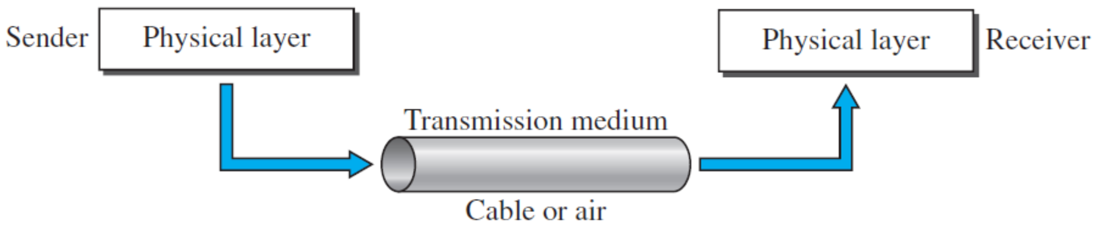
Chapter 6

Data communication and Networks

Network Performance & Transmission Media



6. Network Performance

In previous sections , we have discussed the tools of transmitting data (signals) over a network and how the data behave. In this section we discuss quality of service, an overall measurement of network performance.

6.1 Bandwidth

One characteristic that measures network performance is bandwidth. However, the term can be used in two different contexts with two different measuring values: 1) ***bandwidth in he****rtz* and 2) ***bandwidth in bits per second***.

1) Bandwidth in Hertz

We have discussed this concept. Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass. For example, we can say the bandwidth of a subscriber telephone line is 4 kHz.

2) Bandwidth in Bits per Seconds

The term bandwidth can also refer to the number of bits per second that a channel, a link, or even a network can transmit. For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps.

Relationship

There is an explicit relationship between the bandwidth in hertz and bandwidth in bits per second. Basically, an *increase in bandwidth in hertz* means an *increase in bandwidth in bits per second*. The relationship depends on whether we have *baseband transmission* or *transmission with modulation*.

In networking, we use the term bandwidth in two contexts.

- The first, bandwidth in **hertz**, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
- The second, bandwidth in **bits per second**, refers to the speed of bit transmission in a channel or link.

Example 6.1

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog.

Example 6.2

If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz, we can send 112,000 bps by using the same technology as mentioned in Example 6.1.

Therefore, an *increase in bandwidth in hertz* means an *increase in bandwidth in bits per second*.

6.2 Throughput

The throughput is a **measure** of how fast we can actually send data through a network. The bandwidth in bits per second and throughput are different. For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, if there is problem on the road, this number may be reduced to 100 cars per minute. The *bandwidth* is 1000 cars per minute; the *throughput* is 100 cars per minute.

Example 6.3

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\textbf{Throughput} = (12{,}000 \times 10{,}000) / 60 = 2 \text{ Mbps}$$

The **throughput** is almost *one-fifth* of the **bandwidth** in this case.

6.3 Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination. We can say that latency is made of four components: **propagation time, transmission time, queuing time** and **processing delay**.

Latency = propagation time + transmission time + queuing time + processing delay

Propagation Time

Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

Propagation time = Distance / (Propagation Speed)

The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal. For example, in a vacuum, light is propagated with a speed of 3×10^8 m/s. It is lower in air; it is much lower in cable.

Example 6.4

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

Solution

We can calculate the propagation time as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms: if there is a direct cable between the source and the destination.

Transmission Time

In data communications we don't send just 1 bit, we send a message. The transmission time of a message depends on the size of the message and the bandwidth of the channel.

Transmission time = (Message size) / Bandwidth

Example 6.5

What are the propagation time and the transmission time for a 2.5-KB (kilobyte) message (an email) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission time as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the *propagation time*, not the *transmission time*. The transmission time can be ignored.

Example 6.6

What are the propagation time and the transmission time for a 5-MB (megabyte) message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission times as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (5{,}000{,}000 \times 8) / 10^6 = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the *transmission time*, not the *propagation time*. The propagation time can be ignored.

Queuing Time

The third component in latency is the queuing time, the time needed for each intermediate or end device to hold the message before it can be processed. When there is heavy traffic on the network, the queuing time increases. An intermediate device, such as a **router**, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

6.4 Jitter

Another performance issue that is related to delay is jitter. We can roughly say that jitter is a problem if:

1) different packets of data encounter different delays, and
2) the application using the data at the receiver site is time-sensitive (audio and video data, for example).

If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets will make jitter.

6.5 Transmission Media

Transmission media are actually located below the physical layer and are directly controlled by the physical layer. Figure 6.1 shows the position of transmission media in relation to the physical layer.

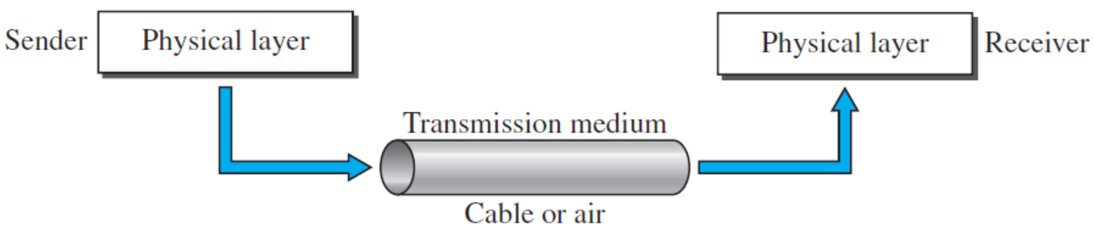


Figure 6.1 Transmission medium and physical layer

A **transmission medium** can be defined as anything that can carry information from a source to a destination. For example, the transmission medium for two people having a dinner conversation is the air.

In data communications the transmission medium is usually free space, metallic cable, or fibre-optic cable. The information is usually a signal that is the result of a conversion of data from another form.

categories: guided and unguided. Guided media include twisted-pair cable, coaxial cable, and fibre-optic cable. Unguided medium is free space. Figure 6.2 shows this taxonomy.

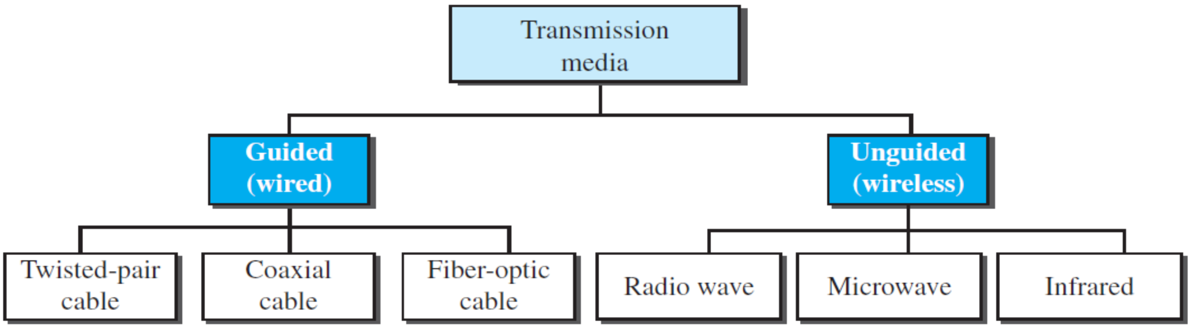


Figure 6.2 Classes of transmission media

6.5.1 Twisted-Pair Cable

A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure 6.3.

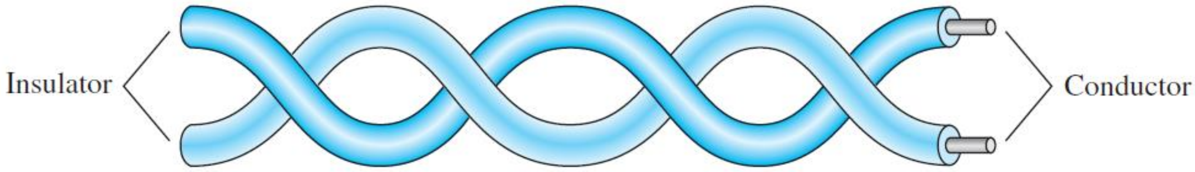
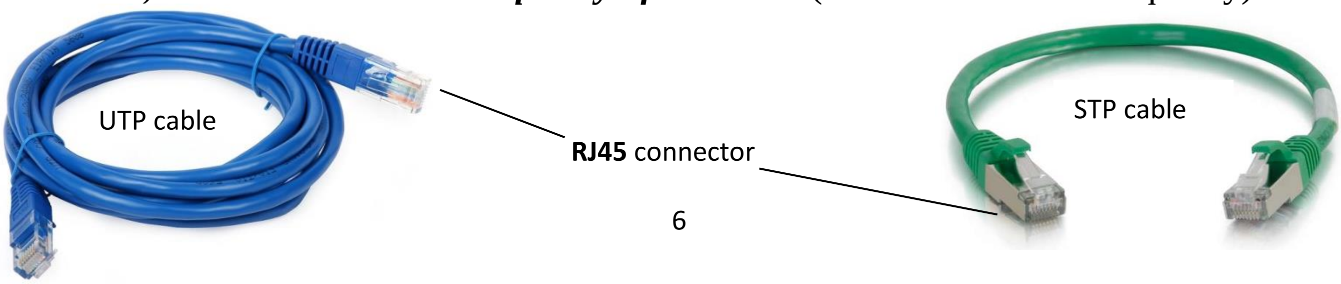


Figure 6.3 Twisted-pair cable

One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference. The receiver uses the difference between the two.

In addition to the signal sent by the sender on one of the wires, interference (noise) and crosstalk may affect both wires and create unwanted signals.

Twisting makes it probable that both wires are ***equally affected*** by external influences (noise or crosstalk). This means that the receiver, which calculates the difference between the two, receives no unwanted signals. The unwanted signals are mostly cancelled out. The ***number of twists*** per unit of length (e.g., inch) has some effect on the ***quality of the cable*** (more twists → more quality).



6.5.1.1 Unshielded Versus Shielded Twisted-Pair Cable

The most common twisted-pair cable used in communications is referred to as **unshielded twisted-pair (UTP)**. IBM has also produced a version of twisted-pair cable for its use, called **shielded twisted-pair (STP)**.

STP cable has a *metal foil* or *braided mesh covering* that encases each pair of insulated conductors. Although metal casing improves the quality of cable by preventing the noise or crosstalk, it is bulkier and more expensive. Figure 6.4 shows the difference between UTP and STP.

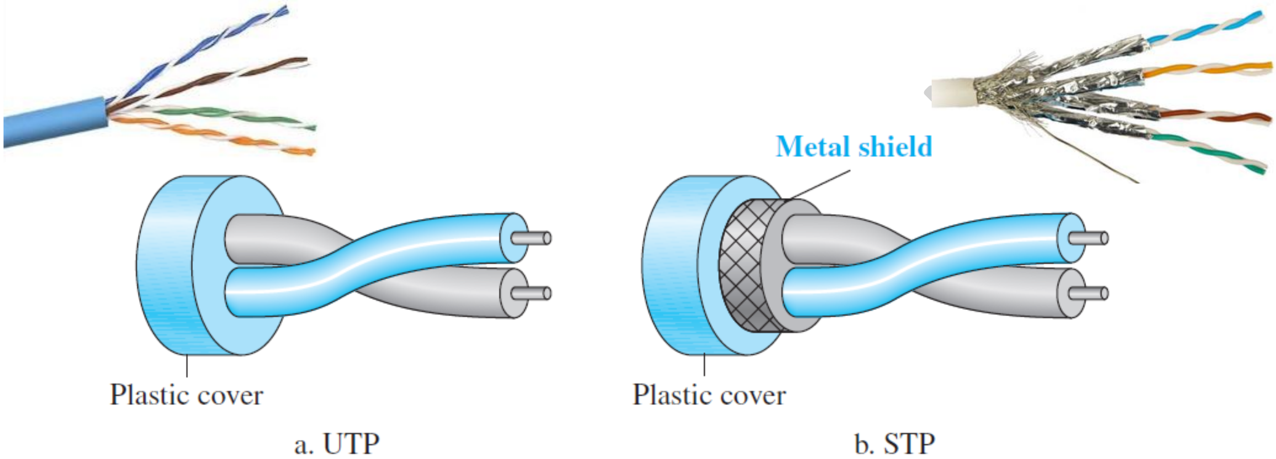
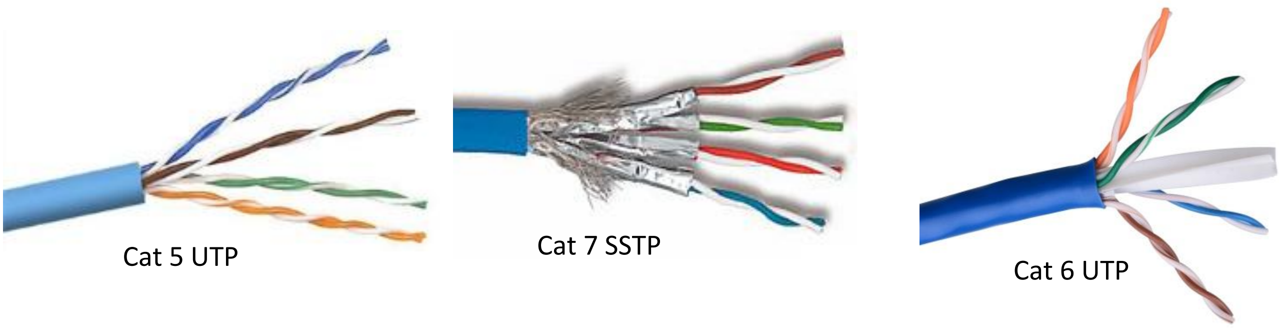


Figure 6.4 UTP and STP cables

6.5.1.2 Categories

Twisted-pair cables are classified into seven categories. These categories are determined by cable quality, for example:

1. **Category 1** (Cat 1) Unshielded twisted-pair used in telephone.
2. **Category 5** (Cat 5) Unshielded twisted-pair used in LANs with 100 Mbps data rate.
3. **Category 6** (Cat 6) A new category that must be tested at a 200-Mbps data rate.
4. **Category 7** Sometimes called **SSTP** (shielded screen twisted-pair). Each pair is individually wrapped in a metallic foil. The data rate is 600 Mbps.



6.5.2 Coaxial Cable

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted pair cable. Instead of having two wires, coax has a **inner core conductor** of solid wire (usually copper) and **outer conductor** serves both as a shield against noise and as the second conductor to completes the circuit (see Figure 6.5).

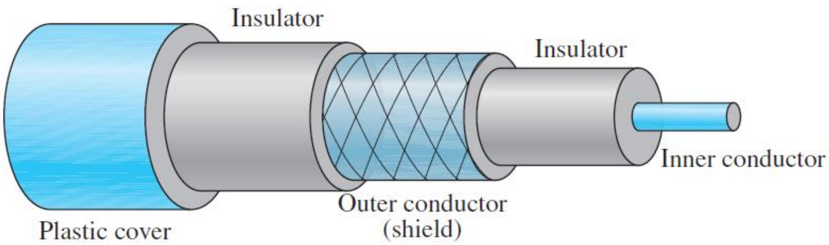


Figure 6.5 Coaxial cable

6.5.2.1 Coaxial Cable Standards

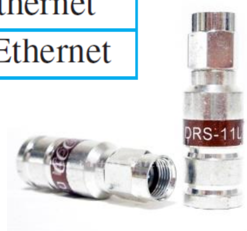
Coaxial cables are categorized by their Radio Government (**RG**) ratings. Each RG number denotes a unique set of physical specifications, such as the wire gauge of the inner conductor, the thickness and type of the inner insulator. Each cable defined by an RG rating is adapted for a specialized function, as shown in the following table.

Categories of coaxial cables

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

RG-59 cable and connectors

RG-58 cable and connectors



RG-11 cable and connectors

6.5.2.2 Coaxial cable applications

Coaxial cables are mainly used in the following:

1. **Telephone networks.** Coaxial cable was widely used in analog telephone networks. Later it was used in digital telephone networks. However, coaxial cable in telephone networks has largely been replaced today with fiberoptic cable.
2. **Cable TV networks**. In the traditional cable TV network, the entire network used coaxial cable. Later, however, cable TV providers replaced most of the media with fiber-optic cable (hybrid networks).
3. **Ethernet LANs**. The 10Base-2, or Thin Ethernet, uses RG-58 coaxial cable with BNC connectors to transmit data at 10 Mbps with a range of 185 m. The 10Base5, or Thick Ethernet, uses RG-11 (thick coaxial cable) to transmit 10 Mbps with a range of 5000 m.

6.5.3 Fiber-Optic Cable

A fiber-optic cable is made of glass or plastic and transmits signals in the form of light. Optical fibers use *reflection to guide light* through a channel. A glass or plastic core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is **reflected off** the cladding instead of being **refracted** into it. See Figure 6.6.

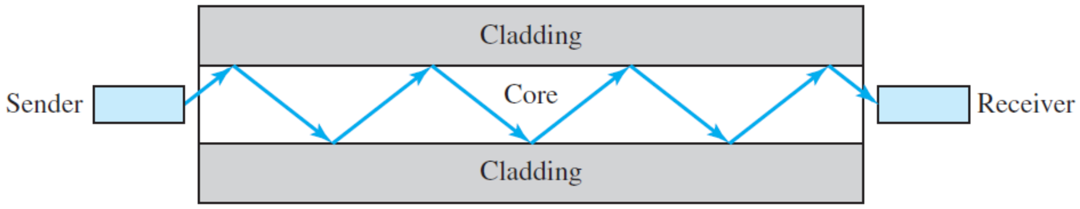
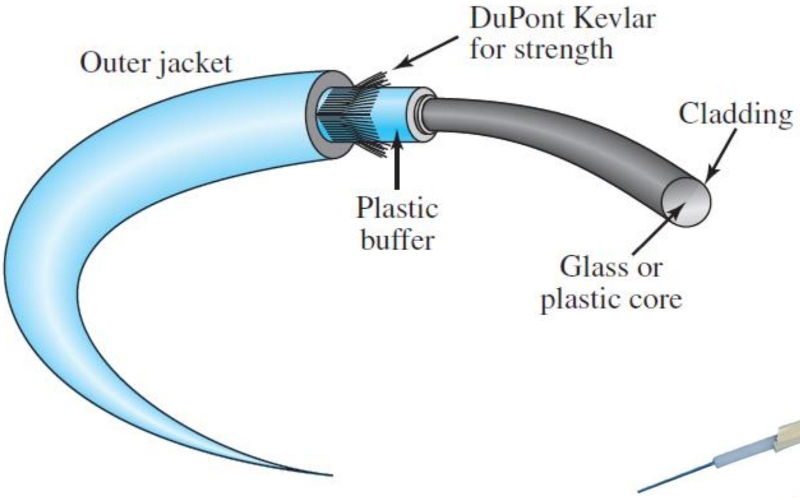


Figure 6.6 Optical fiber

6.5.3.1 Cable Composition

Figure 6.7 shows the composition of a typical fiber-optic cable. The outer jacket is made of either PVC or Teflon. Inside the jacket are Kevlar strands to strengthen the cable. Kevlar is a strong material used in the fabrication of bulletproof vests. Below the Kevlar is another plastic coating to cushion the fiber. The fiber is at the center of the cable, and it consists of cladding and core. Optical fibers are defined by the ratio of the diameter of their core to the diameter of their cladding both expressed in micrometers (for example 50/125µm or 100/125µm).



12 core 50/125

8 core 50/125

Figure 6.7 Fiber construction

6.5.3.2 Fiberoptic applications

Fiberoptics are mainly used in the following:

1. **Backbone networks**. Fiber-optic cable is often found in backbone networks (central large networks) because its wide bandwidth is cost-effective. Today, we can transfer data at a rate of 1600 Gbps.
2. **Cable TV networks**. Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network.
3. **Ethernet LANs**. Local-area networks such as 100Base-FX network (Fast Ethernet) and 1000Base-X also use fiber-optic cable.

Advantages of Optical Fiber

Fiber-optic cable has several advantages over metallic cable (twisted-pair or coaxial).

- **Higher bandwidth**. Fiber-optic cable can support higher bandwidths (and hence data rates) than either cables. Bandwidth utilization are

limited not by the fiber-optic cable **but by** the signal generation and reception technology available at LAN cards, switches, routers, etc.

- **Less signal attenuation**. A signal can run for 50 km without requiring regeneration.
- **No noise.** Electromagnetic noise cannot affect fiber-optic cables.
- **Resistance to corrosiveness**. Glass is more resistant to corrosive materials than copper.
- **Light weight**. Fiber-optic cables are much lighter than copper cables.

Disadvantages of Optical Fiber

- **Installation and maintenance**. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation**. Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.
- **Cost**. The cable and the interfaces are relatively more expensive than those of other copper media.

UNGUIDED MEDIA: WIRELESS

Unguided medium transport electromagnetic waves without using a physical conductor. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

Figure 6.8 shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication (Unguided medium).

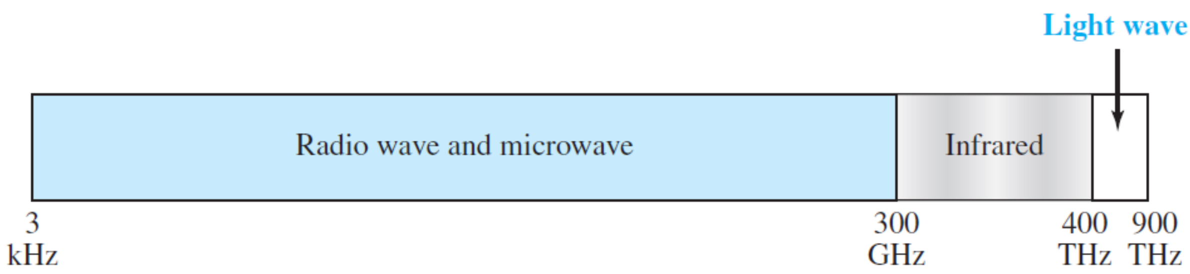


Figure 6.8 Electromagnetic spectrum for wireless communication

Unguided signals can travel from the source to the destination in several ways: **ground propagation**, **sky propagation**, and **line-of-sight propagation**, as shown in Figure 6.9.

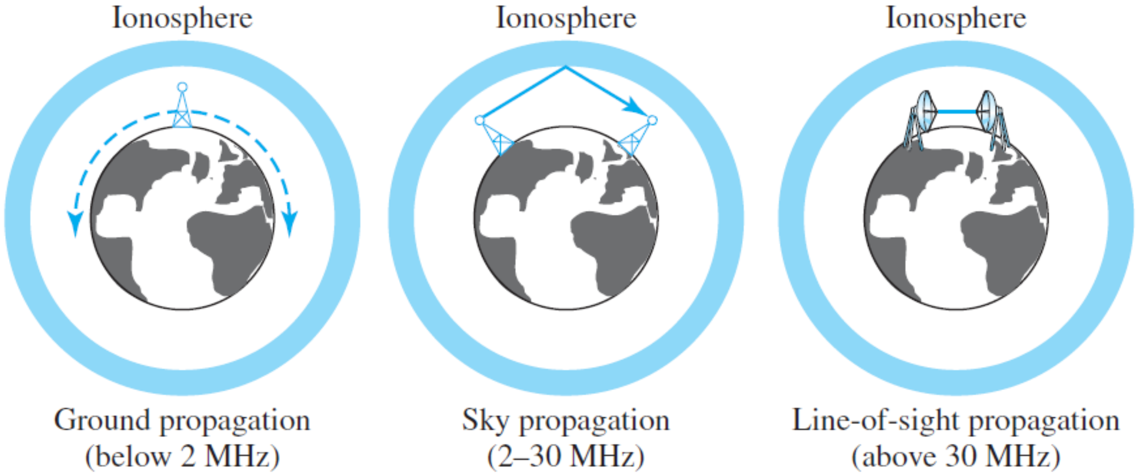


Figure 6.9 Propagation methods

In **ground propagation**, radio waves travel through the lowest portion of the atmosphere, hugging the earth. These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet.

In **sky propagation**, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere) where they are reflected back to earth. This type of transmission allows for greater distances with lower output power.

In **line-of-sight propagation**, very high-frequency signals are transmitted in straight lines directly from antenna to antenna. Antennas must be directional, facing each other.

The radio waves and microwaves is divided into eight ranges, called **bands**. These bands are rated from very low frequency (VLF) to extremely high frequency (EHF) as shown in the following table.

Band	*Range*	*Propagation*	*Application*
very low frequency (VLF)	3–30 kHz	Ground	Long-range radio navigation
low frequency (LF)	30–300 kHz	Ground	Radio beacons and navigational locators
middle frequency (MF)	300 kHz–3 MHz	Sky	AM radio
high frequency (HF)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft
very high frequency (VHF)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
ultrahigh frequency (UHF)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
superhigh frequency (SF)	3–30 GHz	Line-of-sight	Satellite
extremely high frequency (EHF)	30–300 GHz	Line-of-sight	Radar, satellite

We can divide wireless transmission into three broad groups: **radio waves**, **microwaves**, and **infrared** waves.

6.5.4 Radio Waves

Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio **waves**; waves ranging in frequencies between 1 and 300 GHz are called **microwaves**.

Radio waves, for the most part, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. **This means** that the sending and receiving antennas **do not have to be aligned**.

Radio waves, particularly those waves that propagate in the sky mode, can travel long distances. **This makes** radio waves a good candidate for long-distance broadcasting such as AM radio.

6.5.4.1 Omnidirectional Antenna

Radio waves use omnidirectional antennas that send out signals in all directions. Based on the wavelength, strength, and the purpose of transmission, we can have several types of antennas. Figure 6.10 shows an omnidirectional antenna.

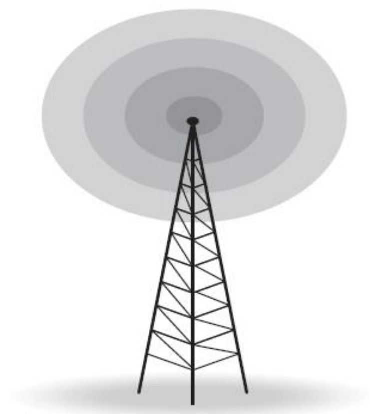


Figure 6.10 Omnidirectional antenna

6.5.4.2 Radio waves applications

The omnidirectional characteristics of radio waves make them useful for multicasting, in which there is one sender but many receivers. **AM and FM radio**, **television**, **maritime radio** and **paging systems** are examples of multicasting.

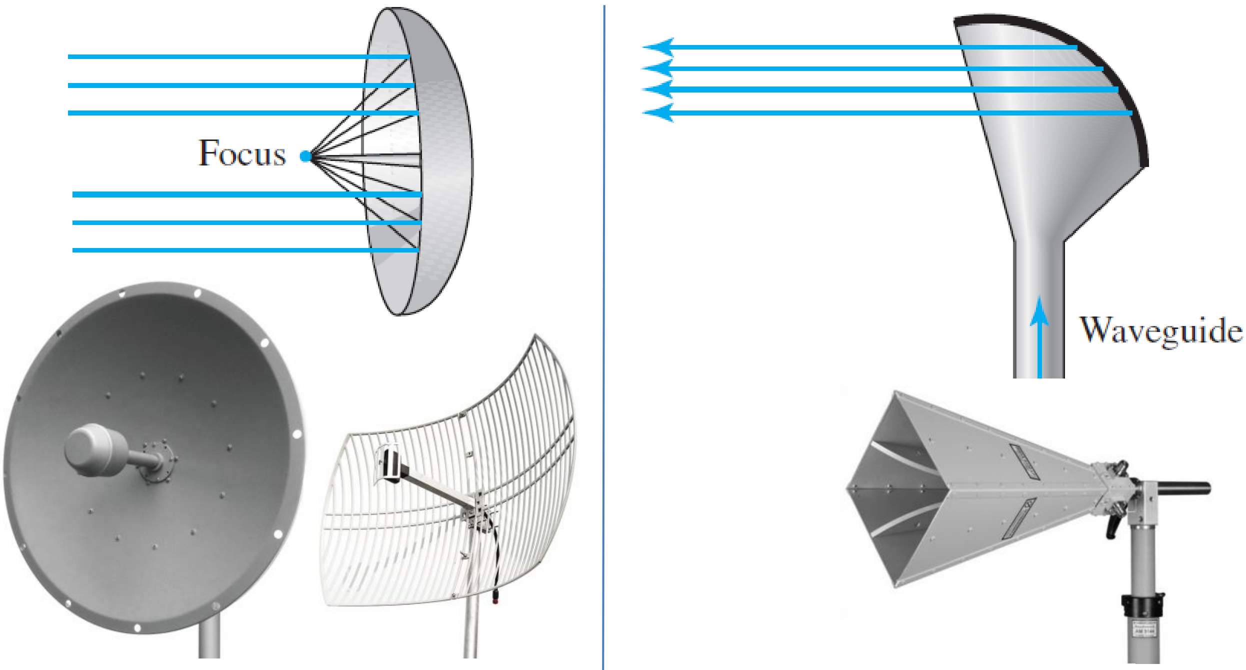
6.5.5 Microwaves

Microwaves have frequencies between 1 and 300 GHz. Microwaves are unidirectional. The sending and receiving antennas need to be aligned. A pair of antennas can be aligned without interfering with another pair of aligned antennas. Following describes some characteristics of microwave propagation:

- **Microwave propagation is line-of-sight.** Since the towers with the mounted antennas need to be in direct sight of each other.
- **Very high-frequency microwaves cannot penetrate walls**.
- **The microwave band is relatively wide**, almost 299 GHz.

6.5.5.1 Unidirectional Antenna

Microwaves need unidirectional antennas that send out signals in one direction. Two types of antennas are used for microwave communications: the parabolic dish and the horn (see Figure 6.11).



a. Parabolic dish antenna

b. Horn antenna

Figure 6.11 Unidirectional antennas

6.5.5.2 Microwave Applications

Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver. They are used in **cellular phones**, **satellite networks**, and **wireless LANs**.

6.5.6 Infrared waves

Infrared waves, with frequencies from 300 GHz to 400 THz, can be used for short-range communication.

Infrared waves, having high frequencies, cannot penetrate walls. This **advantageous characteristic** prevents interference between one system and another. When we use our infrared remote control, we do not interfere with the use of the remote by our neighbours.

We **cannot use** infrared waves outside a building **because** the sun's rays contain infrared waves that can interfere with the communication.

Infrared Applications

The infrared band, almost 400 THz, has an excellent potential for data transmission. Such a wide bandwidth can be used to transmit digital data with a very high data rate.

The **Infrared Data Association** (IrDA), an association for sponsoring the use of infrared waves, has established standards for using these signals for communication between devices such as **keyboards**, **mice**, **PCs**, and **printers**.

Infrared signals defined by IrDA transmit through **line of sight**; the IrDA port on the keyboard needs to point to the PC for transmission to occur.