Module 1: Introduction to Networks

1.1 Introduction

Each of the past three centuries was dominated by a single new technology. The 18th century was the era of the great mechanical systems accompanying the Industrial Revolution. The 19th century was the age of the steam engine. During the 20th century, the key technology was information gathering, processing, and distribution. Among other developments, we saw the installation of worldwide telephone networks, the invention of radio and television, the birth and unprecedented growth of the computer industry, the launching of communication satellites, and, of course, the Internet.

As a result of rapid technological progress, these areas are rapidly converging in the 21st century and the differences between collecting, transporting, storing, and processing information are quickly disappearing. Two computers are said to be interconnected if they are able to exchange information. The connection need not be via a copper wire; fiber optics, microwaves, infrared, and communication satellites can also be used. Networks come in many sizes, shapes and forms.

Computer network refers to interconnected computing devices that can exchange data and share resources with each other. These networked devices use a system of rules, called communications protocols, to transmit information over physical or wireless technologies.

Computer networking refers to connected computing devices (such as laptops, desktops, servers, Smartphone's, and tablets) and an ever-expanding array of IoT devices (such as cameras, door locks, doorbells, refrigerators, audio/visual systems, thermostats, and various sensors) that communicate with one another.

Distributed system is a collection of independent computers appears to its users as a single coherent system. A distributed system is simply any environment where multiple computers or devices are working on a variety of tasks and components, all spread across a network. Components within distributed systems split up the work, coordinating efforts to complete a given job more efficiently than if only a single device ran it.

1.2 Network Hardware

There is no generally accepted taxonomy into which all computer networks fit, but two dimensions stand out as important: *transmission technology* and *scale.*

There are two types of transmission technology that are in widespread use: *broadcast links* and *point-to-point links.*

- **Point-to-point links** connect individual pairs of machines. To go from the source to the destination on a network made up of point-to-point links, short messages, called packets in certain contexts, may have to first visit one or more intermediate machines. Often multiple routes, of different lengths, are possible, so finding good ones is important in point-to-point networks. Point-to-point transmission with exactly one sender and exactly one receiver is sometimes called **unicasting.**
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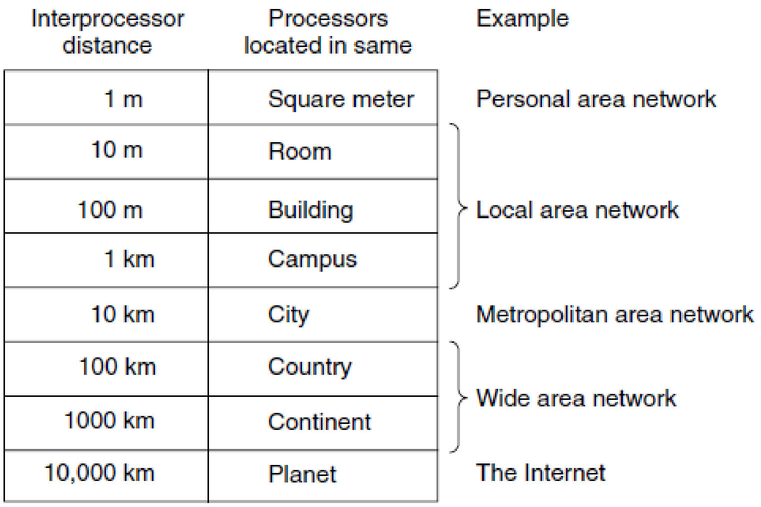
- **In Broadcast network** the communication channel is shared by all the machines on the network; packets sent by any machine are received by all the others. An address field within each packet specifies the intended recipient. A wireless network is a common example of a broadcast link. Some broadcast systems also support transmission to a subset of the machines, which known as **multicasting.**

An alternative criterion for classifying networks is by **scale.** Distance is important as a classification metric because different technologies are used at different scales.
In Fig. 1-1 we classify multiple processor systems by their rough physical size.



Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

Figure 1-1. Classification of interconnected processors by scale.

1.2.1 Personal Area Networks

PANs (**Personal Area Networks**) let devices communicate over the range of a person. A common example is a wireless network that connects a computer with its peripherals. Almost every computer has an attached monitor, keyboard, mouse, and printer. Many new users have a hard time finding the right cables and plugging them into the right little holes (even though they are usually color coded) that most computer vendors offer the option of sending a technician to the user's home to do it. To help these users, some companies got together to design a short-range wireless network called **Bluetooth** to connect these components without wires.

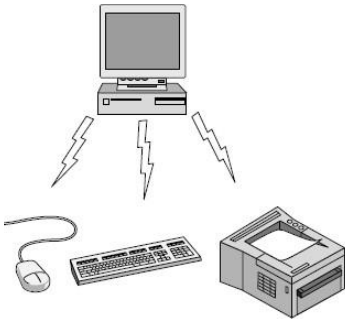


Figure 1-2. Bluetooth PAN configuration.

In the simplest form, Bluetooth networks use the master-slave paradigm of Fig. 1-2. The system unit (the PC) is normally the master, talking to the mouse, keyboard, etc., as slaves. The master tells the slaves what addresses to use, when they can broadcast, how long they can transmit, what frequencies they can use, and so on.

1.2.2 Local Area Networks

A LAN is a privately owned network that operates within and nearby a single building like a home, office or factory. LANs are widely used to connect personal computers and consumer electronics to let them share resources (e.g., printers) and exchange information. When LANs are used by companies, they are called **enterprise networks**.

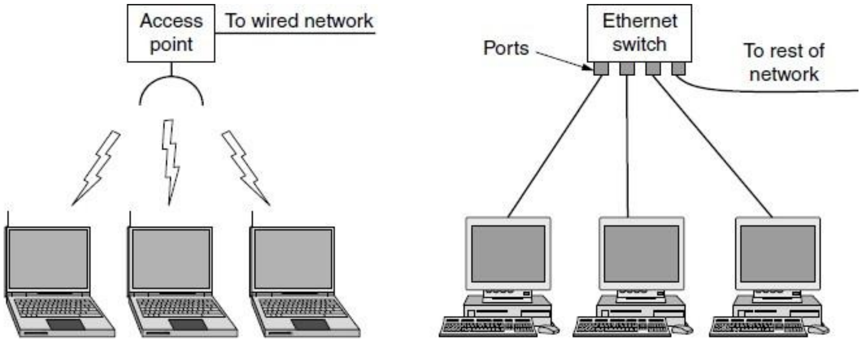


Figure 1-3. Wireless and wired LANs. (a) 802.11. (b) Switched Ethernet.

Wireless LANs are very popular these days, In most cases, each computer talks to a device in the ceiling as shown in Fig. 1-3(a). This device, called an AP (Access Point), wireless router, or base station, relays packets between the wireless computers and also between them and the Internet. There is a standard for wireless LANs called IEEE 802.11, popularly known as WiFi, It runs at speeds anywhere from 11 to hundreds of Mbps.

Wired LANs use a range of different transmission technologies. Most of them use copper wires, but some use optical fiber. Typically, wired LANs run at speeds of 100 Mbps to 1 Gbps, have low delay (microseconds or nanoseconds), and make very few errors. The topology of many wired LANs is built from point-to-point links. IEEE 802.3, popularly called **Ethernet.**

1.2.3 Metropolitan Area Networks

A **MAN** (**Metropolitan Area Network**) covers a city. The best-known examples of MANs are the cable television networks available in many cities.

These systems grew from earlier community antenna systems used in areas with poor over-the-air television reception. In those early systems, a large antenna was placed on top of a nearby hill and a signal was then piped to the subscribers' houses.

Recent developments in highspeed wireless Internet access have resulted in another MAN, which has been standardized as IEEE 802.16 and is popularly known as **WiMAX**.

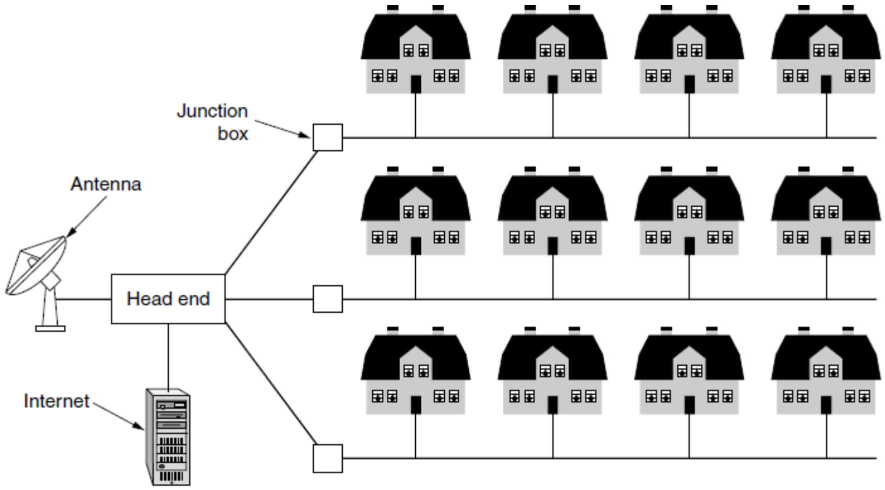


Figure 1-4. A metropolitan area network based on cable TV.

1.2.4 Wide Area Networks

A **WAN** (**Wide Area Network**) spans a large geographical area, often a country or continent. We will begin our discussion with wired WANs, using the example of a company with branch offices in different cities.

The WAN in Fig. 1-4 is a network that connects offices in Perth, Melbourne, and Brisbane. Each of these offices contains computers(hosts) intended for running user programs.

Switching elements, or just **switches**, are specialized computers that connect two or more transmission lines. When data arrive on an incoming line, the switching element must choose an outgoing line on which to forward them. These switching computers have been called by various names in the past; the name **router** is now most commonly used.

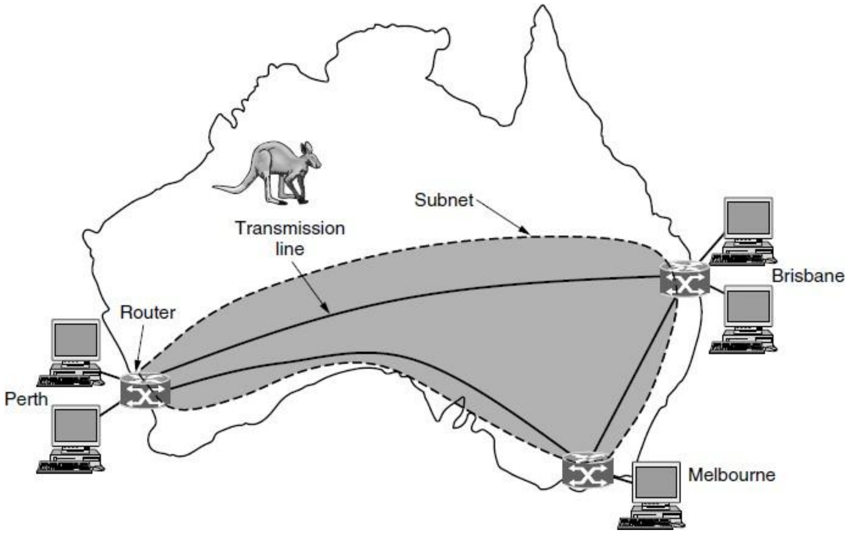


Figure 1-5. WAN that connects three branch offices in Australia.

A virtual private network, or VPN, is an encrypted connection over the Internet from a device to a network. The encrypted connection helps ensure that sensitive data is safely transmitted, traffic remains private as it travels. It prevents unauthorized people from eavesdropping on the traffic and allows the user to conduct work remotely. VPN technology is widely used in corporate

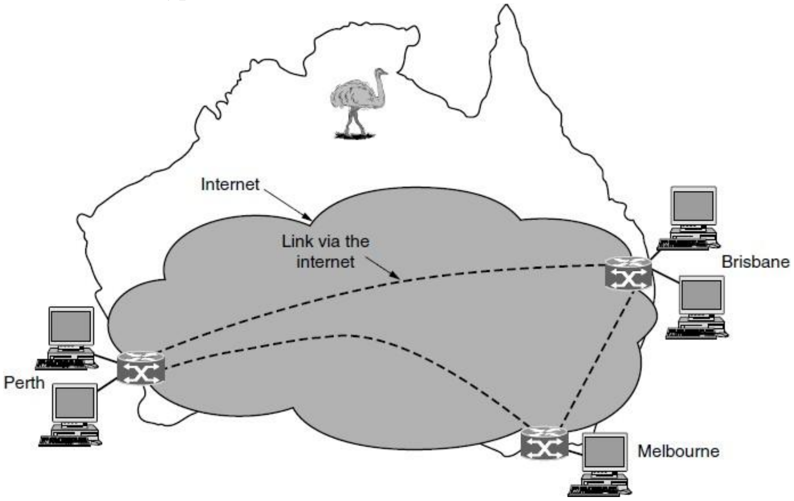


Figure 1-6. WAN using a virtual private network.

The second variation is that the subnet may be run by a different company. The subnet operator is known as a **network service provider** and the offices are its customers.

There may be many paths in the network that connect these two routers. How the network makes the decision as to which path to use is called the **routing algorithm**. Many such algorithms exist. How each router makes the decision as to where to send a packet next is called the **forwarding algorithm**.

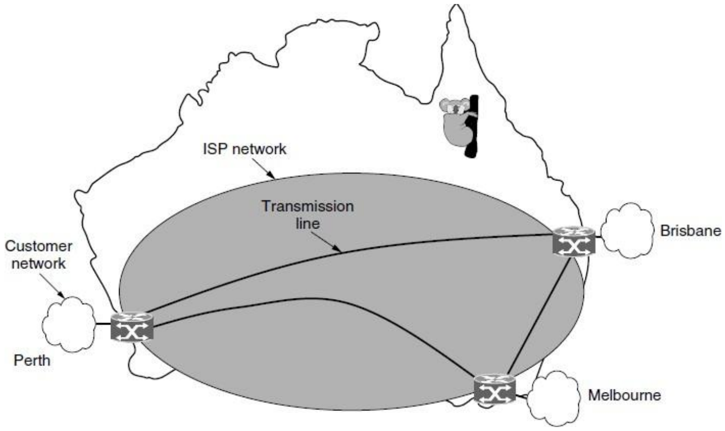


Figure 1-7. WAN using an ISP network.

1.2.5 Internetworks

Many networks exist in the world, often with different hardware and software. People connected to one network often want to communicate with people attached to a different one. The fulfillment of this desire requires that different, and frequently incompatible, networks be connected. A collection of interconnected networks is called an internetwork or internet.

Subnet refers to the collection of routers and communication lines owned by the network operator. A **network** is formed by the combination of a subnet and its hosts. We know that an internet is formed when distinct networks are interconnected. In our view, connecting a LAN and a WAN or connecting two LANs is the usual way to form an **internetwork**, but there is little agreement in the industry over terminology in this area.

There are two rules of thumb that are useful. First, if different organizations have paid to construct different parts of the network and each maintains its part, we have an internetwork rather than a single network. Second, if the underlying technology is different in different parts (e.g., broadcast versus point-to-point and wired versus wireless), we probably have an internetwork. To go deeper, we need to talk about how two different networks can be connected. The general name for a machine that makes a connection between two or more networks and provides the necessary translation, both in terms of hardware and software, is a **gateway**. Gateways are distinguished by the layer at which they operate in the protocol hierarchy.

1.3 Network Software

1.3.1 Protocol Hierarchies

To reduce their design complexity, most networks are organized as a stack of **layers** or **levels**, each one built upon the one below it. The number of layers, the name of each layer, the contents of each layer, and the function of each layer differ from network to network. The purpose of each layer is to offer certain services to the higher layers while shielding those layers from the details of how the offered services are actually implemented. In a sense, each layer is a kind of virtual machine, offering certain services to the layer above it. The fundamental idea is that a particular piece of software (or hardware) provides a service to its users but keeps the details of its internal state and algorithms hidden from them.

Basically, a protocol is an agreement between the communicating parties on how communication is to proceed. A five-layer network is illustrated in Fig. 1-8. The entities comprising the corresponding layers on different machines are called peers. The peers may be software processes, hardware devices, or even human beings. In other words, it is the peers that communicate by using the protocol to talk to each other.

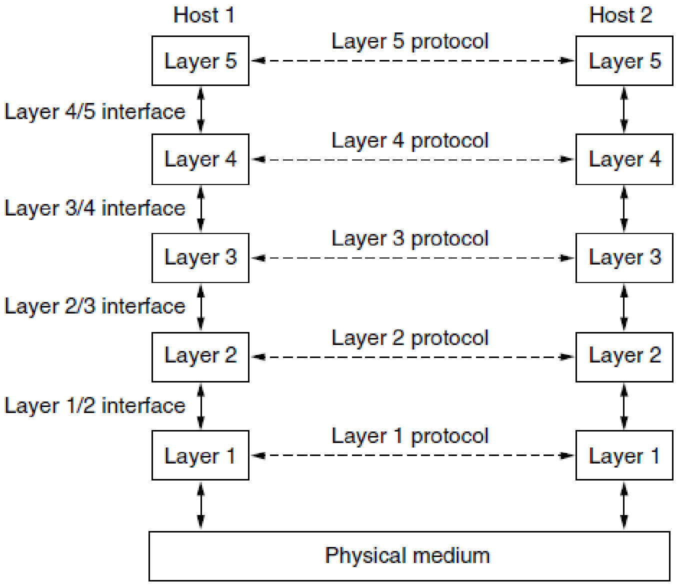


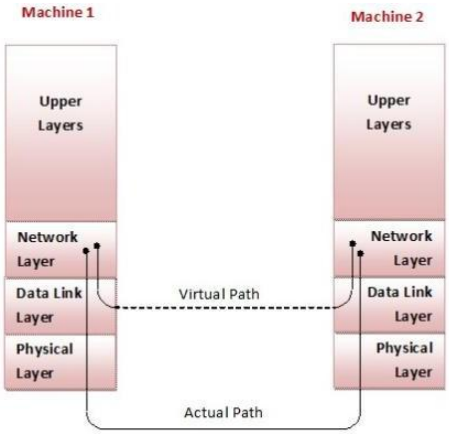
Figure 1-8. Layers, protocols, and interfaces.

In reality, no data are directly transferred from layer *n* on one machine to layer *n* on another machine. Instead, each layer passes data and control information to the layer immediately below it, until the lowest layer is reached. Below layer 1 is the **physical medium** through which actual communication occurs. In Fig. 1-9, virtual communication is shown by dotted lines and physical communication by solid lines.

Between each pair of adjacent layers is an **interface**. The interface defines which primitive operations and services the lower layer makes available to the upper one. A set of layers and protocols is called a **network architecture**. The specification of an architecture must contain enough information to allow an implementer to write the program or build the hardware for each layer so that it will correctly obey the appropriate protocol. A list of the protocols used by a certain system, one protocol per layer, is called a **protocol stack**.
So an interface is the connection between systems or applications, while a protocol defines the rules for data exchange between these systems or applications.

Virtual Communication versus Actual Communication

The main service provided is to transfer data packets from the network layer on the sending machine to the network layer on the receiving machine. Data link layer of the sending machine transmits accepts data from the network layer and sends them to the data link layer of the destination machine which hands them to the network layer there.



In actual communication, the data link layer transmits bits via the physical layers and physical medium. However virtually, this can be visualized as the two data link layers communicating with each other using a data link protocol.

1.3.2 Design Issues for the Layers

Some of the key design issues that occur in computer networks will come up in layer after layer. Below, we will briefly mention the more important ones.

Reliability is the design issue of making a network that operates correctly even though it is made up of a collection of components that are themselves unreliable. Think about the bits of a packet traveling through the network. There is a chance that some of these bits will be received damaged (inverted) due to fluke electrical noise, random wireless signals, hardware flaws, software bugs and so on. How is it possible that we find and fix these errors?

One mechanism for finding errors in received information uses codes for error detection. Information that is incorrectly received can then be retransmitted until it is received correctly. More powerful codes allow for error correction, where the correct message is recovered from the possibly incorrect bits that were originally received.

Routing: Another reliability issue is finding a working path through a network. Often there are multiple paths between a source and destination, and in a large network, there may be some links or routers that are broken.

A second design issue concerns the **evolution of the network**. Over time, networks grow larger and new designs emerge that need to be connected to the existing network. We have recently seen the key structuring mechanism used to support change by dividing the overall problem and hiding implementation details: **protocol layering**. [**addressing** or **naming].**

Internetworking: mechanisms for disassembling, transmitting, and then reassembling messages.

Scalable: Designs that continue to work well when the network gets large

Statistical multiplexing: meaning sharing based on the statistics of demand

Flow control: Feedback from the receiver to the sender

Congestion: overloading of the network

Real time: delivery at the same time that they provide service to applications

Confidentiality: defend against to threats

Authenticity: prevent someone from impersonating someone else

Integrity: prevent surreptitious changes to messages

QoS: Quality of service is the name given to mechanisms that reconcile above competing demands.

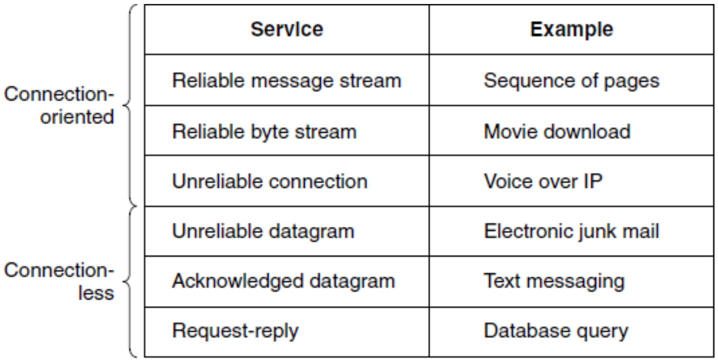
1.3.3 Connection-Oriented Versus Connectionless Service

Connection-oriented service is modeled after the telephone system. To talk to someone, you pick up the phone, dial the number, talk, and then hang up. Similarly, to use a connection-oriented network service, the service user first establishes a connection, uses the connection, and then releases the connection. The essential aspect of a connection is that it acts like a tube: the sender pushes objects (bits) in at one end, and the receiver takes them out at the other end. In most cases the order is preserved so that the bits arrive in the order they were sent.

In some cases when a connection is established, the sender, receiver, and subnet conduct a negotiation about the parameters to be used, such as maximum message size, quality of service required, and other issues. Typically, one side makes a proposal and the other side can accept it, reject it, or make a counterproposal. A circuit is another name for a connection with associated resources, such as a fixed bandwidth. This dates from the telephone network in which a circuit was a path over copper wire that carried a phone conversation.

In contrast to connection-oriented service, **connectionless** service is modeled after the postal system. Each message (letter) carries the full destination address, and each one is routed through the intermediate nodes inside the system independent of all the subsequent messages. There are different names for messages in different contexts; a **packet** is a message at the network layer. When the intermediate nodes receive a message in full before sending it on to the next node, this is called **store-and-forward switching**. The alternative, in which the onward transmission of a message at a node starts before it is completely received by the node, is called **cut-through switching**. Normally, when two messages are sent to the same destination, the first one sent will be the first one to arrive. However, it is possible that the first one sent can be delayed so that the second one arrives first.

Usually, a **reliable service** is implemented by having the receiver acknowledge the receipt of each message so the sender is sure that it arrived. The acknowledgement process introduces overhead and delays, which are often worth it but are sometimes undesirable. Reliable connection-oriented service has two minor variations: **message sequences and byte streams**. **Unreliable** (meaning not acknowledged) connectionless service is often called **datagram** service, in analogy with telegram service, which also does not return an acknowledgement to the sender.

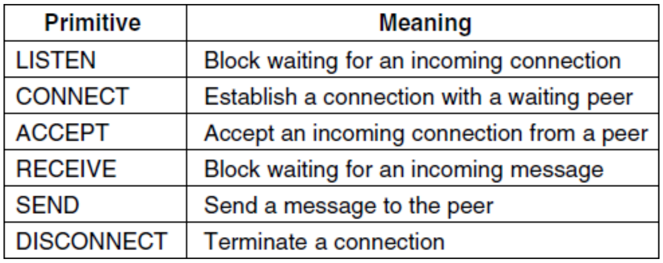


	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Movie download
	Unreliable connection	Voice over IP
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Text messaging
	Request-reply	Database query

Figure 1-10. Six different types of service.

1.1.1 Service Primitives

A service is formally specified by a set of primitives (operations) available to user processes to access the service. These primitives tell the service to perform some action or report on an action taken by a peer entity. If the protocol stack is located in the operating system, the primitives are normally system calls. The set of primitives available depends on the nature of the service being provided. The primitives for connection-oriented service are different from those of connectionless service.



Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
ACCEPT	Accept an incoming connection from a peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Figure 1-11. Six service primitives that provide a simple connection-oriented service.

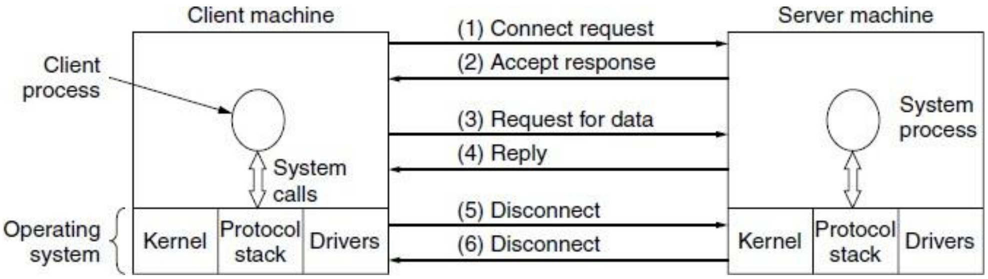


Figure 1-12. A simple client-server interaction using acknowledged datagrams.

1.3.4 The Relationship of Services to Protocols

A ***service*** is a set of primitives (operations) that a layer provides to the layer above it. The service defines what operations the layer is prepared to perform on behalf of its users, but it says nothing at all about how these operations are implemented.

A ***protocol*,** in contrast, is a set of rules governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer. Entities use protocols to implement their service definitions.

A service is like an abstract data type or an object in an object-oriented language. It defines operations that can be performed on an object but does not specify how these operations are implemented. In contrast, a protocol relates to the implementation of the service and as such is not visible to the user of the service.

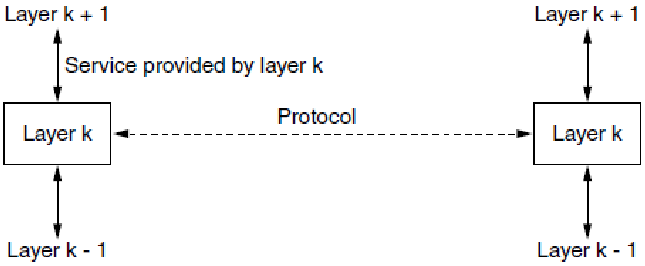


Figure 1-13. The relationship between a service and a protocol.

1.4 Reference Models

We will discuss two important network architectures: the OSI reference model and the TCP/IP reference model.

1.4.1 The OSI Reference Model

The OSI model (minus the physical medium) is shown in Fig. 1-14. This model is based on a proposal developed by the International Standards Organization (ISO) as a first step toward international standardization of the protocols used in the various layers (Day and Zimmermann, 1983). It was revised in 1995 (Day, 1995). The model is called the ISO **OSI** (**Open Systems Interconnection**) **model,** it is a Reference Model because it deals with connecting open systems—that is, systems that are open for communication with other systems.

The OSI model has seven layers. The principles that were applied to arrive at the seven layers can be briefly summarized as follows:

1. A layer should be created where a different abstraction is needed.

2. Each layer should perform a well-defined function.

3. The function of each layer should be chosen with an eye toward defining internationally standardized protocols.

4. The layer boundaries should be chosen to minimize the information flow across the interfaces.

5. The number of layers should be large enough that distinct functions need not be thrown together in the same layer out of necessity and small enough that the architecture does not become unwieldy.

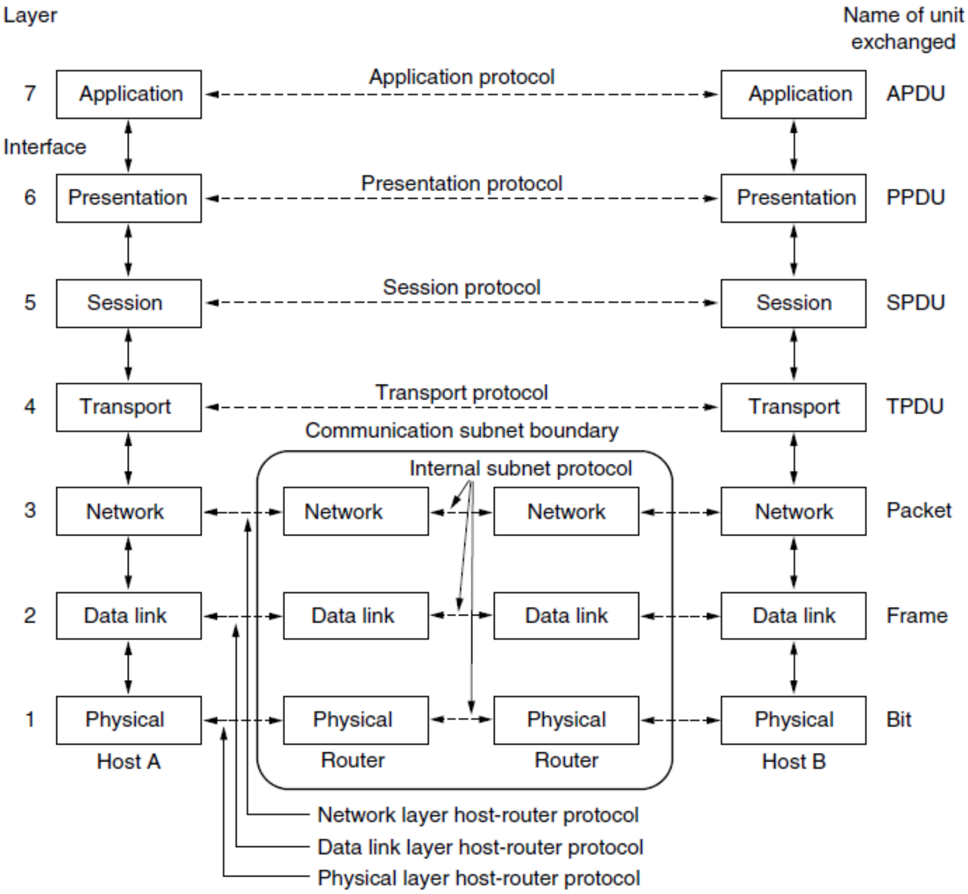


Figure 1-14. The OSI reference model.

Layer 1. The Physical Layer

The **physical layer** is concerned with transmitting raw bits over a communication channel. The physical layer transports data using electrical, mechanical or procedural interfaces. This layer is responsible for sending computer bits from one device to another along the network. It determines how physical connections to the network are set up and how bits are represented into predictable signals as they're transmitted either electrically, optically or via radio waves.

Layer 2. The data-link layer

The data-link, or protocol layer, in a program handles moving data into and out of a physical link in a network. This layer handles problems that occur as a result of bit transmission errors. It accomplishes this task by having the sender break up the input data into **data frames** (typically a few hundred or a few thousand bytes) and transmit the frames sequentially. This layer also permits the transmission of data to Layer 3, the network layer, where it's addressed and routed.

The data-link layer can be further divided into two sublayers. The higher layer, which is called *logical link control* (LLC), is responsible for multiplexing, flow control, acknowledgement and notifying upper layers if transmit/receive (TX/RX) errors occur.

The media access control sublayer is responsible for tracking data frames using MAC addresses of the sending and receiving hardware. It's also responsible for organizing each frame, marking the starting and ending bits and organizing timing regarding when each frame can be sent along the physical layer medium.

Layer 3. The network layer

The **network layer** controls the operation of the subnet. A key design issue is determining how packets are routed from source to destination. Routes can be based on static tables that are ‘‘wired into’’ the network and rarely changed, or more often they can be updated automatically to avoid failed components. From a TCP/IP perspective, this is where IP addresses are applied for routing purposes. Handling congestion is also a responsibility of the network layer, in conjunction with higher layers that adapt the load they place on the network. More generally, the quality of service provided (delay, transit time, jitter, etc.) is also a network layer issue.

Layer 4. The transport layer

The transport layer is a true end-to-end layer; it carries data all the way from the source to the destination. The basic function of the **transport layer** is to accept data from above it, 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 end. The transport layer also determines what type of service to provide to the session layer, the type of service is determined when the connection is established.

Layer 5. The session layer

The session layer allows users on different machines to establish **sessions** between them. Sessions offer various services, including **dialog control** (keeping track of whose turn it is to transmit), **token management** (preventing two parties from attempting the same critical operation simultaneously), and **synchronization.** Examples of session layer protocols include X.225 and Zone Information Protocol (ZIP).

Layer 6. The presentation layer

presentation layer is concerned with the syntax and semantics of the information transmitted. In order to make it possible for computers with different internal data representations to communicate, the data structures to be exchanged can be defined in an abstract way, along with a standard encoding to be used ‘‘on the wire.’’ The presentation layer manages these abstract data structures and allows higher-level data structures (e.g., banking records) to be defined and exchanged. This layer also handles the encryption and decryption that the application layer requires.

Layer 7. The application layer

The **application layer** contains a variety of protocols that are commonly needed by users. The application layer enables the user -- human or software -- to interact with the application or network whenever the user elects to read messages, transfer files or perform other network-related tasks. Other application protocols are used for file transfer, electronic mail, and network news.

Pros and cons of the OSI model

The OSI model has a number of advantages, including the following:

- It's considered a standard model in computer networking.
- The model supports connectionless, as well as connection-oriented, services. Users can take advantage of connectionless services when they need faster data transmissions over the internet and the connection-oriented model when they're looking for reliability.

- It has the flexibility to adapt to many protocols.
- The model is more adaptable and secure than having all services bundled in one layer.

The disadvantages of the OSI model include the following:

- It doesn't define any particular protocol.
- The session layer, which is used for session management, and the presentation layer, which deals with user interaction, aren't as useful as other layers in the OSI model.
- Some services are duplicated at various layers, such as the transport and data-link layers.
- Layers can't work in parallel; each layer must wait to receive data from the previous layer.

1.4.2 The TCP/IP Reference Model

The ARPANET was a research network sponsored by the DoD (U.S. Department of Defense). It eventually connected hundreds of universities and government installations, using leased telephone lines. When satellite and radio networks were added later, the existing protocols had trouble interworking with them, so a new reference architecture was needed. Thus, from nearly the beginning, the ability to connect multiple networks in a seamless way was one of the major design goals.

This architecture later became known as the **TCP/IP Reference Model**, after its two primary protocols. It was first described by Cerf and Kahn (1974), and later refined and defined as a standard in the Internet community (Braden, 1989). The design philosophy behind the model is discussed by Clark (1988). **TCP/IP Model** helps you to determine how a specific computer should be connected to the internet and how data should be transmitted between them. It helps you to create a virtual network when multiple computer networks are connected together. The purpose of TCP/IP model is to allow communication over large distances.

TCP/IP stands for Transmission Control Protocol/ Internet Protocol. TCP/IP Stack is specifically designed as a model to offer highly reliable and end-to-end byte stream over an unreliable internetwork.

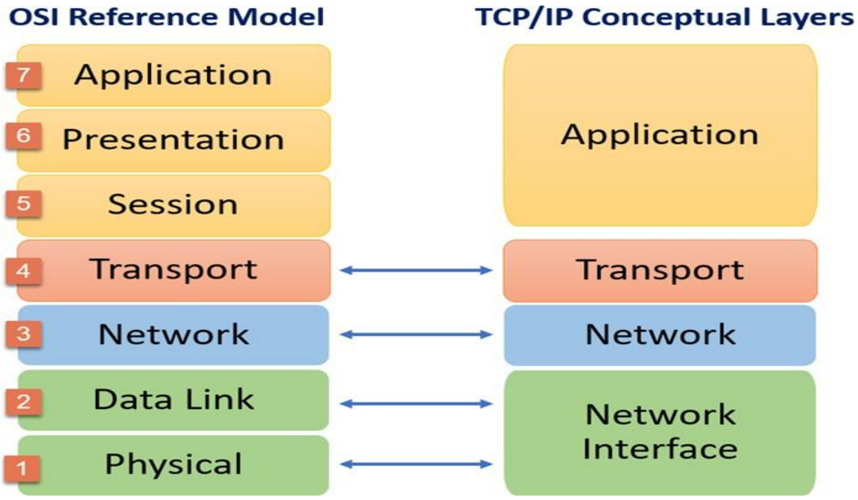


Figure 1-15. TCP / IP reference model.

Application layer: On top of the transport layer is the application layer. It contains all the higher-level protocols. This layer interacts with software applications to implement a communicating

- Application-layer helps you to identify communication partners, determining resource availability, and synchronizing communication.
- It allows users to log on to a remote host
- This layer provides various e-mail services
- This application offers distributed database sources and access for global information about various objects and services.

Transport Layer: Transport layer builds on the network layer in order to provide data transport from a process on a source system machine to a process on a destination system. Two end-to-end transport protocols have been defined here. The first one, **TCP** (**Transmission Control Protocol**), is a reliable connection-oriented protocol that allows a byte stream originating on one machine to be delivered without error on any other machine in the internet. It segments the incoming byte stream into discrete messages and passes each one on to the internet layer. At the destination, the receiving TCP process reassembles the received messages into the output stream. TCP also handles flow control to make sure a fast sender cannot swamp a slow receiver with more messages than it can handle.

The second protocol in this layer, **UDP** (**User Datagram Protocol**), is an unreliable, connectionless protocol for applications that do not want TCP's sequencing or flow control and wish to provide their own.

Internet Layer: An internet layer is a second layer of TCP/IP layes of the TCP/IP model. It is also known as a network layer. The main work of this layer is to send the packets from any network, and any computer still they reach the destination irrespective of the route they take.

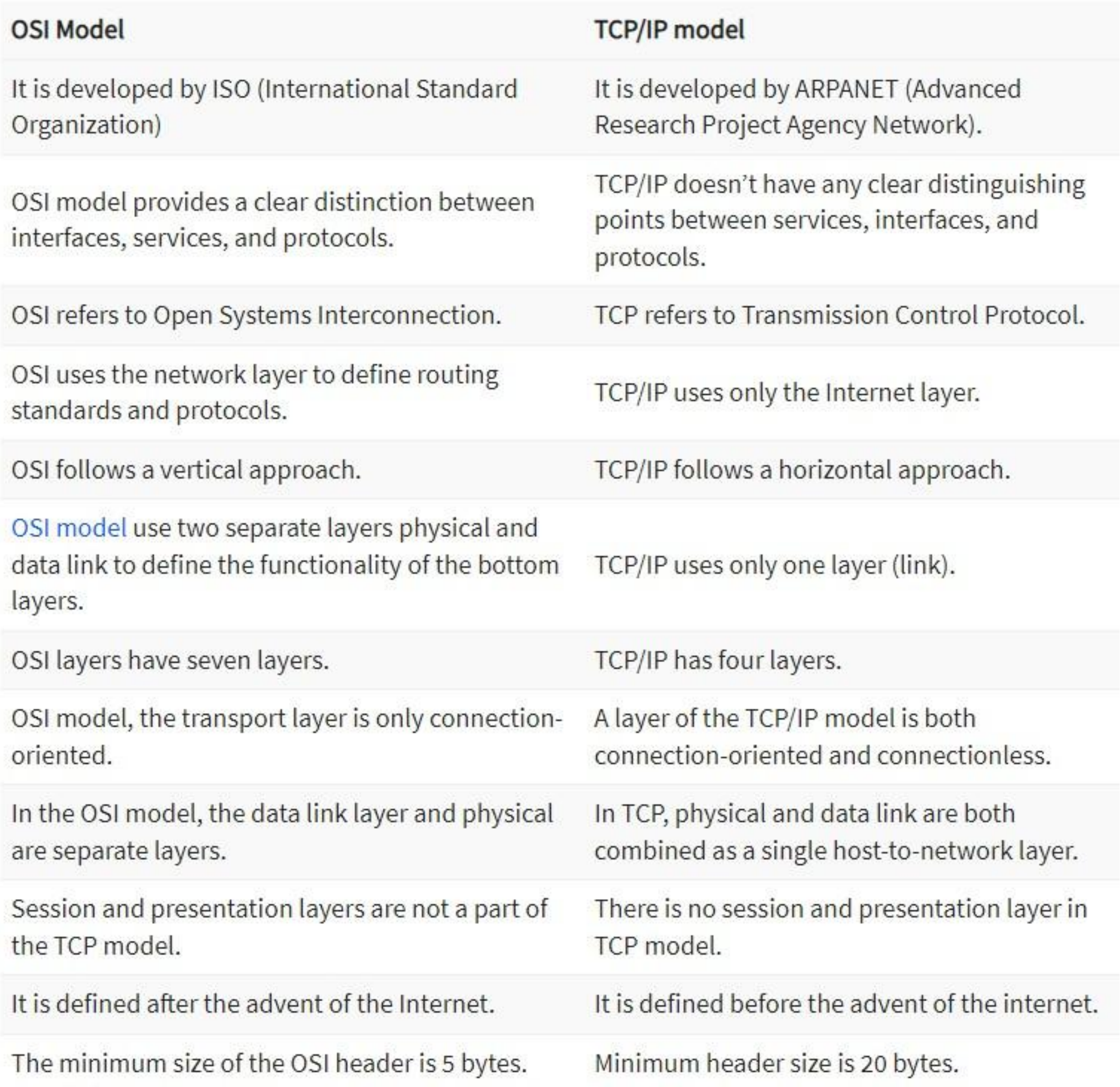
The internet layer defines an official packet format and protocol called **IP** (**Internet Protocol**), plus a companion protocol called **ICMP** (**Internet Control Message Protocol**) that helps it function. The job of the internet layer is to deliver IP packets where they are supposed to go. Layer-management protocols that belong to the network layer are:

1. Routing protocols
2. Multicast group management

details of how data should be sent using the network. It also includes how bits should optically be signaled by hardware devices which directly interfaces with a network medium, like coaxial, optical, coaxial, fiber, or twisted-pair cables.

A network layer is a combination of the data line and defined in the article of OSI reference model. This layer defines how the data should be sent physically through the network. This layer is responsible for the transmission of the data between two devices on the same network.

Differences between the OSI and TCP/IP models include the following:



OSI Model	TCP/IP model
It is developed by ISO (International Standard Organization)	It is developed by ARPANET (Advanced Research Project Agency Network).
OSI model provides a clear distinction between interfaces, services, and protocols.	TCP/IP doesn't have any clear distinguishing points between services, interfaces, and protocols.
OSI refers to Open Systems Interconnection.	TCP refers to Transmission Control Protocol.
OSI uses the network layer to define routing standards and protocols.	TCP/IP uses only the Internet layer.
OSI follows a vertical approach.	TCP/IP follows a horizontal approach.
OSI model use two separate layers physical and data link to define the functionality of the bottom layers.	TCP/IP uses only one layer (link).
OSI layers have seven layers.	TCP/IP has four layers.
OSI model, the transport layer is only connection-oriented.	A layer of the TCP/IP model is both connection-oriented and connectionless.
In the OSI model, the data link layer and physical are separate layers.	In TCP, physical and data link are both combined as a single host-to-network layer.
Session and presentation layers are not a part of the TCP model.	There is no session and presentation layer in TCP model.
It is defined after the advent of the Internet.	It is defined before the advent of the internet.
The minimum size of the OSI header is 5 bytes.	Minimum header size is 20 bytes.

1.5 Guided Transmission Media

The purpose of the physical layer is to transport bits from one machine to another. Various physical media can be used for the actual transmission. Each one has its own niche in terms of bandwidth, delay, cost, and ease of installation and maintenance. Media are roughly grouped into guided media, such as copper wire and fiber optics, and unguided media, such as terrestrial wireless, satellite, and lasers through the air.

1.5.1 Magnetic Media

One of the most common ways to transport data from one computer to another is to write them onto magnetic tape or removable media (e.g., recordable DVDs), physically transport the tape or disks to the destination machine, and read them back in again

1.5.2 Twisted Pairs

A twisted pair consists of two insulated copper wires, typically about 1 mm thick. The wires are twisted together in a helical form, just like a DNA molecule. Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, the waves from different twists cancel out, so the wire radiates less effectively. A signal is usually carried as the difference in voltage between the two wires in the pair. This provides better immunity to external noise because the noise tends to affect both wires the same, leaving the differential unchanged. Twisted pairs can be used for transmitting either analog or digital information.

The bandwidth depends on the thickness of the wire and the distance traveled, but several megabits/sec can be achieved for a few kilometers in many cases.

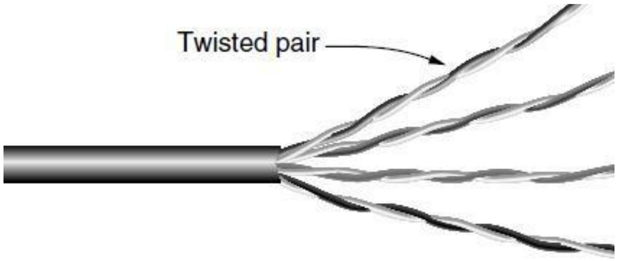


Figure 1-16. Category 5 UTP cable with four twisted pairs.

Category 3 cables with a similar cable that uses the same connector, but has more twists per meter. More twists result in less crosstalk and a better-quality signal over longer distances, making the cables more suitable for high-speed computer communication, especially 100-Mbps and 1-Gbps Ethernet LANs.

Category 5 cabling, or ‘‘Cat 5.’’ twisted pair consists of two insulated wires gently twisted together. Four such pairs are typically grouped in a plastic sheath to protect the wires and keep them together.

Category 6 or even **Category 7**. These categories has more stringent specifications to handle signals with greater bandwidths. Some cables in Category 6 and above are rated for signals of 500 MHz and can support the 10-Gbps links that will soon be deployed.

Through Category 6, these wiring types are referred to as **UTP** (**Unshielded Twisted Pair**) as they consist simply of wires and insulators. In contrast to these, Category 7 cables have shielding on the individual twisted pairs, as well as around the entire cable (but inside the plastic protective sheath). Shielding reduces the susceptibility to external interference and crosstalk with other nearby cables to meet demanding performance specifications.

1.5.3 Coaxial Cable

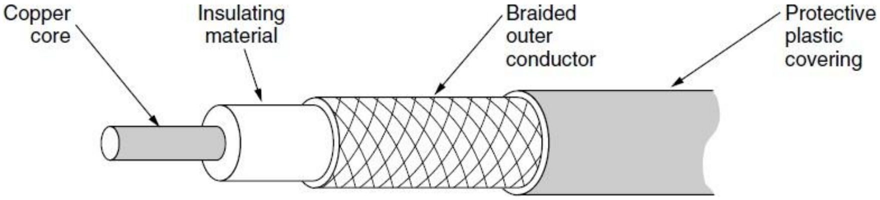


Figure 1-17. A coaxial cable.

It has better shielding and greater bandwidth than unshielded twisted pairs, so it can span longer distances at higher speeds. Two kinds of coaxial cable are widely used. One kind, 50-ohm cable, is commonly used when it is intended for digital transmission from the start. The other kind, 75-ohm cable, is commonly used for analog transmission and cable television. A coaxial cable consists of a stiff copper wire as the core, surrounded by an insulating material. The insulator is encased by a cylindrical conductor, often as a closely woven braided mesh. The outer conductor is covered in a protective plastic sheath. A cutaway view of a coaxial cable is shown in Fig. 1-17.

1.5.4 Power Lines

Power lines deliver electrical power to houses, and electrical wiring within houses distributes the power to electrical outlets. Electrical signals are sent at 50–60 Hz and the wiring attenuates the much higher frequency (MHz) signals needed for high-rate data communication. The electrical properties of the wiring vary from one house to the next and change as appliances are turned on and off, which causes data signals to bounce around the wiring. Transient currents when appliances switch on and off create electrical noise over a wide range of frequencies.

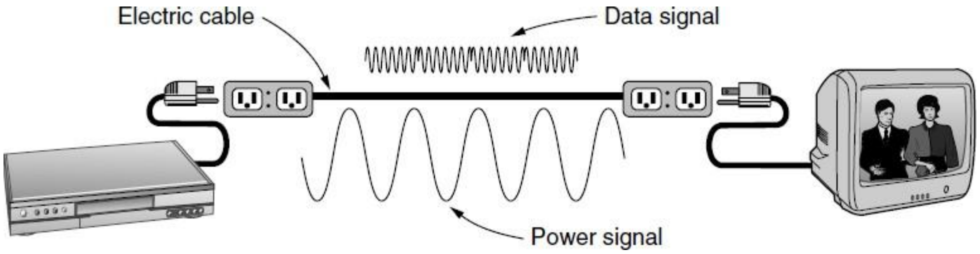


Figure 1-18. A network that uses household electrical wiring.

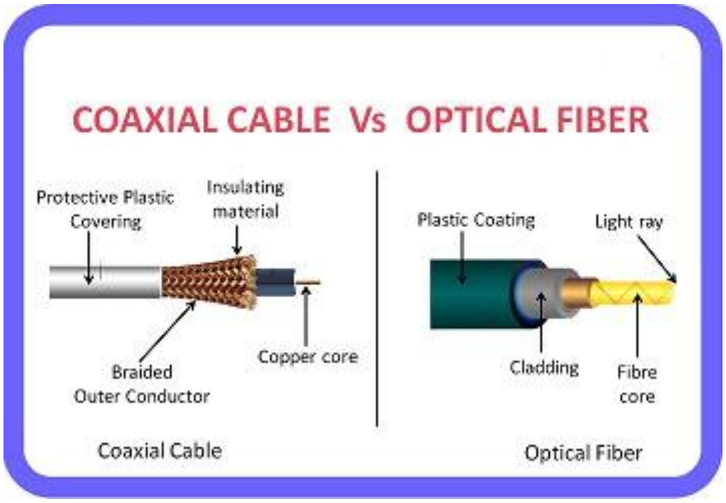
1.5.5 Fiber Optics

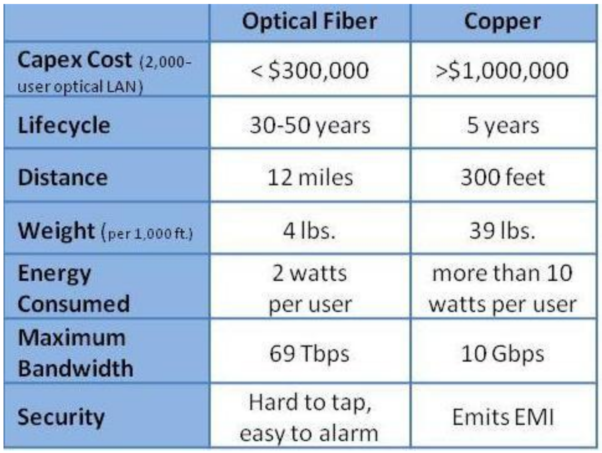
Fiber optics are used for long-haul transmission in network backbones, highspeed LANs. and high-speed Internet access such as FttH (Fiber to the Home). An optical transmission system has three key components: the light source, the transmission medium, and the detector. Conventionally, a pulse of light indicates a 1 bit and the absence of light indicates a 0 bit. The transmission medium is an ultra-thin fiber of glass. The detector generates an electrical pulse when light falls on it. By attaching a light source to one end of an optical fiber and a detector to the other, we have a unidirectional data

transmission system that accepts an electrical signal, converts and transmits it by light pulses, and then reconverts the output to an electrical signal at the receiving end.

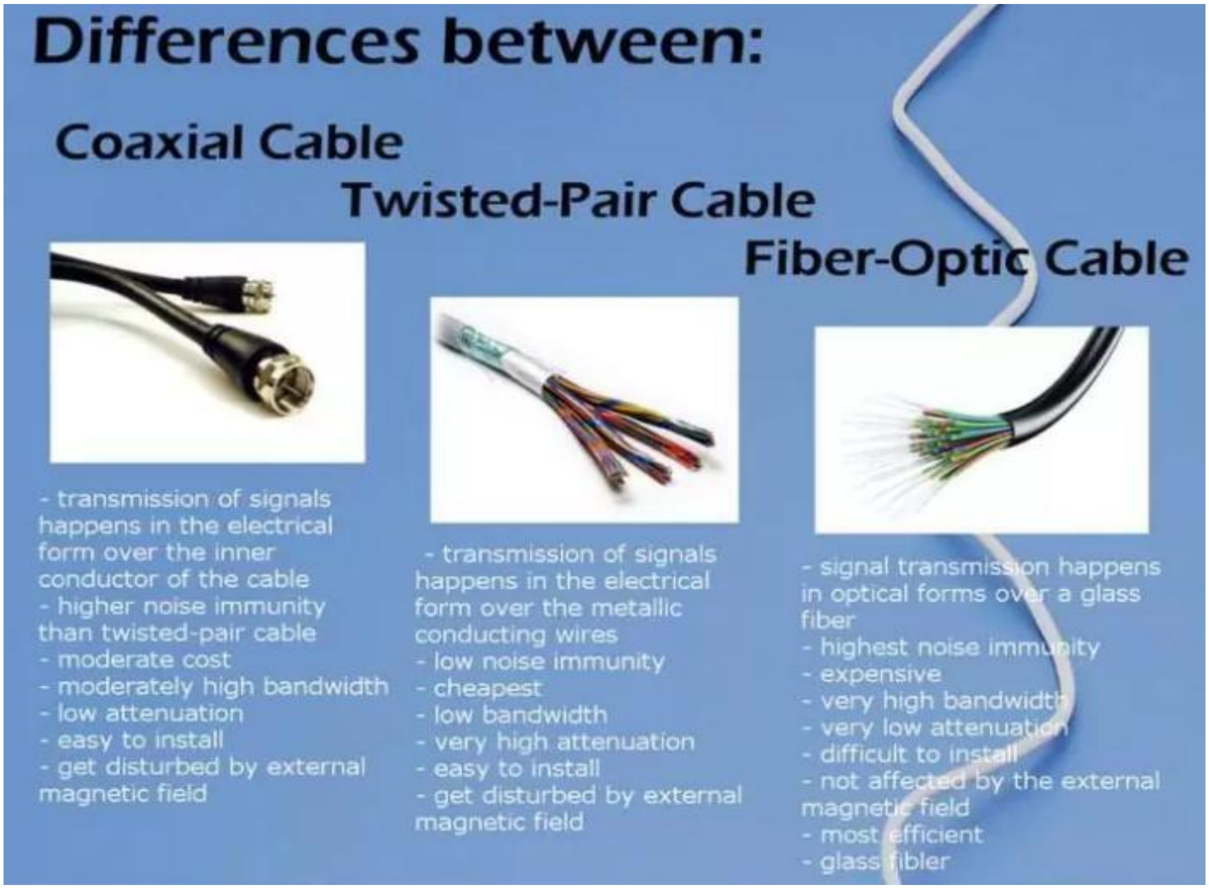
Fiber optics is the technology used by internet services such as Verizon Fios home internet to transmit information as pulses of light through strands of fiber made of glass or plastic over long distances. A fiber-optic cable contains anywhere from a few to hundreds of optical fibers within a plastic casing. Also known as optic cables or optical fiber cables, they transfer data signals in the form of light and travel hundreds of miles significantly faster than those used in traditional electrical cables. And because fiber-optic cables are non-metallic, they are not affected by electromagnetic interference (i.e. lightening) that can reduce speed of transmission. Fiber cables are also safer as they do not carry a current and therefore cannot generate a spark.

Comparison of Fiber Optics and Copper Wire





	Optical Fiber	Copper
Capex Cost (2,000-user optical LAN)	< $300,000	>$1,000,000
Lifecycle	30-50 years	5 years
Distance	12 miles	300 feet
Weight (per 1,000 ft.)	4 lbs.	39 lbs.
Energy Consumed	2 watts per user	more than 10 watts per user
Maximum Bandwidth	69 Tbps	10 Gbps
Security	Hard to tap, easy to alarm	Emits EMI



Differences between:

Coaxial Cable

Twisted-Pair Cable

Fiber-Optic Cable

- transmission of signals happens in the electrical form over the inner conductor of the cable
- higher noise immunity than twisted-pair cable
- moderate cost
- moderately high bandwidth
- low attenuation
- easy to install
- get disturbed by external magnetic field

- transmission of signals happens in the electrical form over the metallic conducting wires
- low noise immunity
- cheapest
- low bandwidth
- very high attenuation
- easy to install
- get disturbed by external magnetic field

- signal transmission happens in optical forms over a glass fiber
- highest noise immunity
- expensive
- very high bandwidth
- very low attenuation
- difficult to install
- not affected by the external magnetic field
- most efficient
- glass fibler

1.6 Wireless Transmission

It is noteworthy that modern wireless digital communication began in the Hawaiian Islands, where large chunks of Pacific Ocean separated the users from their computer center and the telephone system was inadequate. Our age has given rise to information junkies: people who need to be online all the time. For these mobile users, twisted pair, coax, and fiber optics are of no use. They need to get their ‘‘hits’’ of data for their laptop, notebook, shirt pocket, palmtop, or wristwatch computers without being tethered to the terrestrial communication infrastructure. For these users, wireless communication is the answer.

1.6.1 The Electromagnetic Spectrum

When electrons move, they create electromagnetic waves that can propagate through space (even in a vacuum). These waves were predicted by the British physicist James Clerk Maxwell in 1865 and first observed by the German physicist Heinrich Hertz in 1887. The number of oscillations per second of a wave is called its frequency, f, and is measured in Hz (in honor of Heinrich Hertz). The distance between two consecutive maxima (or minima) is called the wavelength, which is universally designated by the Greek letter λ (lambda). When an antenna of the appropriate size is attached to an electrical circuit, the electromagnetic waves can be broadcast efficiently and received by a receiver some distance away. All wireless communication is based on this principle.

In a vacuum, all electromagnetic waves travel at the same speed, no matter what their frequency. This speed, usually called the **speed of light**, *c*, is approximately 3 × 108 m/sec, or about 1 foot (30 cm) per nanosecond. (A case could be made for redefining the foot as the distance light travels in a vacuum in 1 nsec rather than basing it on the shoe size of some long-dead king.) In copper or fiber the speed slows to about 2/3 of this value and becomes slightly frequency dependent. The speed of light is the ultimate speed limit. No object or signal can ever move faster than it.

The fundamental relation between *f*, λ, and *c* (in a vacuum) is

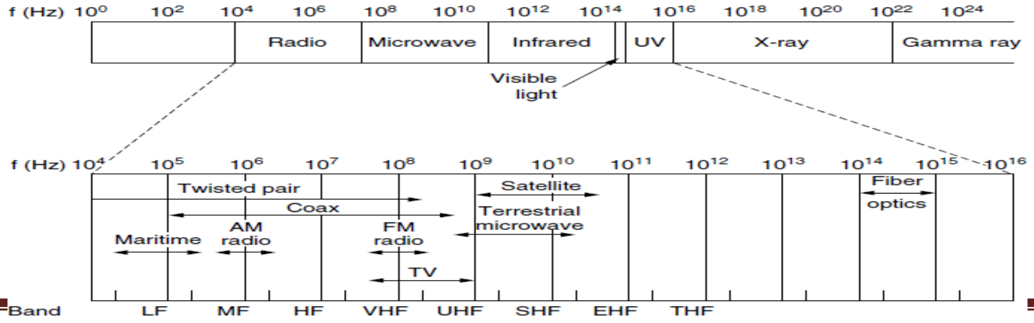
$$\lambda f = c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Since *c* is a constant, if we know *f*, we can find λ, and vice versa. As a rule of thumb, when λ is in meters and *f* is in MHz, λf ∼∼ 300. For example, 100-MHz waves are about 3 meters long, 1000-MHz waves are 0.3 meters long, and 0.1-meter waves have a frequency of 3000 MHz. The electromagnetic spectrum is shown in Fig. 2-10. The radio, microwave, infrared, and visible light portions of the spectrum can all be used for transmitting information by modulating the amplitude, frequency, or phase of the waves.

Ultraviolet light, X-rays, and gamma rays would be even better, due to their higher frequencies, but they are hard to produce and modulate, do not propagate well through buildings, and are dangerous to living things. The bands listed at the bottom of Fig. 2-10 are the official ITU (International Telecommunication Union) names and are based on the wavelengths, so the LF band goes from 1 km to 10 km (approximately 30 kHz to 300 kHz). The terms LF, MF, and HF refer to Low, Medium, and High Frequency, respectively. Clearly, when the names were assigned nobody expected to go above 10 MHz, so the higher bands were later named the Very, Ultra, Super, Extremely, and Tremendously High Frequency bands. Beyond that there are no names, but Incredibly, Astonishingly, and Prodigiously High Frequency (IHF, AHF, and PHF) would sound nice.

We know from Shannon [Eq. (2-3)] that the amount of information that a signal such as an electromagnetic wave can carry depends on the received power and is proportional to its bandwidth. From Fig. 1-19 it should now be obvious why networking people like fiber optics so much. Many GHz of bandwidth are available to tap for data transmission in the microwave band, and even more in fiber because it is further to the right in our logarithmic scale. As an example, consider the 1.30-micron band of Fig. 2-7, which has a width of 0.17 microns. If we use Eq. (2-4) to find the start and end frequencies from the start and end wavelengths, we find the frequency range to be about 30,000 GHz. With a reasonable signalto-noise ratio of 10 dB, this is 300 Tbps.

Figure 1-19. The electromagnetic spectrum and its uses for communication.


f (Hz) 10^0 10^2 10^4 10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22} 10^{24}
Radio
Microwave
Infrared
UV
X-ray
Gamma ray
Visible light
f (Hz) 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16}
Twisted pair
Coax
Satellite
Terrestrial microwave
Fiber optics
Maritime
AM radio
FM radio
TV
Band
LF
MF
HF
VHF
UHF
SHF
EHF
THF

Most transmissions use a relatively narrow frequency band (i.e., $\Delta f / f << 1$). They concentrate their signals in this narrow band to use the spectrum efficiently and obtain reasonable data rates by transmitting with enough power. However, in some cases, a wider band is used, with three variations. In **frequency hopping spread spectrum**, the transmitter hops from frequency to frequency hundreds of times per second. It is popular for military communication because it makes transmissions hard to detect and next to impossible to jam. It also offers good resistance to multipath fading and narrowband interference because the receiver will not be stuck on an impaired frequency for long enough to shut down communication.

A second form of spread spectrum, **direct sequence spread spectrum**, uses a code sequence to spread the data signal over a wider frequency band. It is widely used commercially as a spectrally efficient way to let multiple signals share the same frequency band. These signals can be given different codes, a method called **CDMA** (**Code Division Multiple Access**) that we will return to later in this chapter.

This method is shown in contrast with frequency hopping in Fig. 1-20. It forms the basis of 3G mobile phone networks and is also used in GPS (Global Positioning System). Even without different codes, direct sequence spread spectrum, like frequency hopping spread spectrum, can tolerate narrowband interference and multipath fading because only a fraction of the desired signal is lost. It is used in this role in older 802.11b wireless LANs.

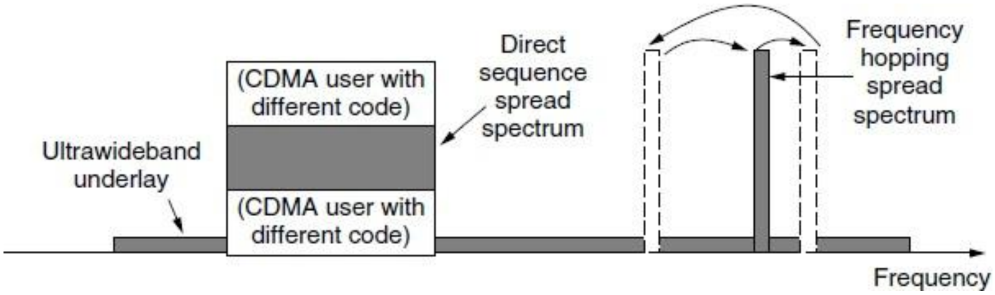

(CDMA user with different code)
Direct sequence spread spectrum
Frequency hopping spread spectrum
Ultrawideband underlay
(CDMA user with different code)
Frequency

Figure 1-20. Spread spectrum and ultra-wideband (UWB) communication.

A third method of communication with a wider band is **UWB** (**Ultra-Wide Band**) communication. UWB sends a series of rapid pulses, varying their positions to communicate information. The rapid transitions lead to a signal that is spread thinly over a very wide frequency band. UWB is defined as signals that have a bandwidth of at least 500 MHz or at least 20% of the center frequency of their

frequency band. UWB is also shown in Fig. 1-21. With this much bandwidth, UWB has the potential to communicate at high rates. Because it is spread across a wide band of frequencies, it can tolerate a substantial amount of relatively strong interference from other narrowband signals. Just as importantly, since UWB has very little energy at any given frequency when used for short-range transmission, it does not cause harmful interference to those other narrowband radio signals. It is said to **underlay** the other signals.

1.1.1 Radio Transmission

Radio frequency (RF) waves are easy to generate, can travel long distances, and can penetrate buildings easily, so they are widely used for communication, both indoors and outdoors. Radio waves also are omnidirectional, meaning that they travel in all directions from the source, so the transmitter and receiver do not have to be carefully aligned physically.

The properties of radio waves are frequency dependent. At low frequencies, radio waves pass through obstacles well, but the power falls off sharply with distance from the source—at least as fast as 1/*r* 2 in air—as the signal energy is spread more thinly over a larger surface. This attenuation is called **path loss**.

At high frequencies, radio waves tend to travel in straight lines and bounce off obstacles. Path loss still reduces power, though the received signal can depend strongly on reflections as well. High-frequency radio waves are also absorbed by rain and other obstacles to a larger extent than are low-frequency ones. At all frequencies, radio waves are subject to interference from motors and other electrical equipment.

It is interesting to compare the attenuation of radio waves to that of signals in guided media. With fiber, coax and twisted pair, the signal drops by the same fraction per unit distance, for example 20 dB per 100m for twisted pair. With radio, the signal drops by the same fraction as the distance doubles, for example 6 dB per doubling in free space.

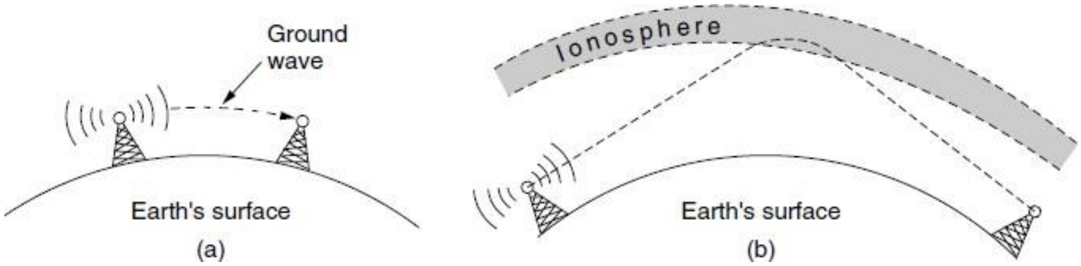


Figure 1-22. (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF band, they bounce off the ionosphere.

In the HF and VHF bands, the ground waves tend to be absorbed by the earth. However, the waves that reach the ionosphere, a layer of charged particles circling the earth at a height of 100 to 500 km, are refracted by it and sent back to earth, as shown in Fig. 1-22(b). Under certain atmospheric conditions, the signals can bounce several times. Amateur radio operators (hams) use these bands to talk long distance. The military also communicate in the HF and VHF bands.

1.1.2 Microwave Transmission

Above 100 MHz, the waves travel in nearly straight lines and can therefore be narrowly focused. Concentrating all the energy into a small beam by means of a parabolic antenna (like the familiar satellite TV dish) gives a much higher signal to-noise ratio, but the transmitting and receiving antennas must be accurately aligned with each other.

Microwaves travel in a straight line, so if the towers are too far apart, the earth will get in the way (think about a Seattle-to-Amsterdam link). Thus, repeaters are needed periodically. The higher the towers are, the farther apart they can be. The distance between repeaters goes up very roughly with the square root of the tower height. For 100-meter-high towers, repeaters can be 80 km apart.

Unlike radio waves at lower frequencies, microwaves do not pass through buildings well. In addition, even though the beam may be well focused at the transmitter, there is still some divergence in space. Some waves may be refracted off low-lying atmospheric layers and may take slightly longer to arrive than the direct waves. The delayed waves may arrive out of phase with the direct wave and thus cancel the signal. This effect is called **multipath fading** and is often a serious problem. It is weather and frequency dependent. Some operators keep 10% of their channels idle as spares to switch on when multipath fading temporarily wipes out some frequency band.

The demand for more and more spectrum drives operators to yet higher frequencies. Bands up to 10 GHz are now in routine use, but at about 4 GHz a new problem sets in: absorption by water. These waves are only a few centimeters long and are absorbed by rain. This effect would be fine if one were planning to build a huge outdoor microwave oven for roasting passing birds, but for communication it is a severe problem. As with multipath fading, the only solution is to shut off links that are being rained on and route around them.

In summary, microwave communication is so widely used for long-distance telephone communication, mobile phones, television distribution, and other purposes that a severe shortage of spectrum has developed. It has several key advantages over fiber. The main one is that no right of way is needed to lay down cables. By buying a small plot of ground every 50 km and putting a microwave tower on it, one can bypass the telephone system entirely. This is how MCI managed to get started as a new long-distance telephone company so quickly. (Sprint, another early competitor to the deregulated AT&T, went a completely different route: it was formed by the Southern Pacific Railroad, which already owned a large amount of right of way and just buried fiber next to the tracks.)

Microwave is also relatively inexpensive. Putting up two simple towers (which can be just big poles with four guy wires) and putting antennas on each one may be cheaper than burying 50 km of fiber through a congested urban area or up over a mountain, and it may also be cheaper than leasing the telephone company's fiber, especially if the telephone company has not yet even fully paid for the copper it ripped out when it put in the fiber.

The Politics of the Electromagnetic Spectrum

To prevent total chaos, there are national and international agreements about who gets to use which frequencies. Since everyone wants a higher data rate, everyone wants more spectrum. National governments allocate spectrum for AM and FM radio, television, and mobile phones, as well as for telephone companies, police, maritime, navigation, military, government, and many other competing users. Worldwide, an agency of ITU-R (WRC) tries to coordinate this allocation so devices that work in multiple countries can be manufactured. However, countries are not bound by ITU-R's recommendations, and the FCC (Federal Communication Commission), which does the allocation for the United States, has occasionally rejected ITU-R's recommendations (usually because they required some politically powerful group to give up some piece of the spectrum).

Even when a piece of spectrum has been allocated to some use, such as mobile phones, there is the additional issue of which carrier is allowed to use which frequencies. Three algorithms were widely used in the past. The oldest algorithm, often called the **beauty contest**, requires each carrier to explain why its proposal serves the public interest best. Government officials then decide which of the nice stories they enjoy most. Having some government official award property worth billions of dollars to his favorite company often leads to bribery, corruption, nepotism, and worse. Furthermore, even a scrupulously honest government official who thought that a foreign company could do a better job than any of the national companies would have a lot of explaining to do.

This observation led to algorithm 2, holding a **lottery** among the interested companies. The problem with that idea is that companies with no interest in using the spectrum can enter the lottery. If, say, a fast food restaurant or shoe store chain wins, it can resell the spectrum to a carrier at a huge profit and with no risk.

Bestowing huge windfalls on alert but otherwise random companies has been severely criticized by many, which led to algorithm 3: **auction** off the bandwidth to the highest bidder. When the British government auctioned off the frequencies needed for third-generation mobile systems in 2000, it expected to get about $4 billion. It actually received about $40 billion because the carriers got into a feeding frenzy, scared to death of missing the mobile boat. This event switched on nearby governments' greedy bits and inspired them to hold their own auctions. It worked, but it also left some of the carriers with so much debt that they are close to bankruptcy. Even in the best cases, it will take many years to recoup the licensing fee.

A completely different approach to allocating frequencies is to not allocate them at all. Instead, let everyone transmit at will, but regulate the power used so that stations have such a short range that they do not interfere with each other. Accordingly, most governments have set aside some frequency bands, called the **ISM** (**Industrial, Scientific, Medical**) bands for unlicensed usage. Garage door openers, cordless phones, radio-controlled toys, wireless mice, and numerous other wireless household devices use the ISM bands. To minimize interference between these uncoordinated devices, the FCC mandates that all devices in the ISM bands limit their transmit power (e.g., to 1 watt) and use other techniques to spread their signals over a range of frequencies. Devices may also need to take care to avoid interference with radar installations. The location of these bands varies somewhat from country to country. In the United States, for example, the bands that networking devices use in practice without requiring a FCC license are shown in Fig. 1-23. The 900-MHz band was used for early versions of 802.11, but it is crowded. The 2.4-GHz band is available in most countries and widely used for 802.11b/g and Bluetooth, though it is subject to interference from microwave ovens and radar installations. The 5-GHz part of the spectrum includes **U-NII** (**Unlicensed National Information Infrastructure**) bands. The 5-GHz bands are relatively undeveloped but, since they have the most bandwidth and are used by 802.11a, they are quickly gaining in popularity.

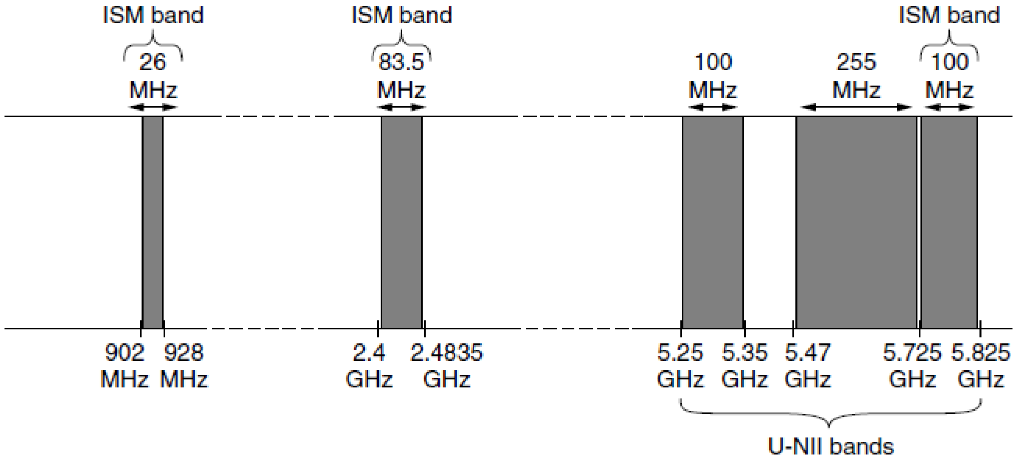


Figure 1-23The unlicensed bands have been a roaring success over the past decade.

The ability to use the spectrum freely has unleashed a huge amount of innovation in wireless LANs and PANs, evidenced by the widespread deployment of technologies such as 802.11 and Bluetooth. To continue this innovation, more spectrum is needed. One exciting development in the U.S. is the FCC decision in 2009 to allow unlicensed use of white spaces around 700 MHz. White spaces are frequency bands that have been allocated but are not being used locally. The transition from analog to all-digital television broadcasts in the U.S. in 2010 freed up white spaces around 700 MHz. The only difficulty is that, to use the white spaces, unlicensed devices must be able to detect any nearby licensed transmitters, including wireless microphones, that have first rights to use the frequency band.

Another flurry of activity is happening around the 60-GHz band. The FCC opened 57 GHz to 64 GHz for unlicensed operation in 2001. This range is an enormous portion of spectrum, more than all the other ISM bands combined, so it can support the kind of high-speed networks that would be needed to stream high-definition TV through the air across your living room. At 60 GHz, radio waves are absorbed by oxygen. This means that signals do not propagate far, making them well suited to short- range networks. The high frequencies (60 GHz is in the Extremely High Frequency or ‘‘millimeter’’ band, just below infrared radiation) posed an initial challenge for equipment makers, but products are now on the market.. ISM and U-NII bands used in the United States by wireless devices.

1.1.3 Infrared Transmission

Unguided infrared waves are widely used for short-range communication. The remote controls used for televisions, VCRs, and stereos all use infrared communication. They are relatively directional, cheap, and easy to build but have a major drawback: they do not pass through solid objects. (Try standing between your remote control and your television and see if it still works.) In general, as we go from long-wave radio toward visible light, the waves behave more and more like light and less and less like radio. On the other hand, the fact that infrared waves do not pass through solid walls well is also a plus. It means that an infrared system in one room of a building will not interfere with a similar system in adjacent rooms or buildings: you cannot control your neighbor's television with your remote control. Furthermore, security of infrared systems against eavesdropping is better than that of radio systems precisely for this reason. Therefore, no government license is needed to operate an infrared system, in contrast to radio systems, which must be licensed outside the ISM bands. Infrared communication has a limited use on the desktop, for example, to connect notebook computers and printers with the **IrDA** (**Infrared Data Association**) standard, but it is not a major player in the communication game.

1.1.4 Light Transmission

Unguided optical signaling or **free-space optics** has been in use for centuries. Paul Revere used binary optical signaling from the Old North Church just prior to his famous ride. A more modern application is to connect the LANs in two buildings via lasers mounted on their rooftops. Optical signaling using lasers is inherently unidirectional, so each end needs its own laser and its own photodetector. This scheme offers very high bandwidth at very low cost and is relatively secure because it is difficult to tap a narrow laser beam. It is also relatively easy to install and, unlike microwave transmission, does not require an FCC license. The laser's strength, a very narrow beam, is also its weakness here. Aiming a laser beam 1 mm wide at a target the size of a pin head 500 meters away requires the marksmanship of a latter-day Annie Oakley. Usually, lenses are put into the system to defocus the beam slightly. To add to the difficulty, wind and temperature changes can distort the beam and laser beams also cannot penetrate rain or thick fog, although they normally work well on sunny days. However, many of these factors are not an issue when the use is to connect two spacecraft.

One of the authors (AST) once attended a conference at a modern hotel in Europe at which the conference organizers thoughtfully provided a room full of terminals to allow the attendees to read their email during boring presentations. Since the local PTT was unwilling to install a large number of telephone lines for just 3 days, the organizers put a laser on the roof and aimed it at their university's computer science building a few kilometers away. They tested it the night before the conference and it worked perfectly. At 9 A.M. on a bright, sunny day, the link failed completely and stayed down all day. The pattern repeated itself the next two days. It was not until after the conference that the organizers discovered the problem: heat from the sun during the daytime caused convection currents to rise up from the roof of the building, as shown in Fig. 1-24. This turbulent air diverted the beam and made it dance around the detector, much like a shimmering road on a hot day. The lesson here is that to work well in difficult conditions as well as good conditions, unguided optical links need to be engineered with a sufficient margin of error.

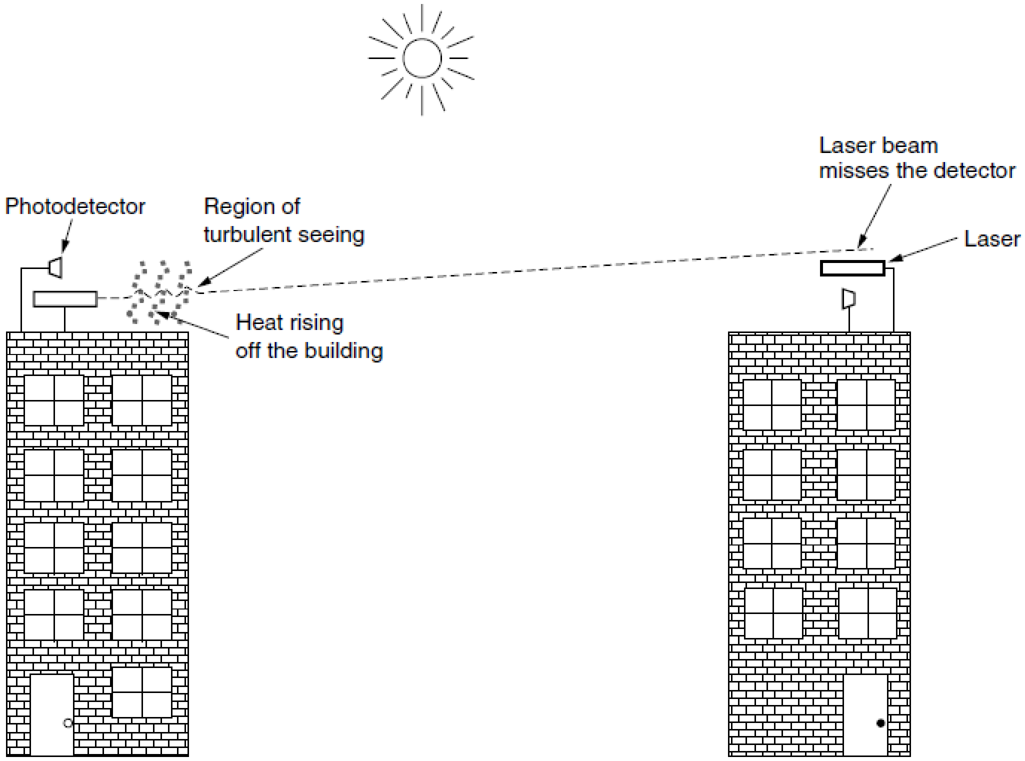

Laser beam misses the detector
Photodetector
Region of turbulent seeing
Laser
Heat rising off the building

Figure 1-24. Convection currents can interfere with laser communication systems.

A bidirectional system with two lasers is pictured here. Unguided optical communication may seem like an exotic networking technology today, but it might soon become much more prevalent. We are surrounded by cameras (that sense light) and displays (that emit light using LEDs and other technology). Data communication can be layered on top of these displays by encoding information in the pattern at which LEDs turn on and off that is below the threshold of human perception. Communicating with visible light in this way is inherently safe and creates a low-speed network in the immediate vicinity of the display. This could enable all sorts of fanciful ubiquitous computing scenarios.

The flashing lights on emergency vehicles might alert nearby traffic lights and vehicles to help clear a path. Informational signs might broadcast maps. Even festive lights might broadcast songs that are synchronized with their display.