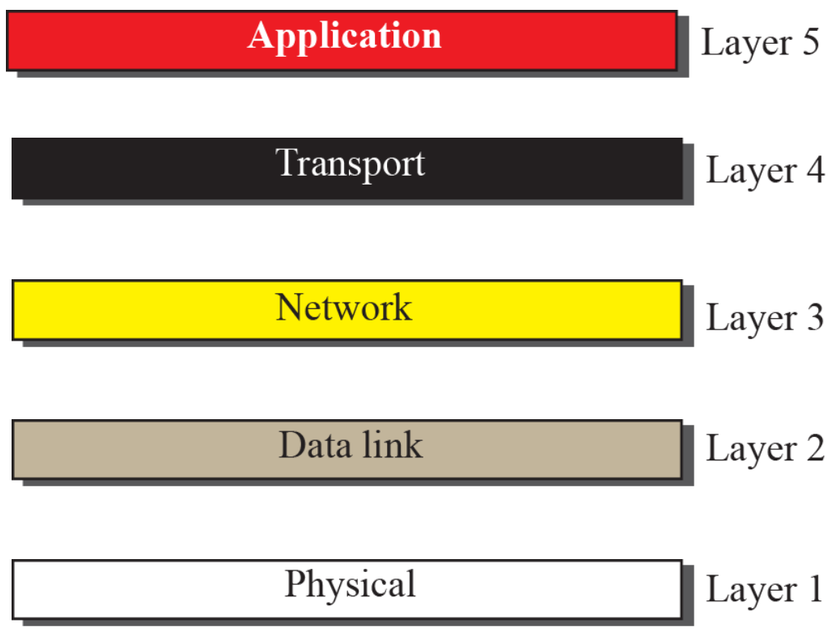
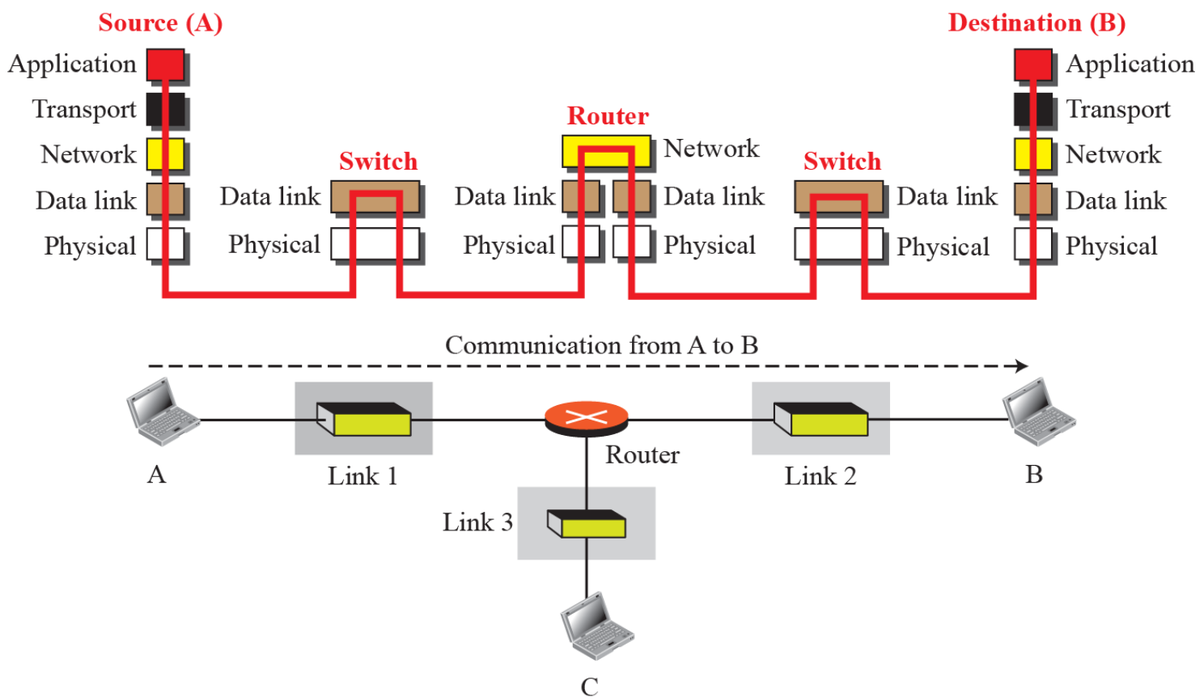


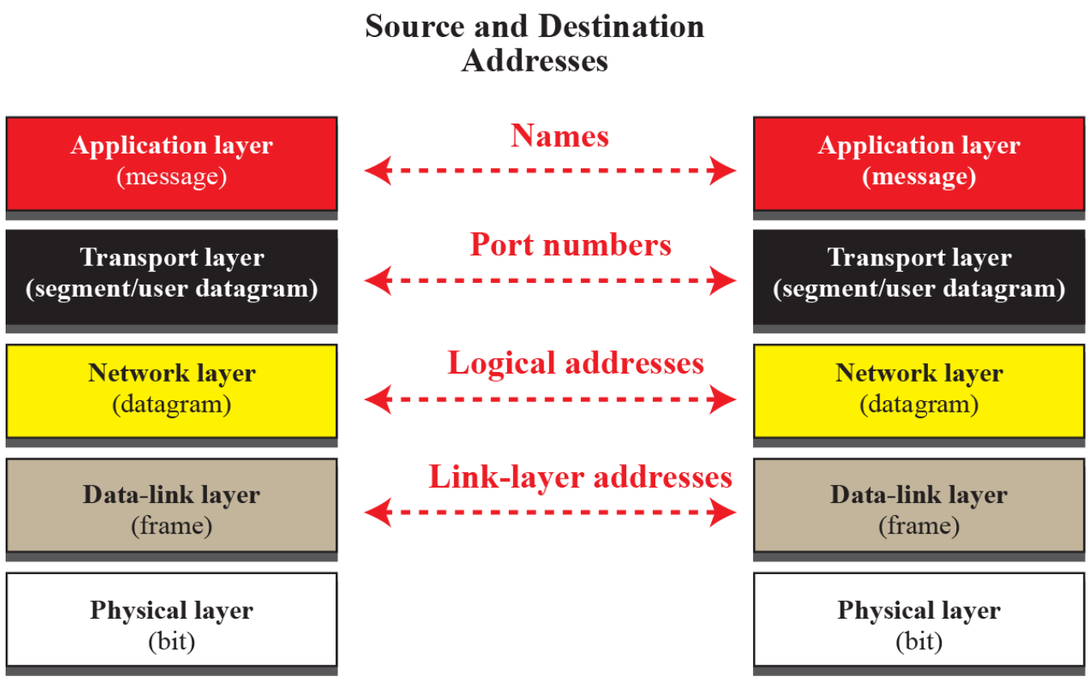
Figure 6.8: Communication through an internet



Addressing and packet names

It is worth mentioning another two concepts related to protocol layering in the Internet,addressing and packet names. As we discussed before, we have logical communication between pairs of layers in this model. Any communication that involves two parties needs two addresses: source address and destination address.

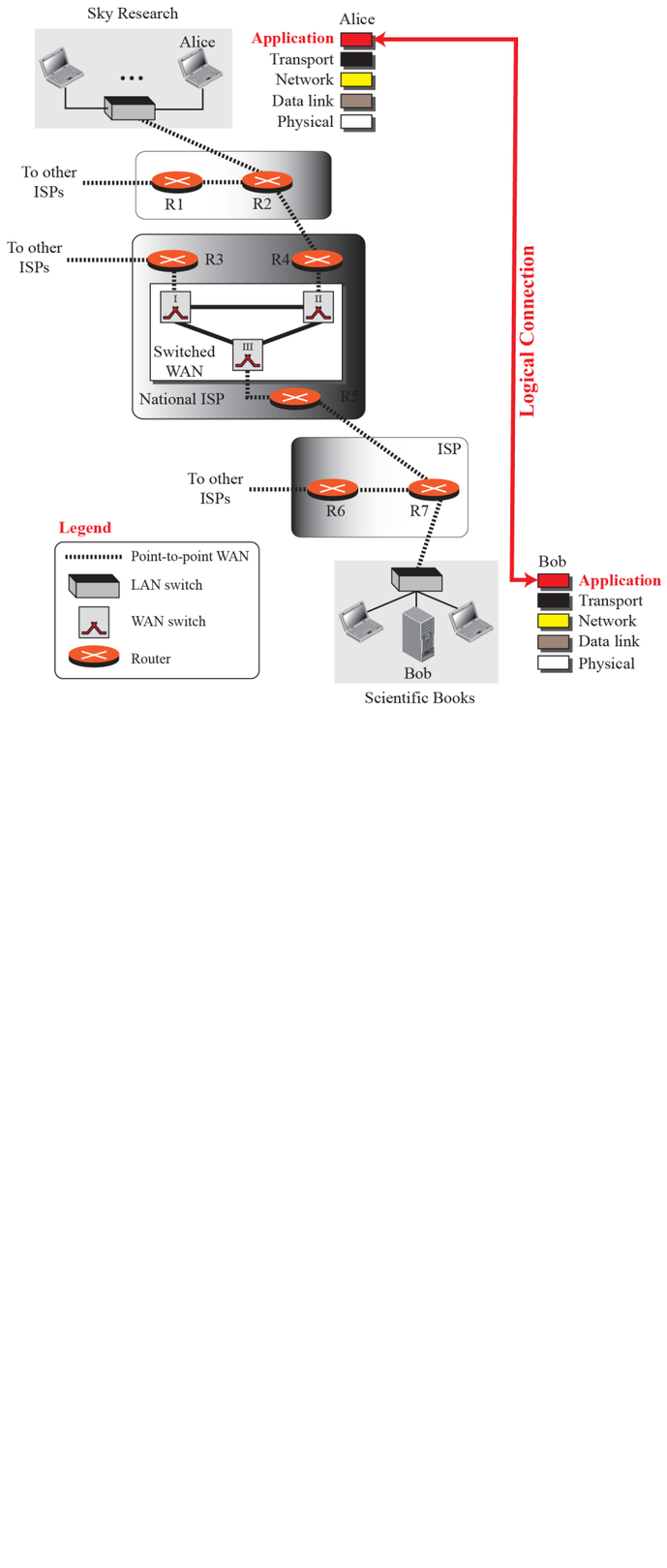
Figure 6.9: Addressing and packets names in TCP/IP



6.2 APPLICATION LAYER

After the brief discussion of networks, Internetworks, and the Internet, we are ready to give some discussion about each layer of the TCP/IP protocol. We start from the fifth layer and move to the first layer. The fifth layer of the TCP/IP protocol is called the application layer. The application layer provides services to the user. Communication is provided using a logical connection.

Figure 6.10: Logical connection at the application layer



Providing services

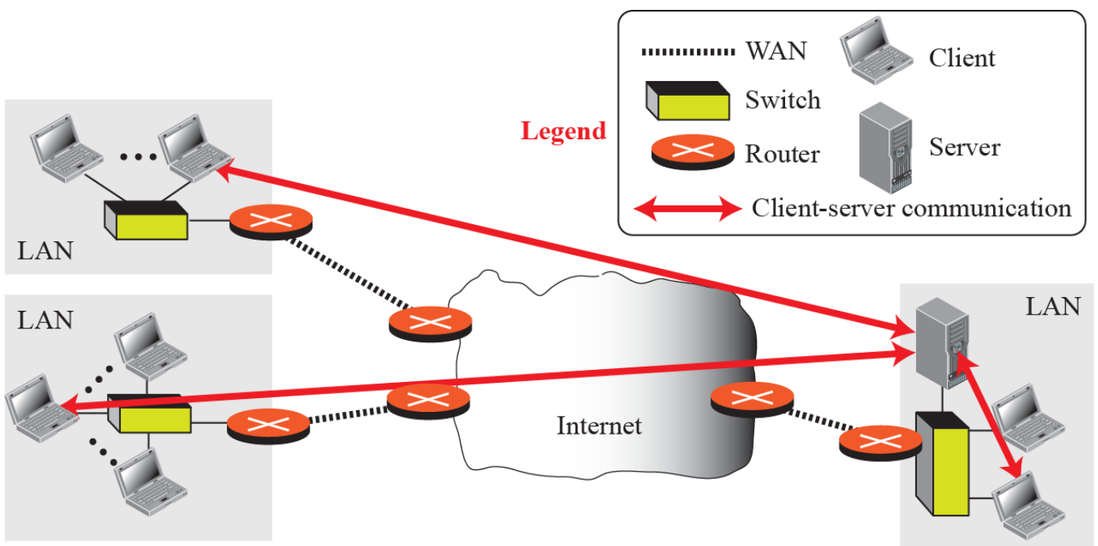
The application layer is somehow different from other layers in that it is the highest layer in the suite. The protocols in this layer do not provide services to any other protocol in the suite; they only receive services from the protocols in the transport layer. This means that protocols can be removed from this layer easily. New protocols can be also added to this layer as long as the new protocol can use the service provided by one of the transport-layer protocols.

Application-layer paradigms

Traditional paradigm: client-server

The traditional paradigm is called the client-server paradigm. It was the most popular paradigm until a few years ago. In this paradigm, the service provider is an application program,called the server process; it runs continuously, waiting for another application program,called the client process, to make a connection through the Internet and ask for service.

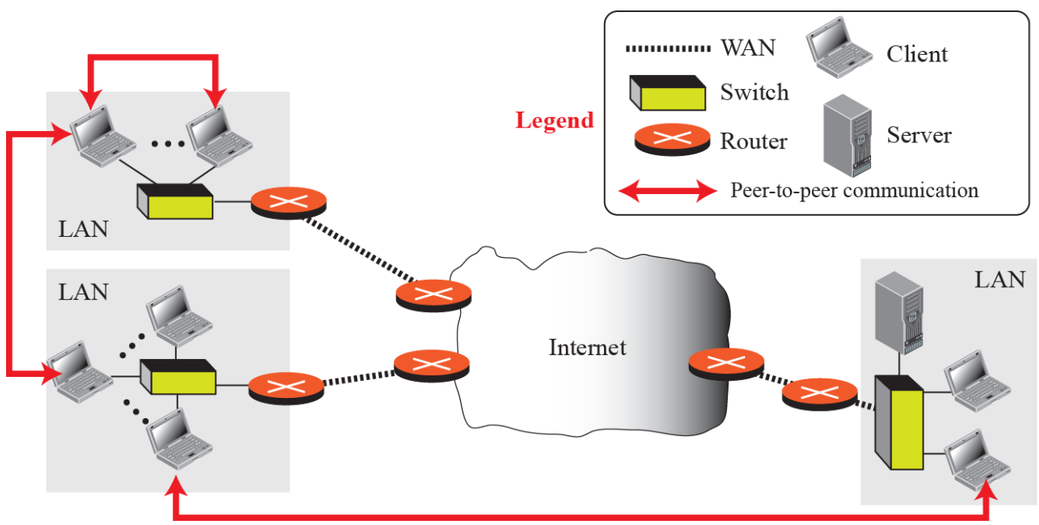
Figure 6.11: **Example of a client-server paradigm**



New paradigm: peer-to-peer

A new paradigm, called the peer-to-peer paradigm (often abbreviated P2P paradigm) has emerged to respond to the needs of some new applications.

Figure 6.12: Example of a peer-to-peer paradigm



Standard client-server applications

During the lifetime of the Internet,several client-server application programs have been developed. We do not have to redefine them, but we need to understand what they do.

World Wide Web and HTTP

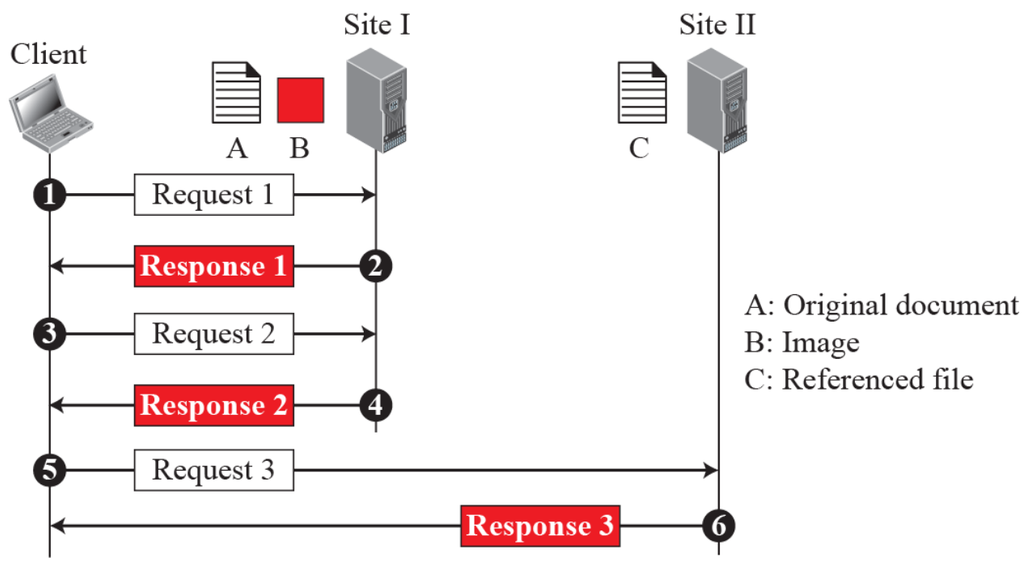
World Wide Web

The WWW today is a distributed client-server service, in which a client using a browser can access a service using a server. However, the service provided is distributed over many locations called sites. Each site holds one or more documents, referred to as web pages.Each web page, however, can contain some links to other web pages in the same or other sites. In other words, a web page can be simple or composite.

Example 6.1

Assume we need to retrieve a scientific document that contains one reference to another text file and one reference to a large image. Figure 6.13 shows the situation.

Figure 6.13: Example 6.1



Web client (browser)

A variety of vendors offer commercial browsers that interpret and display a web page, and all of them use nearly the same architecture. Each browser usually consists of three parts: a controller, client protocols, and interpreters.

Web server

Uniform resource locator (URL)

The first is the type of vehicle to be used to fetch the web page; the last three make up the combination that defines the destination object (web page).

- ❑ Protocol
- ❑ Host.
- ❑ Port.
- ❑ Path.

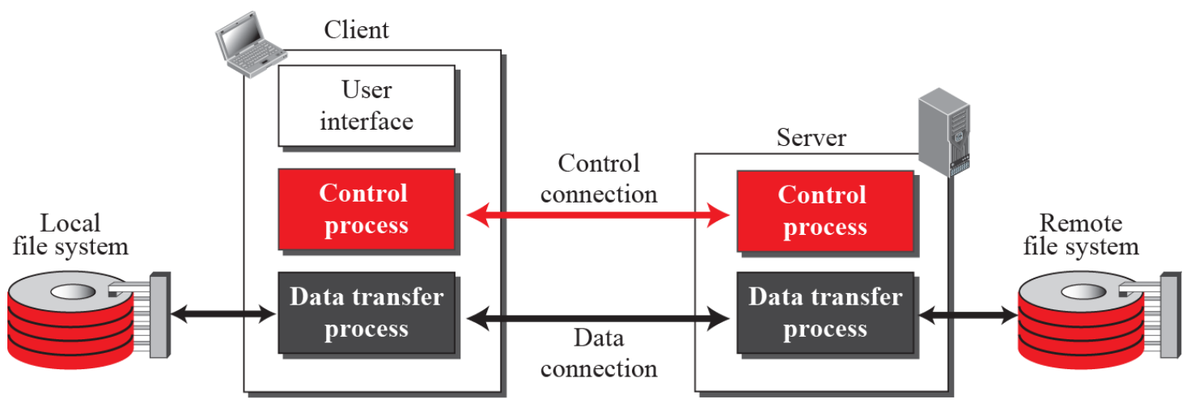
protocol://host/path	**Used most of the time**
protocol://host:port/path	**Used when port number is needed**

HyperText Transfer Protocol (HTTP)

File Transfer Protocol (FTP)

File Transfer Protocol (FTP) is the standard protocol provided by TCP/IP for copying a file from one host to another. Although transferring files from one system to another seems simple and straightforward, some problems must be dealt with first. For example, two systems may use different file name conventions. Two systems may have different ways to represent data. Two systems may have different directory structures. All of these problems have been solved by FTP in a very simple and elegant approach.

Figure 6.14: **FTP**



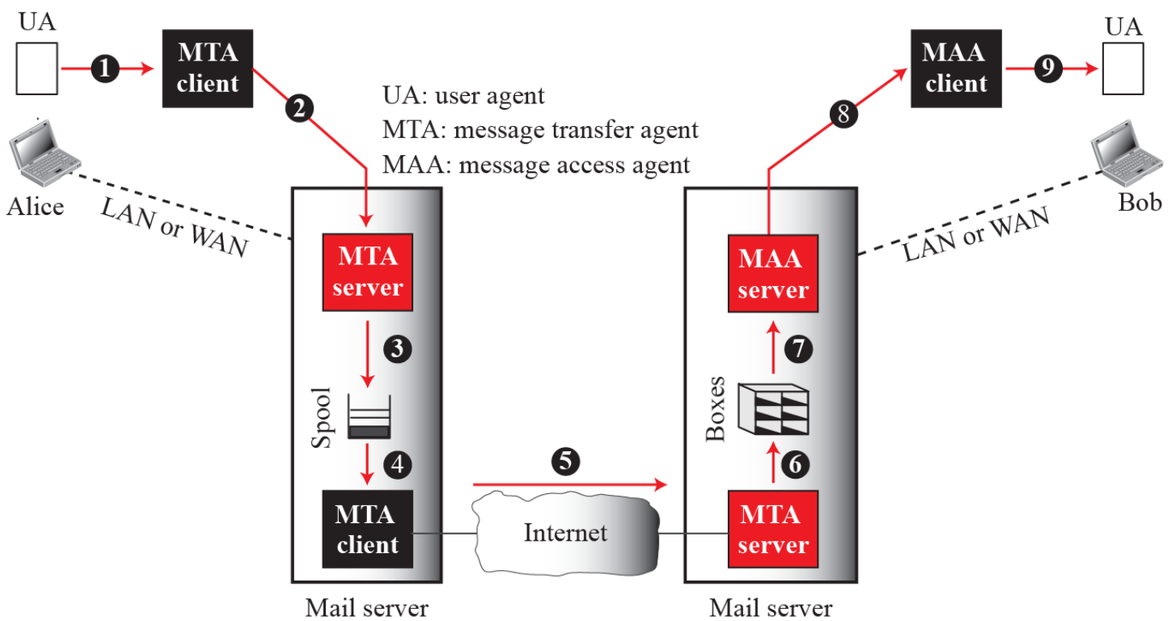
Lifetimes of two connections

Electronic mail

Electronic mail (or email) allows users to exchange messages. The nature of this application,however, is different from other applications discussed so far. In an application such as HTTP or FTP, the server program is running all the time, waiting for a request from a client.When the request arrives, the server provides the service.

To explain the architecture of email, we give a common scenario, as shown in Figure 6.15.
A simple email from Alice to Bob takes nine different steps, as shown in the figure. Alice and Bob use three different agents: a User Agent (UA), a Mail Transfer Agent (MTA), and a Message Access Agent (MAA). When Alice needs to send a message to Bob, she runs a UA program to prepare the message and send it to her mail server. The mail server at her site uses a queue (spool) to store messages waiting to be sent. The message, however, needs to be sent through the Internet from Alice's site to Bob's site using an MTA. Here two message transfer agents are needed: one client and one server.

Figure 6.15: Common scenario (Email)



TELNET

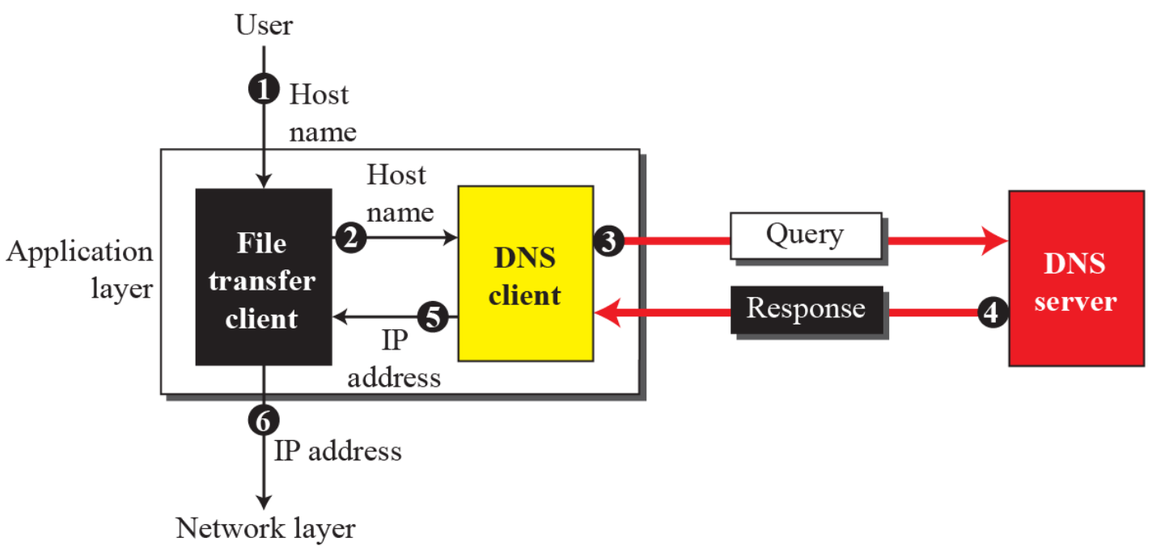
One of the original remote logging protocols is TELNET, which is an abbreviation for TErminaL NETwork. Although TELNET requires a logging name and password, it is vulnerable to hacking because it sends all data including the password in plaintext (not encrypted). A hacker can eavesdrop and obtain the logging name and password. Because of this security issue, the use of TELNET has diminished in favor of another protocol, Secure Shell (SSH), which we describe in the next section.

Secure Shell (SSH)

Domain Name System (DNS)

The following six steps map the host name to an IP address:
1. The user passes the host name to the file transfer client.
2. The file transfer client passes the host name to the DNS client.
3. Each computer, after being booted, knows the address of one DNS server. The DNS client sends a message to a DNS server with a query that gives the file transfer server name using the known IP address of the DNS server.
4. The DNS server responds with the IP address of the desired file transfer server.
5. The DNS client passes the IP address to the file transfer server.
6. The file transfer client now uses the received IP address to access the file transfer server.

Figure 6.16: Purpose of DNS



Name space

The management of the organization need not worry that the prefix chosen for a host is taken by another organization because, even if part of an address is the same, the whole address is different. For example, assume two organizations call one of their computers caesar. The first organization is given a name by the central authority, such as first.com, the second organization is given the name second.com. When each of these organizations adds the name caesar to the name they have already been given, the end result is two distinguishable names: ceasar.first.com and ceasar.second.com.

The generic domains define registered hosts according to their generic behavior. Each node in the tree defines a domain, which is an index to the domain name space database (see Figure 6.17).

Figure 6.17: **Generic domains**

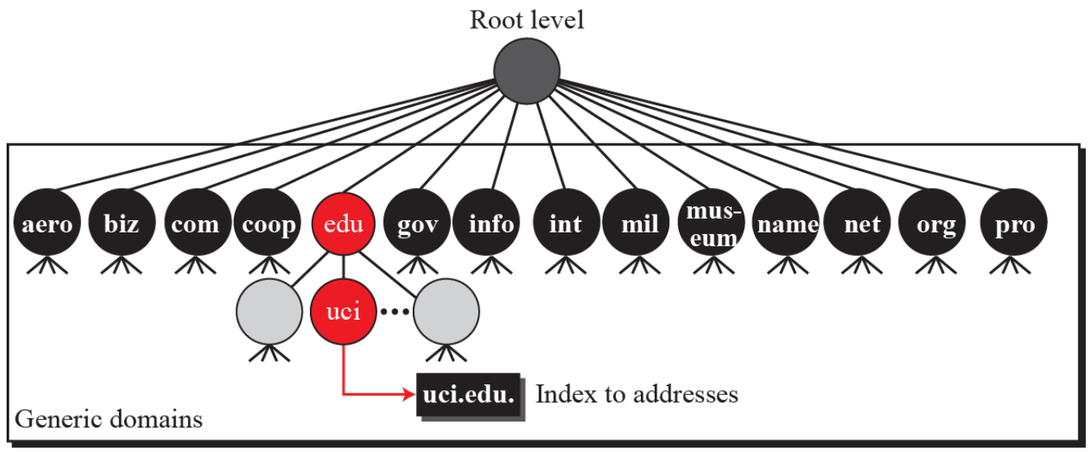
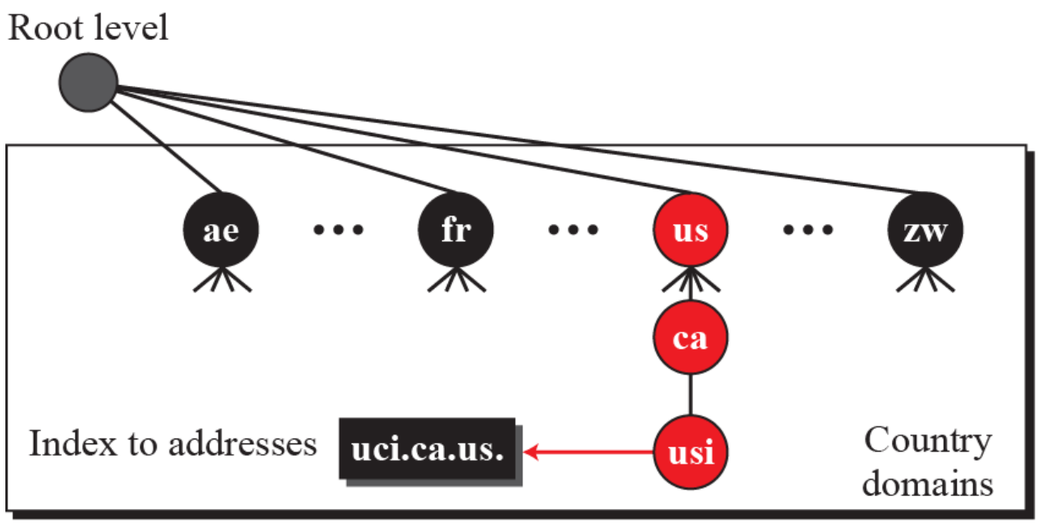


Table 6.1: Generic domain labels

Label	*Description*	*Label*	*Description*
aero	Airlines and aerospace	int	International organizations
biz	Businesses or firms	mil	Military groups
com	Commercial organizations	museum	Museums
coop	Cooperative organizations	name	Personal names (individuals)
edu	Educational institutions	net	Network support centers
gov	Government institutions	org	Nonprofit organizations
info	Information service providers	pro	Professional organizations

Figure 6.18: **Country domains**



Peer-to-peer paradigm

We discussed the client-server paradigm early in the chapter. The first instance of peer-to-peer file sharing goes back to December 1987 when Wayne Bell created WWIVnet, the network component of WWIV (World War Four) bulletin board software. In July 1999, Ian Clarke designed Freenet, a decentralized, censorship-resistant distributed data store, aimed to provide freedom of speech through a peer-to-peer network with strong protection of anonymity.

Centralized networks

The peer then provides its IP address and a list of files it has to share. To avoid system collapse, Napster used several servers for this purpose, but we show only one in Figure 6.18.

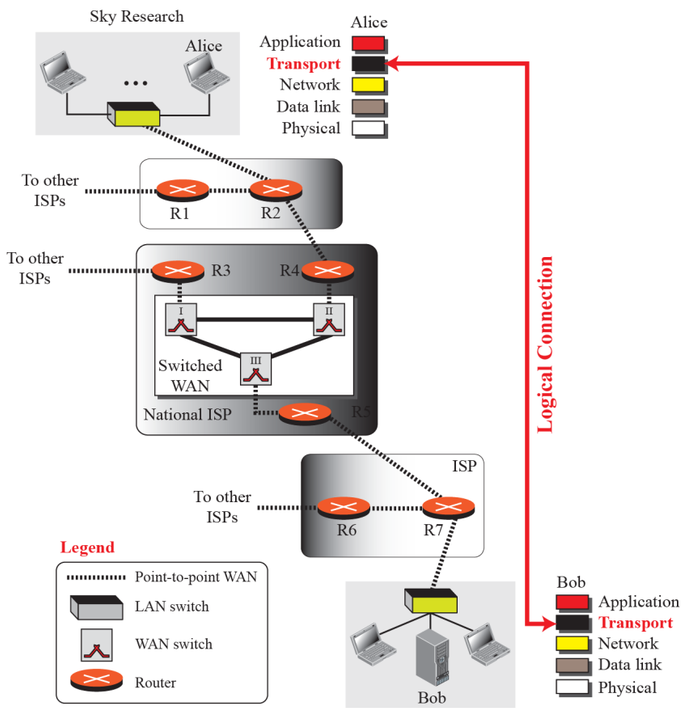
Decentralized network

A structured network uses a predefined set of rules to link nodes so that a query can be effectively and efficiently resolved. The most common technique used for this purpose is the Distributed Hash Table (DHT).

6.3 TRANSPORT LAYER

The transport layer in the TCP/IP suite is located between the application layer and the network layer. It provides services to the application layer and receives services from the network layer. The transport layer acts as a liaison between a client program and a server program.

Figure 6.19: Logical connection at the transport layer

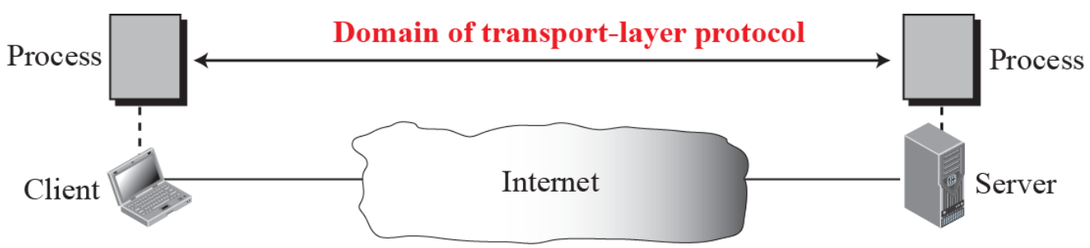


Transport-layer services

Process-to-process communication

The first duty of a transport-layer protocol is to provide process-to-process communication.A process is an application-layer entity (running program) that uses the services of the transport layer.

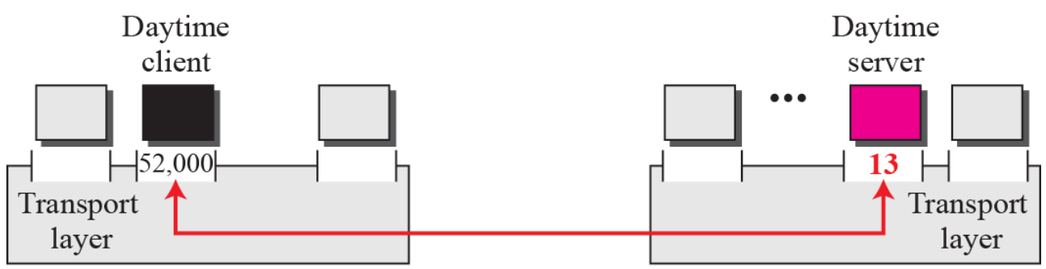
Figure 6.20: Network layer versus transport layer



Addressing: port numbers

Although there are a few ways to achieve process-to-process communication, the most common is through the client-server paradigm (discussed before). A process on the local host, called a client, needs services from a process usually on the remote host, called a server. Both processes (client and server) have the same name.
The client program defines itself with a port number, called the ephemeral port Number.The word ephemeral means short-lived and is used because the life of a client is normally short.

Figure 6.21: **Port numbers**



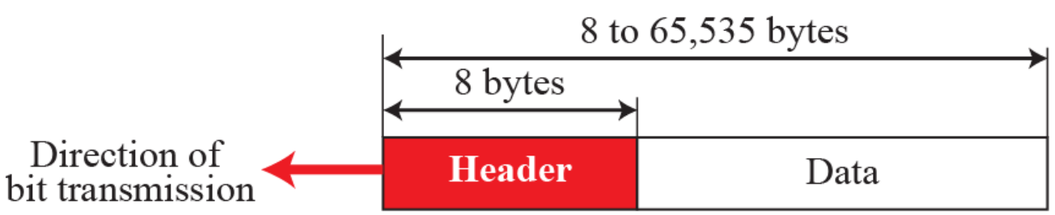
Transport-layer protocols

User Datagram Protocol (UDP)

User datagrams

UDP packets, called user datagrams, have a fixed-size header of 8 byte. Figure 6.22 shows the format of a user datagram. However, the total length needs to be less because a UDP user datagram is stored in an IP datagram with the total length of 65,535 bytes.

Figure 6.22: **User datagram packet format**

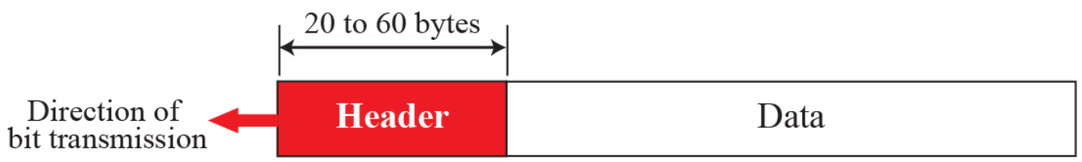


Transmission Control Protocol (TCP)

Segments

At the transport layer, TCP groups a number of bytes together into a packet called a segment. TCP adds a header to each segment (for control purposes) and delivers the segment to the network layer for transmission. The segments are encapsulated in an IP datagram and transmitted as shown in Figure 6.23.

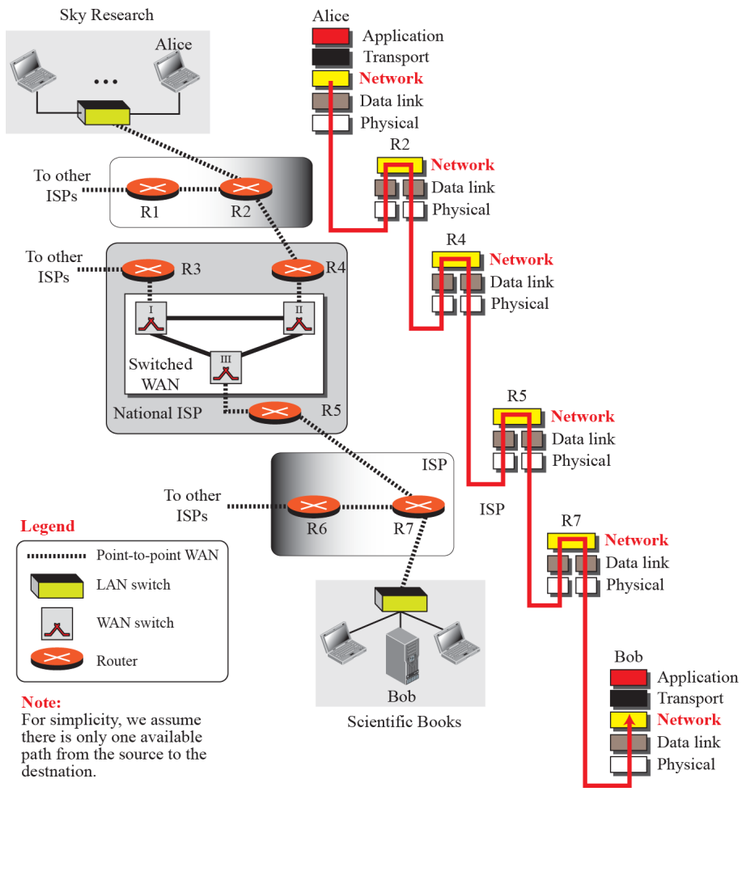
Figure 6.23: **TCP segments**



6.4 NETWORK LAYER

The network layer in the TCP/IP protocol suite is responsible for the host-to-host delivery of messages. The network layer accepts a packet from a transport layer, encapsulates the packet in a datagram, and delivers the packet to the data-link layer. At the destination host , the datagram is de-capsulated, the packet is extracted and delivered to the corresponding transport layer.

Figure 6.24: Communication at the network layer



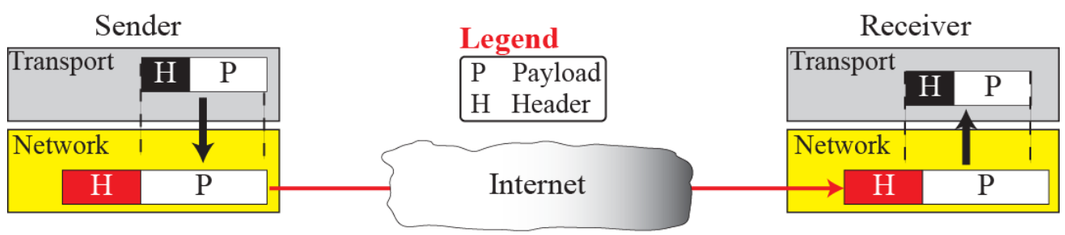
Services Provided by network layer

Packetizing

The first duty of the network layer is definitely packetizing: encapsulating the payload (data received from upper layer) in a network-layer packet at the source and decapsulating the payload from the network-layer packet at the destination.
This is done in three steps as shown in Figure 6.25.

Figure 6.25: Packetizing at the network layer

Note:
A transport-layer payload may become several network-layer packets



Packet delivery

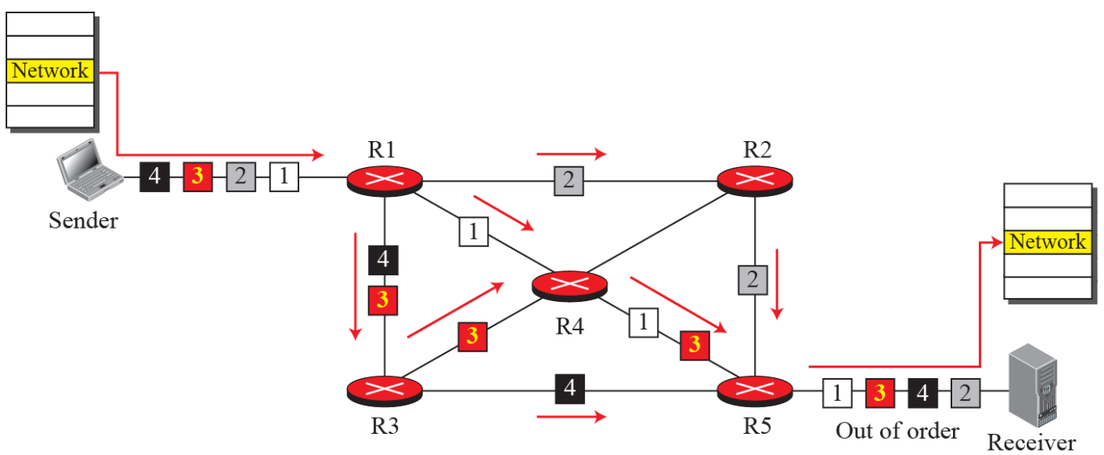
Unreliable delivery

The delivery of packets at the network layer is unreliable. This means that the packets can be corrupted, lost, duplicated. In other words, the network layer provides a best-effort delivery, but there is no guarantee that a packet reaches the destination as we expect.

Connectionless delivery

The delivery at the network layer is also connectionless, but the word connectionless here does not mean that there is no physical connection between the sender and receiver.

Figure 6.26: **Packets travelling different paths**



Routing

Another duty of the network layer, which is as important as the others, is routing. The network layer is responsible for routing the packet from its source to the destination. A physical network is a combination of networks (LANs and WANs) and routers that connect them.

Network-layer protocols

Although there are several protocols at the network layer, the main protocol is called the Internet Protocol (IP).

Internet Protocol Version 4 (IPv4)

IPv4 addressing

The identifier used in the IPv4 layer of the TCP/IP protocol suite to identify the connection of each device to the Internet is called the Internet address or IP address.
There are three common notations to show an IPv4 address: binary notation (base 2), dotted-decimal notation (base 256), and hexadecimal notation (base 16). In binary notation,an IPv4 address is displayed as 32 bits.

Figure 6.27: **Address notation**

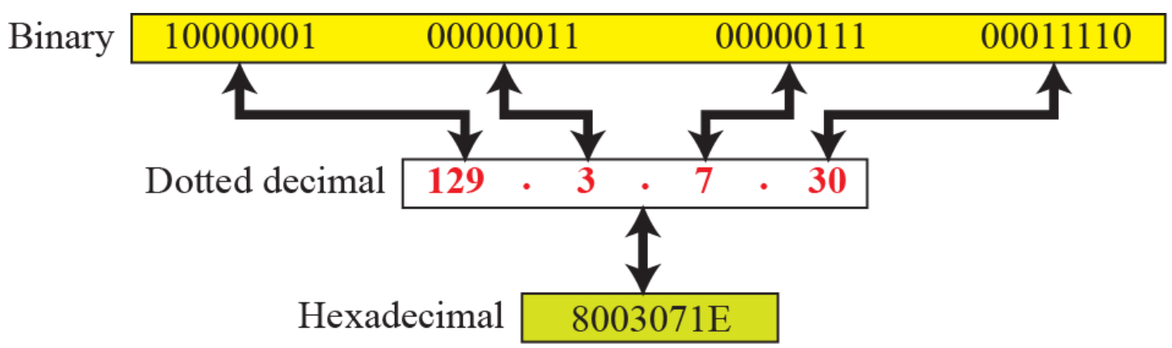


Figure 6.28: **Hierarchy in IPv4 addressing**

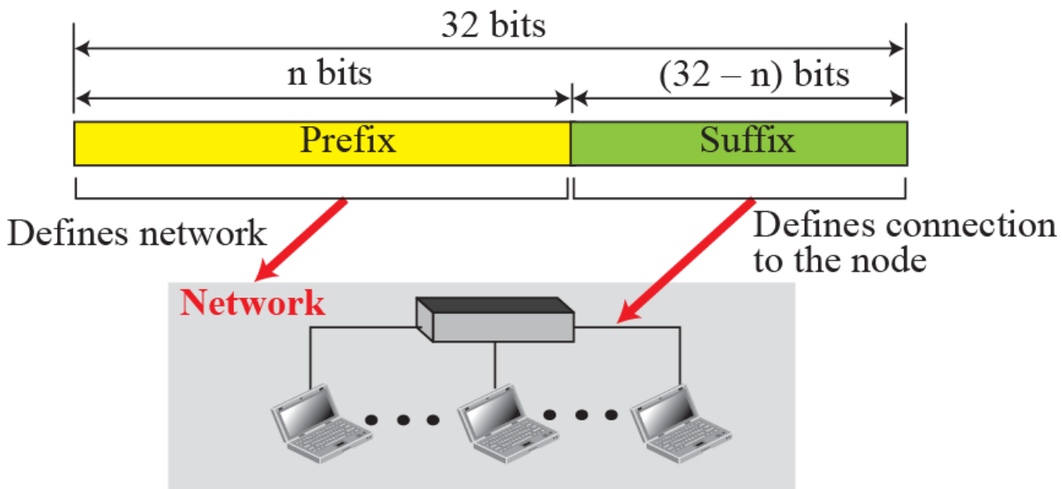
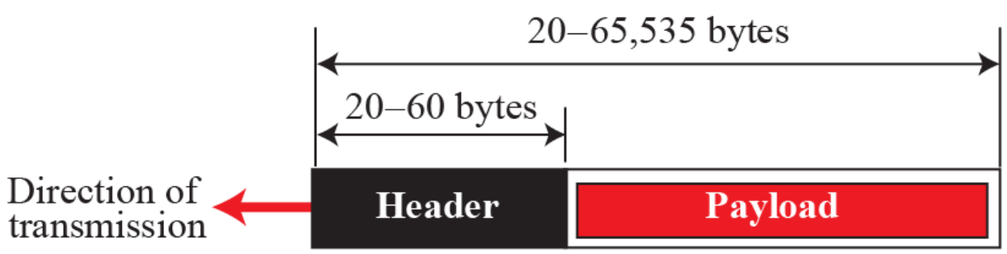


Figure 6.29: **IPv4 datagram**



Internet Protocol Version 6 (IPv6)

The new version, which is called Internet Protocol version 6 (IPv6) or IP new generation (IPng) was a proposal to augment the address space of IPv4 and at the same time redesign the format of the IP packet and revise some auxiliary protocols.

Figure 6.30: IPv6 address notations

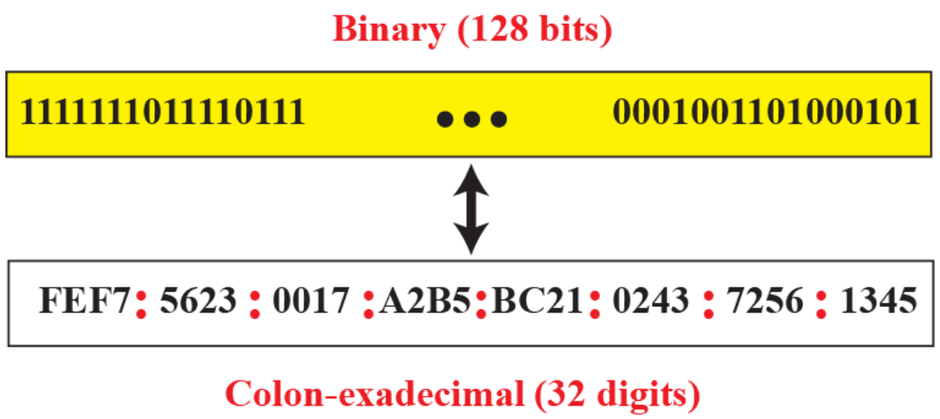


Figure 6.31: Hierarchy in IPv6 addressing

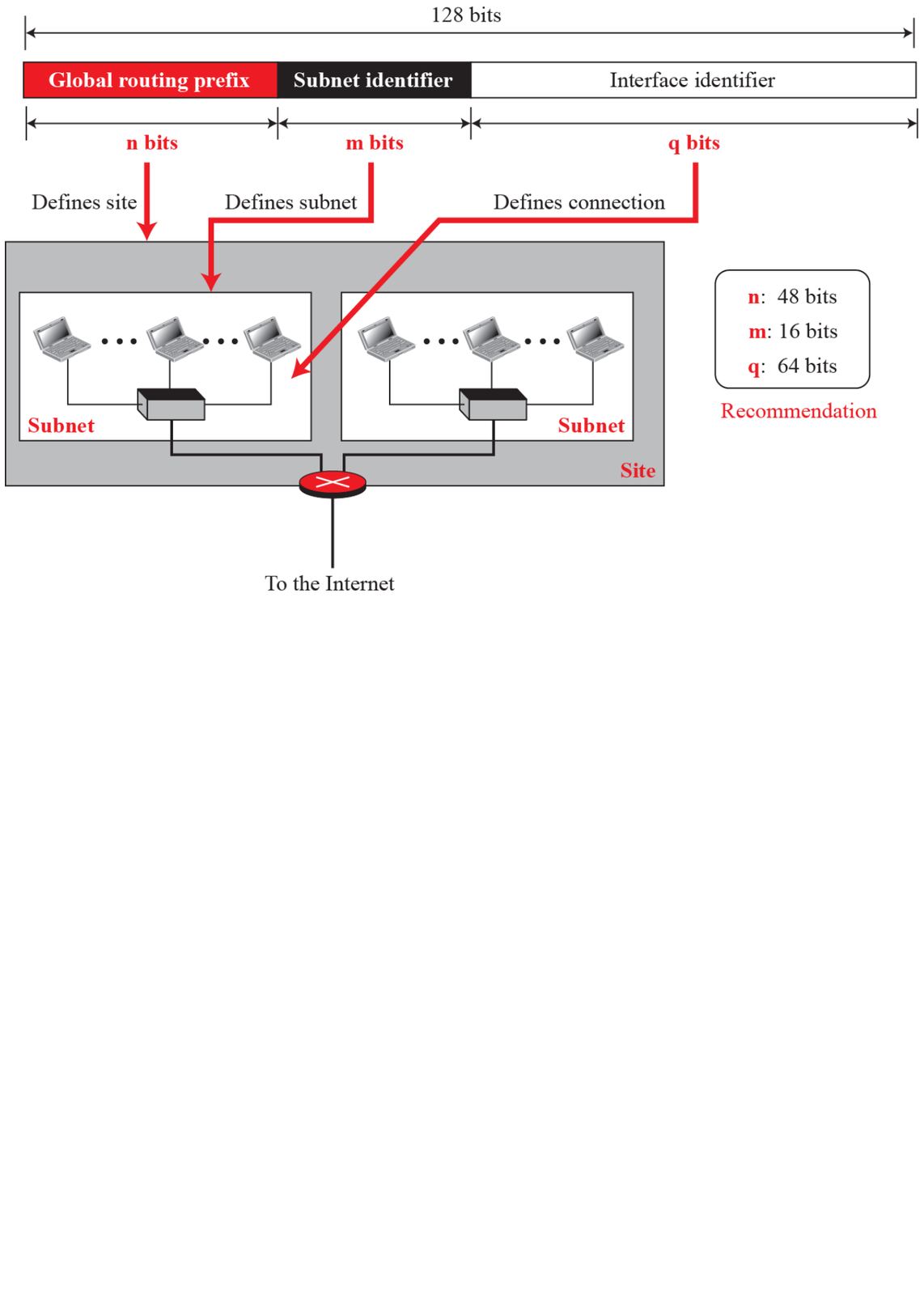
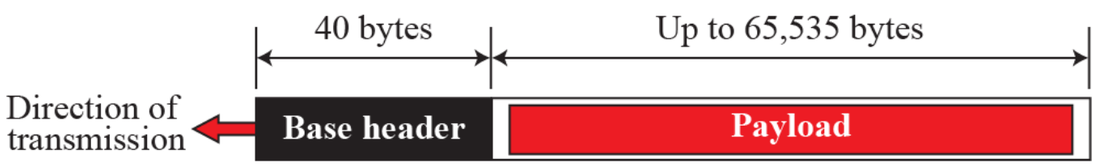


Figure 6.32: **IPv6 datagram**



6.5 DATA-LINK LAYER

The TCP/IP suite does not define any protocol in the data-link layer. This layer is the territories of networks that when connected make up the Internet. These networks, wired or wireless, receive services and provide services to the network layer. This may give us a clue that there are several standard protocols in the market today.

Figure 6.33: Communication at the data-link layer

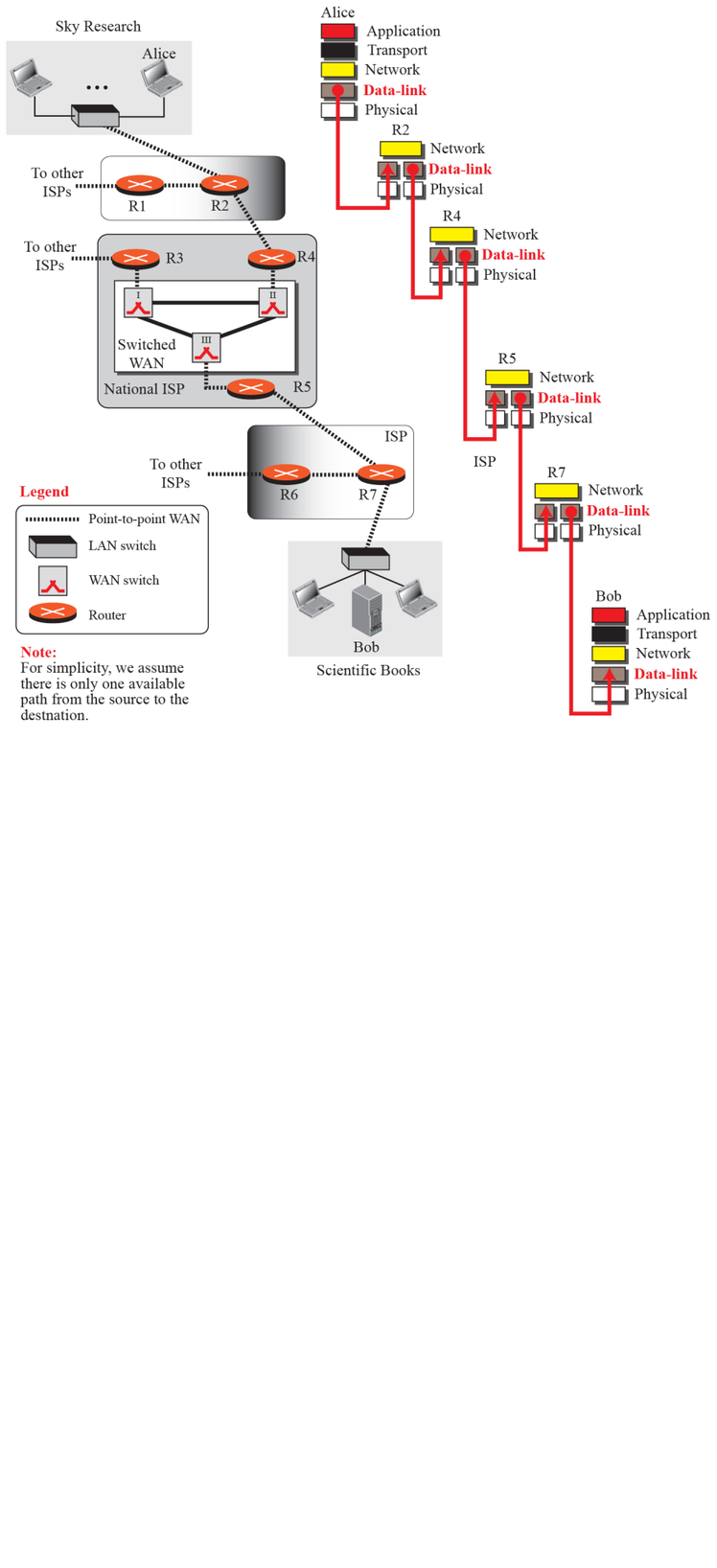
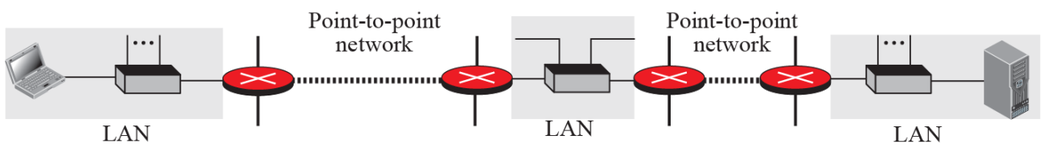


Figure 6.34: Nodes and links



a. A small part of the Internet

b. Nodes and links

Local area networks (LANs)

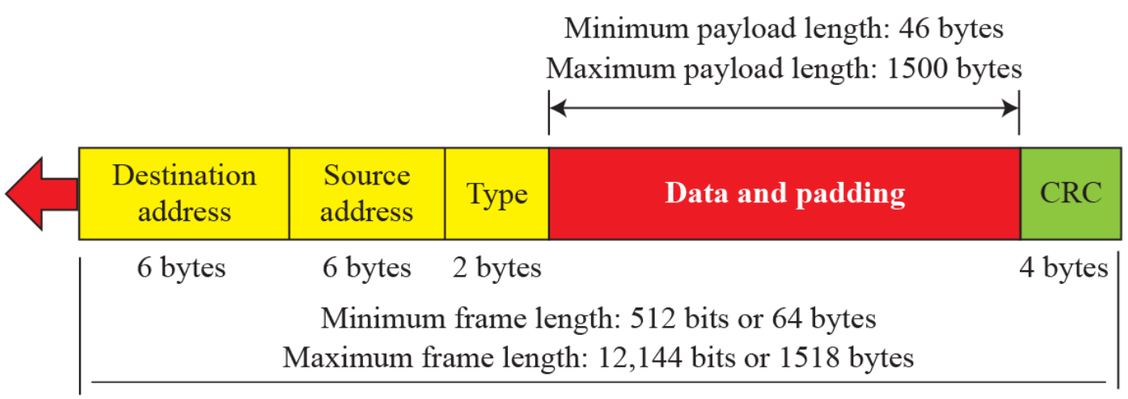
LANs can be wired or wireless networks. In the first group, the stations in the LANs are connected by wired; in the second group the stations are logically connected by air. We discuss each group separately.

Wired LANS: Ethernet

The Ethernet LAN was developed in the 1970s by Robert Metcalfe and David Boggs. Since then, it has gone through four generations: Standard Ethernet (10 Mbps), Fast Ethernet (100 Mbps), Gigabit Ethernet (1 Gbps), and 10 Gigabit Ethernet (10 Gbps).The data rate, the speed in which bits are sent in each second, has been increased ten times in each generation.

Standard Ethernet

Figure 6.35: **Ethernet frame**



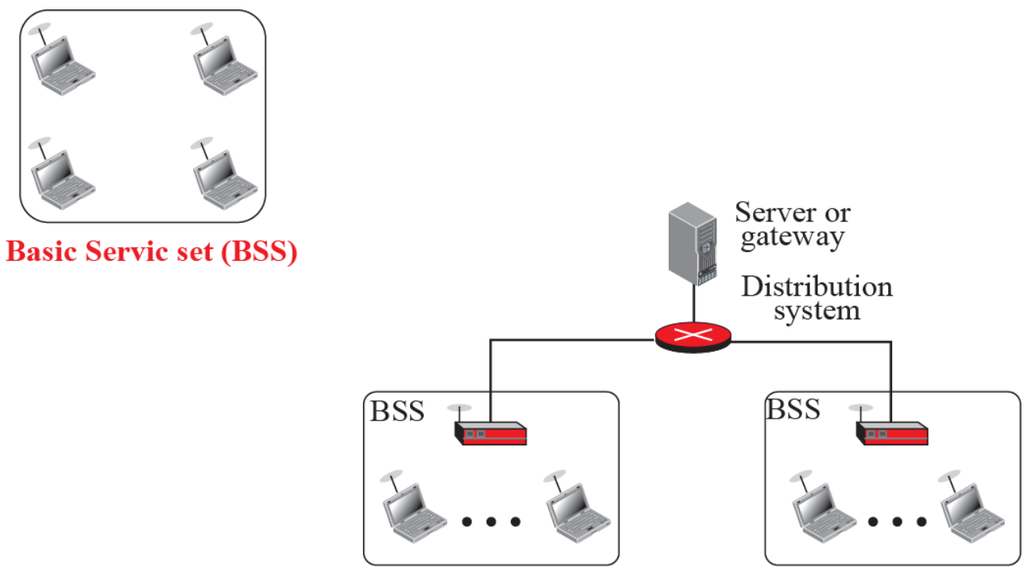
Fast Ethernet (100 Mbps)

Gigabit Ethernet

Wireless LANs

Wireless communication is one of the fastest-growing technologies. The demand for connecting devices without the use of cables is increasing everywhere. Wireless LANs can be found on college campuses, in office buildings, and in many public areas.
When hosts in a wireless LAN communicate with each other, they are sharing the same medium (multiple access). Two technology have been in this area: Wireless Ethernet and Bluetooth.

Figure 6.36: BSSs and ESSs



Bluetooth is a wireless LAN technology designed to connect devices of different functions such as telephones, notebooks, computers (desktop and laptop), cameras, printers, and even coffee makers when they are at a short distance from each other. A Bluetooth LAN is an ad hoc network, which means that the network is formed spontaneously; the devices, sometimes called gadgets, find each other and make a network called a piconet. A Bluetooth LAN can even be connected to the Internet if one of the gadgets has this capability. A Bluetooth LAN, by nature, cannot be large. If there are many gadgets that try to connect, there is chaos.

Wide area networks (WANs)

Wired WANs

Dial-up service

The term modem is a composite word that refers to the two functional entities that make up the device: a signal modulator and a signal demodulator. A modulator creates signal from data. A demodulator recovers the data from the modulated signal. Figure 6.37 shows the idea behind a modem.

Figure 6.37: **Dial-up network to provide Internet access**

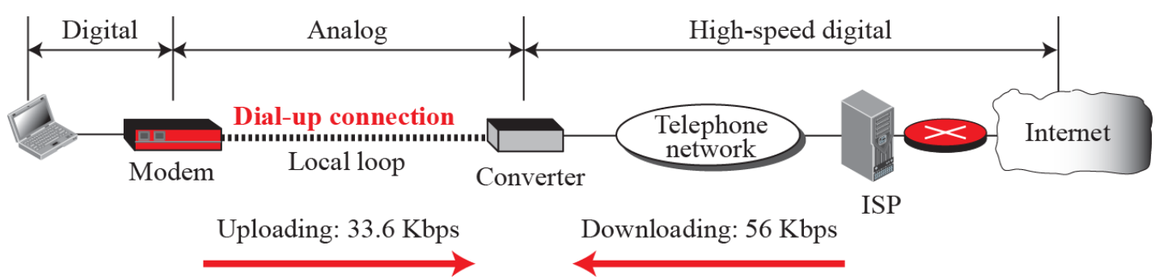


Figure 6.38: ASDL point-to-point network

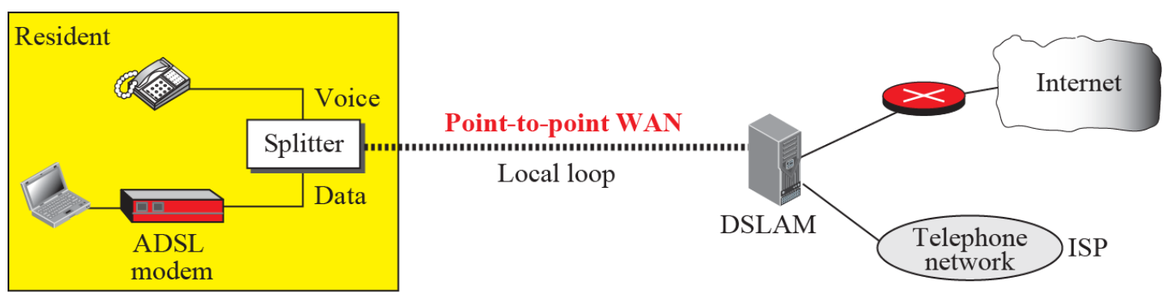


Figure 6.39: Cable service

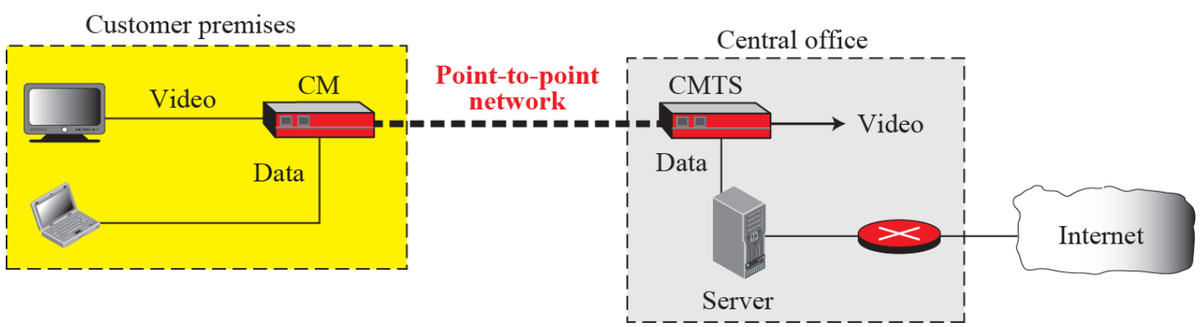
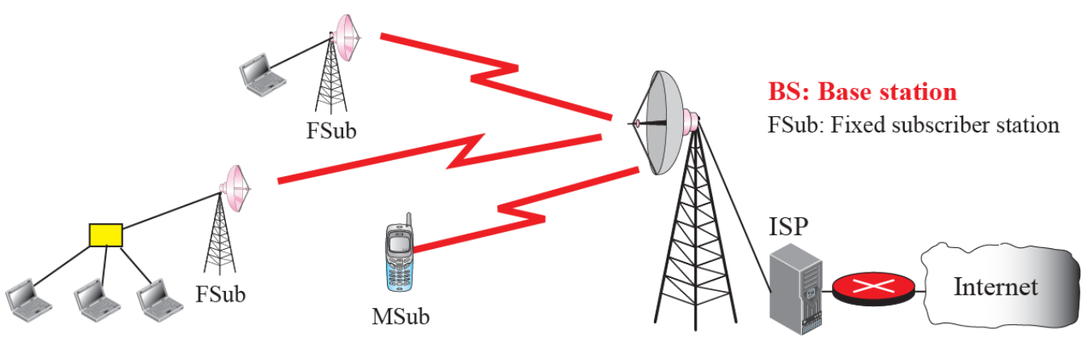


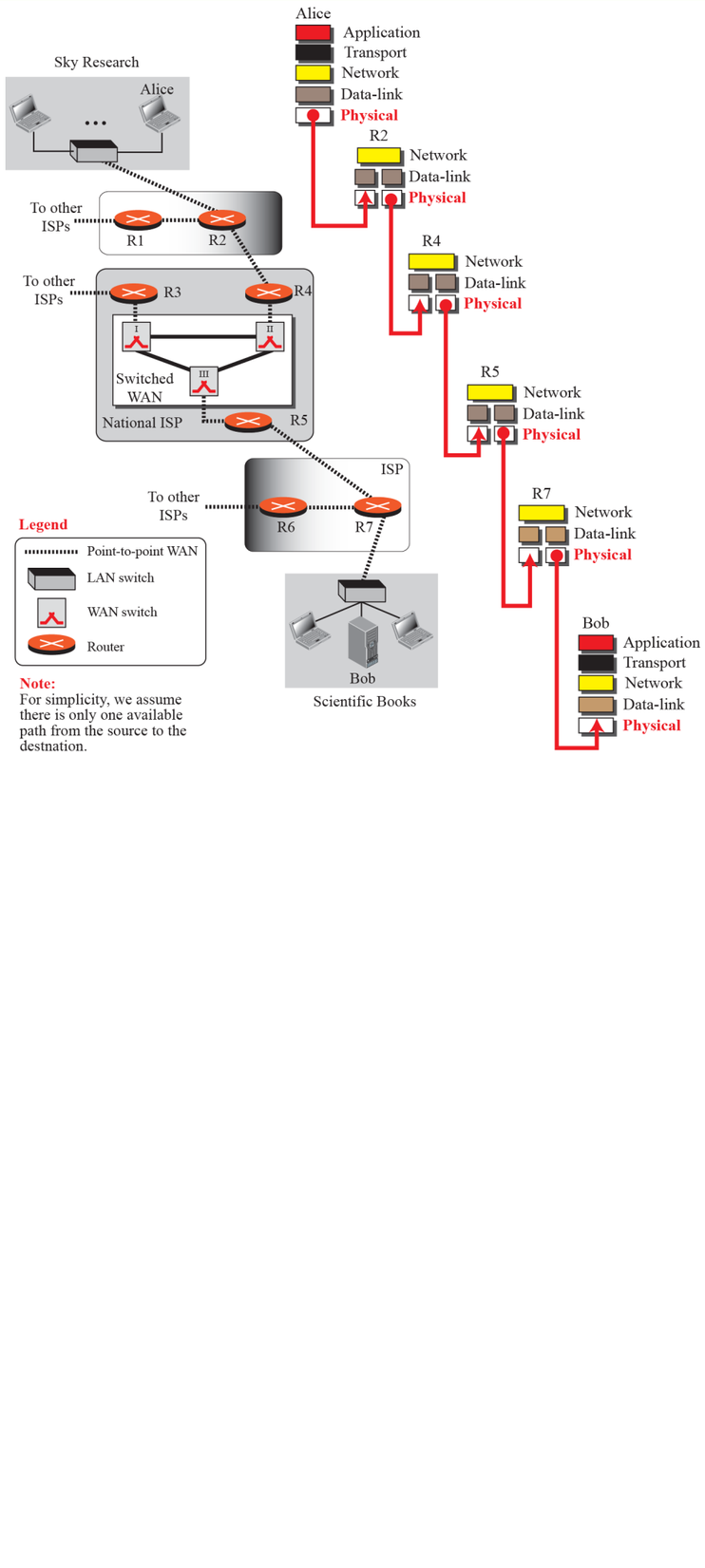
Figure 6.40: WiMax



6.6 PHYSICAL LAYER

Our discussion of the TCP/IP protocol suite would be incomplete without the discussion of the physical layer. The role of the physical layer is to transfer the bits received from the data-link layer and convert them to electromagnetic signals for transmission. After the bits are converted to signals, the signals are delivered to the transmission media.

Figure 6.41: Communication at the physical layer

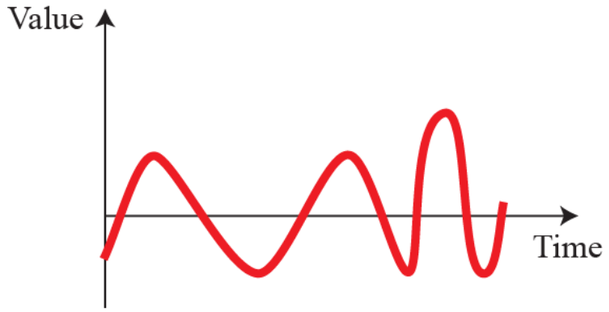


Data and signals

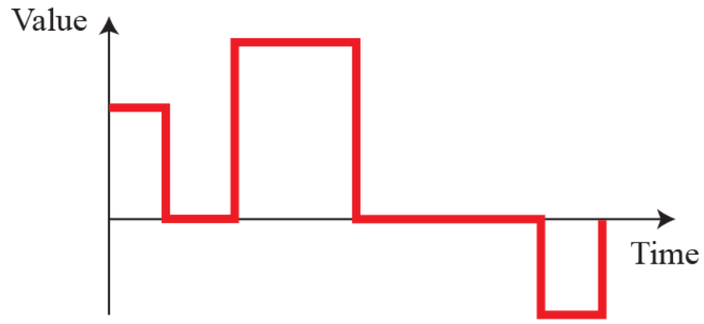
Analog and digital

Like the data they represent, signals can be either analog or digital. An analog signal has infinitely many levels of intensity over a period of time. As the wave moves from value A to value B, it passes through and includes an infinite number of values along its path. A digital signal, on the other hand, can have only a limited number of defined values.

Figure 6.42: **Comparison of analog and digital signals**



a. Analog signal



b. Digital signal

Figure 6.43: **Digital to digital conversion**

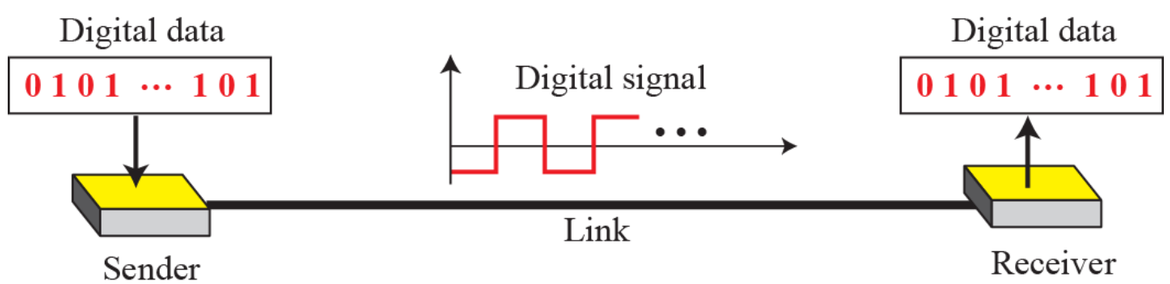
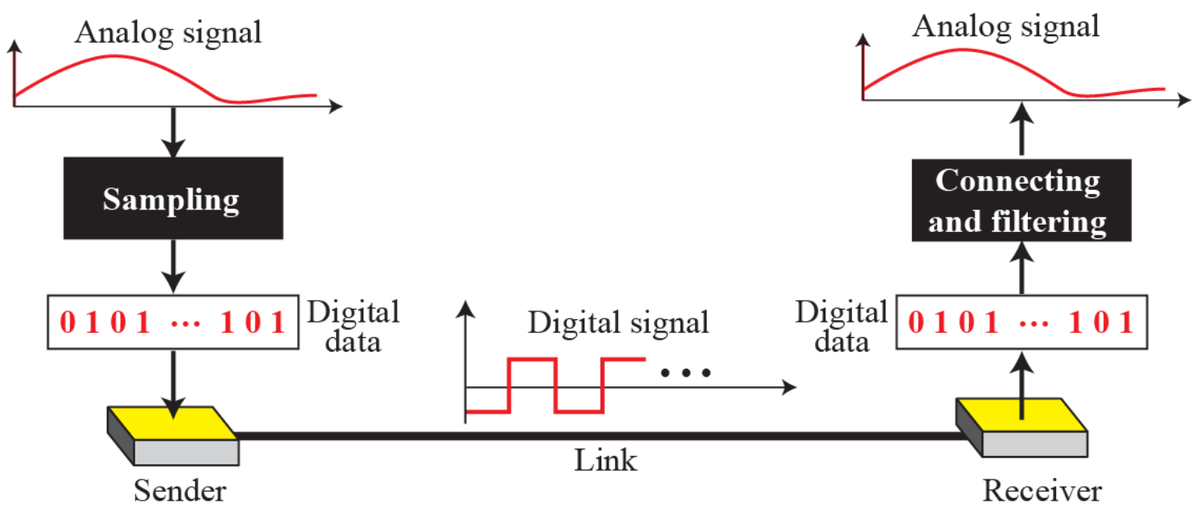


Figure 6.44: Analog to digital conversion



Analog transmission

Digital-to-analog conversion

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data. Figure 6.45 shows the relationship between the digital information, the digital-to-analog conversion process, and the resultant analog signal.

Figure 6.45: **Digital-to-analog conversion**

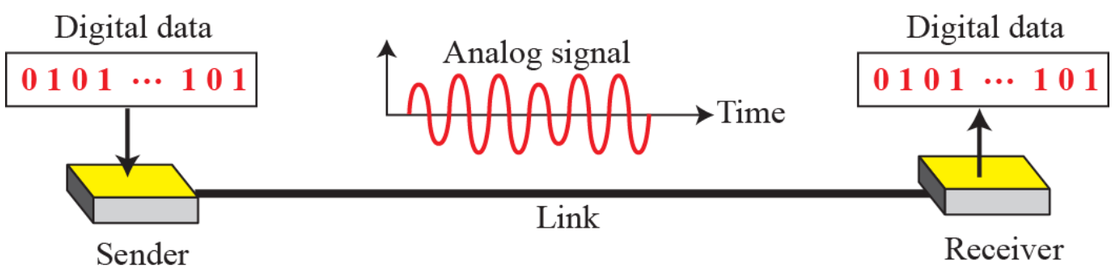
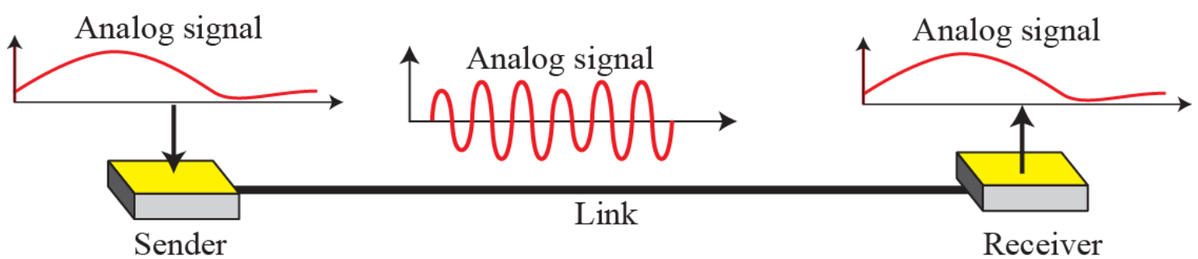


Figure 6.46: **Analog-to-analog conversion**



6.7 TRANSMISSION MEDIA

Electrical signals created at the physical layer need transmission media to go from point to another. Transmission media are actually located below the physical layer and are directly controlled by the physical layer. We could say that transmission media belong to layer zero.

Figure 6.47: **Transmission media and physical layer**

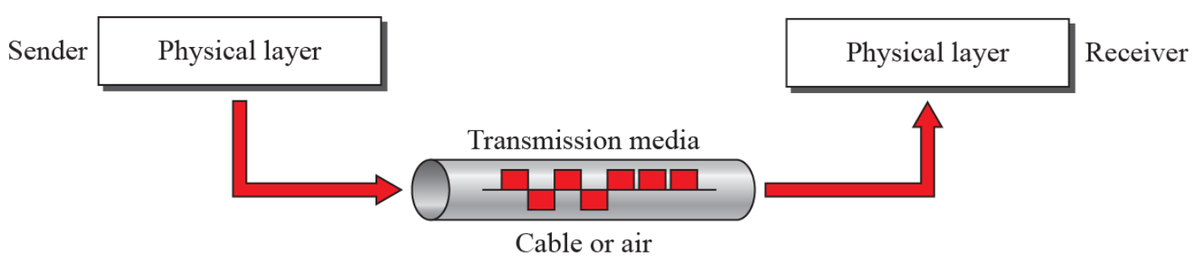
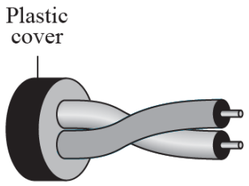
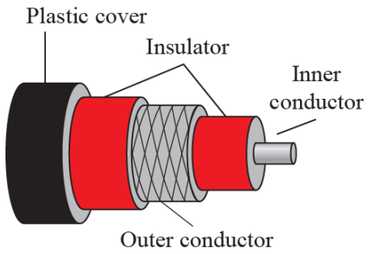


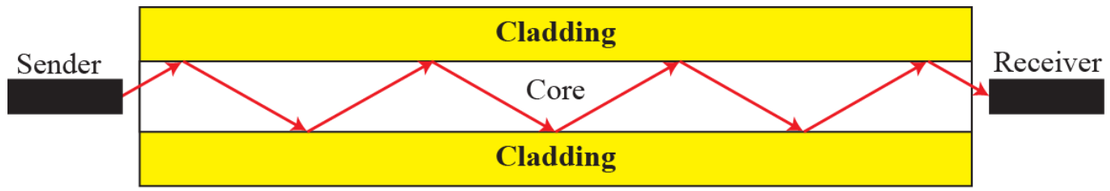
Figure 6.48: Guided media



a. Twisted pair



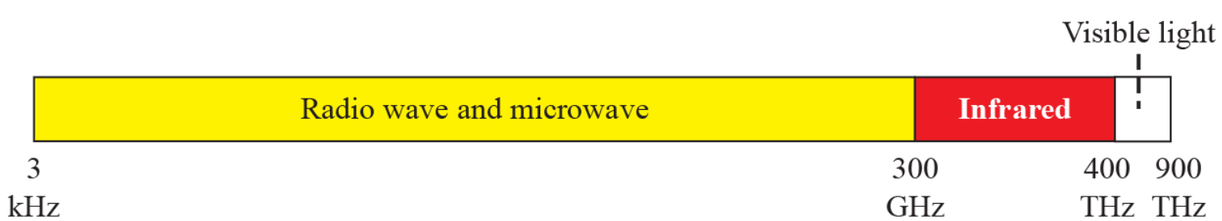
b. Coaxial



c. Fiber optic

Figure 6.49 shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication.

Figure 6.49: Electromagnetic spectrum



Radio waves

Microwaves

Infrared

Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls.