Digital Transmission

A computer network is designed to send information from one point to another. This information needs to be converted to either a digital signal or an analog signal for transmission.

DIGITAL-TO-DIGITAL CONVERSION

We said that data can be either digital or analog. We also said that signals that represent data can also be digital or analog. In this section, **we see how we can represent digital data by using digital signals**. The conversion involves three techniques: **line coding, block coding**, and **scrambling**. Line coding is always needed, block coding and scrambling may or may not be needed.

Line Coding

Line coding is the process of converting digital data to digital signals. We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits. Line coding converts a sequence of bits to a digital signal. At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal.

Characteristics of Line Coding

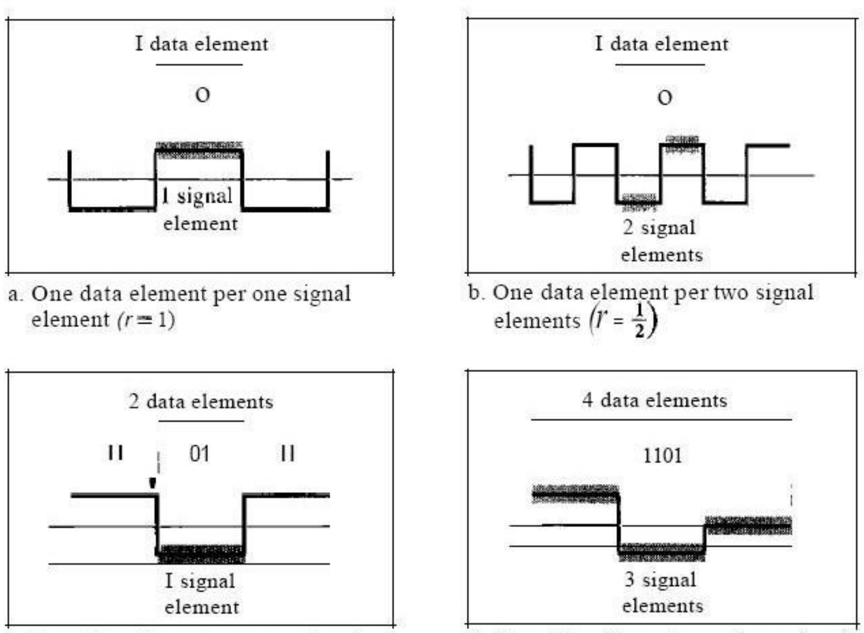
Signal Element Versus Data Element

Let us distinguish between a data element and a signal element. In data communications, our goal is to send data elements. A data element is the smallest entity that can represent a piece of information: this is the bit. In digital data communications**, a signal element carries data elements**. A signal element is the shortest unit (timewise) of a digital signal. In other words, data elements are what we need to send; signal elements are what we can send. Data elements are being carried; signal elements are the carriers.

We define a ratio **r** which is the number of data elements carried by each signal element.

Figure below shows several situations with different values of **r** .

Figure 4.2 *Signal element versus data element*



a. One data element per one signal element ($r = 1$)

b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$

c. Two data elements per one signal element ($r = 2$)

d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Data Rate Versus Signal Rate:

The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (**bps**). The signal rate is the number of signal elements sent in 1s. The unit is the **baud**. There are several common terminologies used in the literature. The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

One goal in data communications is to **increase the data rate while decreasing the signal rate.** Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement. In our vehicle-people analogy, we need to carry more people in fewer vehicles to prevent traffic jams. We have a limited bandwidth in our transportation system.

We now need to consider the relationship between data rate and signal rate (bit rate and baud rate). This relationship, of course, depends on the value of r. It also depends on the data pattern. If we have a data pattern of all 1s or all 0s, the signal rate may be different from a data pattern of alternating 0s and 1s. To derive a formula for the relationship, we need to define three cases: the worst,

best, and average. The worst case is when we need the maximum signal rate; the best case is when we need the minimum.

In data communications, we are usually interested in the average case. We can formulate the relationship between data rate and signal rate as

$S = c * N * (1/r)$ baud

where N is the data rate (bps); c is the case factor, which varies for each case; S is the number of signal elements; and r is the previously defined factor.

Example 4.1

A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and l?

Solution

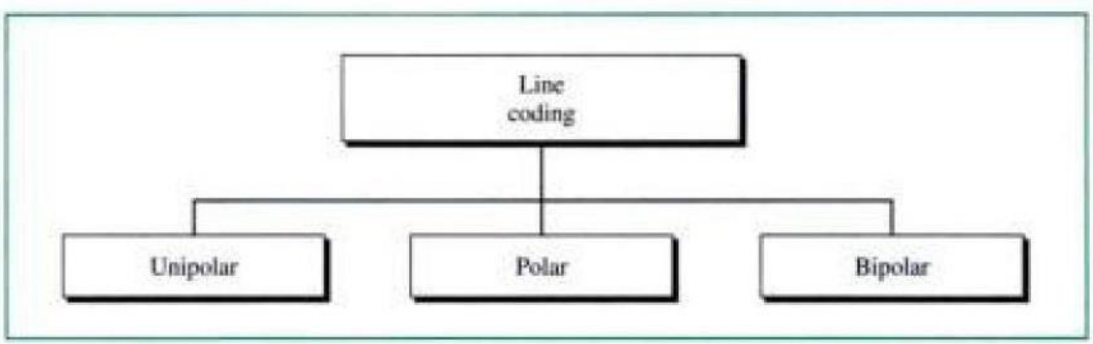
We assume that the average value of c is (1/2). The baud rate is then

$S = c * N * (1/r) = (1/2) * 100,000 * 1 = 50,000 = 50$ Kbaud

Line Coding Schemes

We can roughly divide line coding schemes into three broad categories, as shown in Figure below.

Figure 4.5 *Line coding schemes*



Unipolar Scheme

In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

NRZ (Non-Return-to-Zero) Traditionally, a unipolar scheme was designed as a

non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the

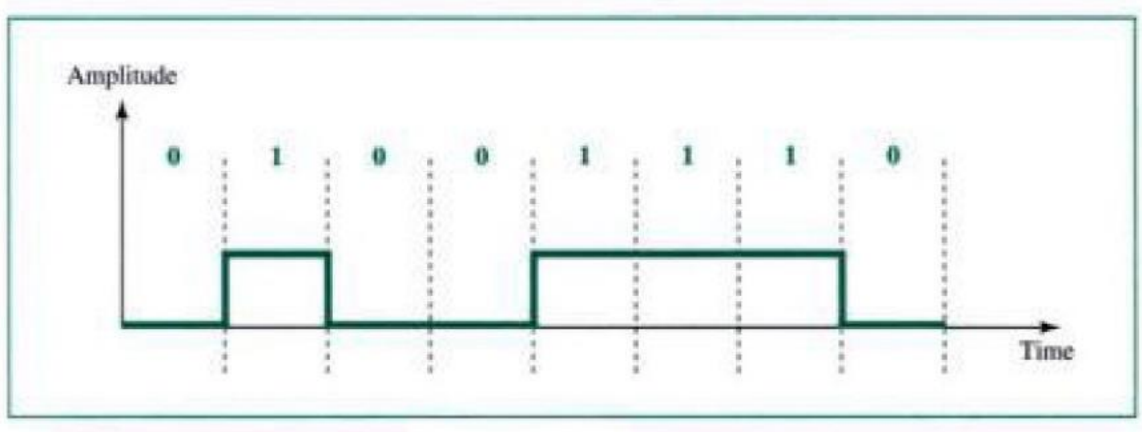
zero voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit. Figure 4.5 show a unipolar NRZ scheme.

Uni Polar

Uni Polar Encoding is very simple and very primitive. Uni Polar is so named because it uses only one polarity. This polarity is assigned to one of the two binary states, usually the 1 . the other state usually the 0 , is represented by zero voltage.

Figure (4.6) show the idea of uni polar encoding.

Figure 4.6 *Unipolar encoding*



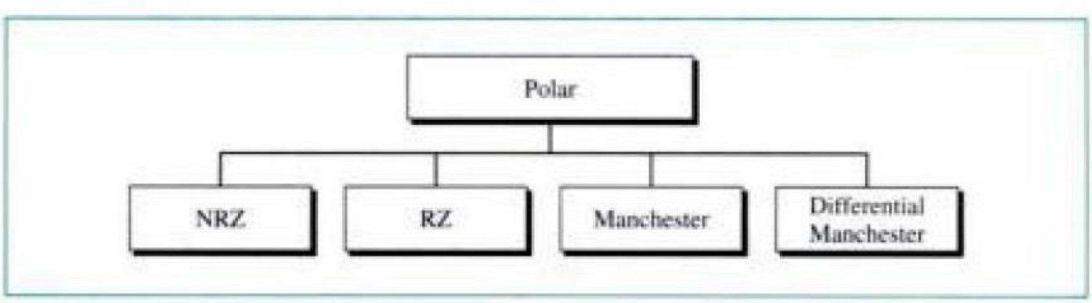
However, unipolar encoding has at least two problems that make it undesirable,a dc component and a lack of synchronization. The average amplitude of a unipolar is encoded as a nonzero.this create a dc component.Lack of synchronization is also an issue in unipolar encoding.if the data contains long sequence of 0's or 1's. there is no change in the signal during this duration that can alert the receiver to potential synchronization problem.

Polar Schemes

In polar schemes, the voltages are on the both sides of the time axis. For example, the voltage level for 0 can be positive and the voltage level for 1 can be negative.

There is 4 most popular variation of polar encoding: nonreturn to zero (NRZ), return to zero (RZ), Manchester, and differential Manchester (see fig 4.7).

Figure 4.7 *Types of polar encoding*



Nonreturn to Zero (NRZ) :

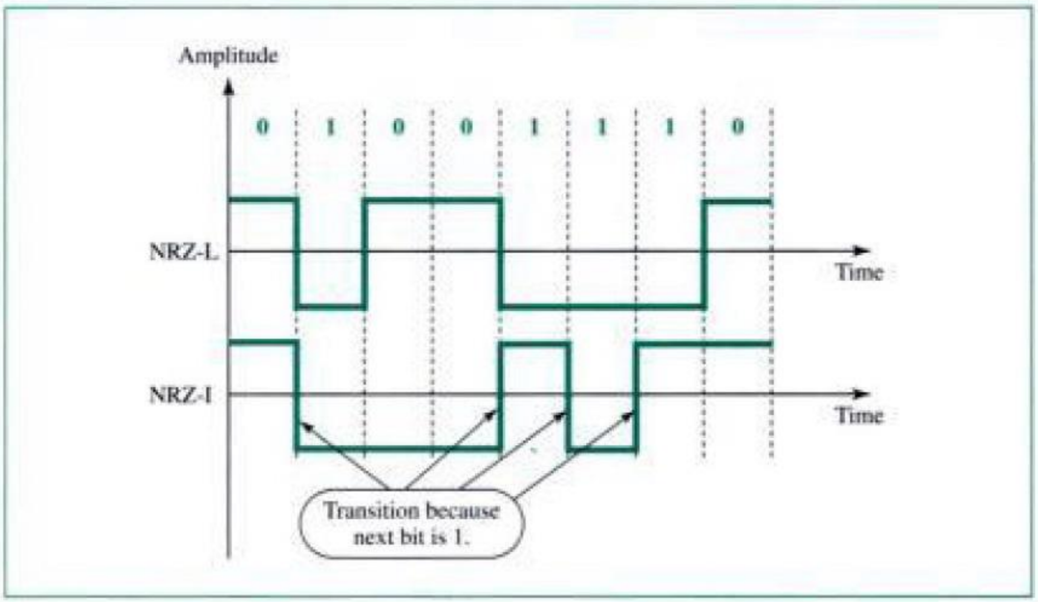
In NRZ encoding , the value of the signal is always either positive or negative. There are two popular forms of NRZ:

In NRZ-L (NRZ-Level) encoding the level of the signal depends on the type of bit that it represent, A positive voltage usually means the bit is a 0 , while a negative voltage means the bit is a 1.

In NRZ-I (NRZ-Invert) an inversion of the voltage level represent a 1 bit. It is the transition between a positive and a negative voltage , not the voltage itself. A 0 bit is represented by no change. If there is no change, the bit is 0; if there is a change, the bit is 1.

Figure below shows the NRZ-L and NRZ-I representation of the same series of bits.

Figure 4.8 *NRZ-L and NRZ-I encoding*

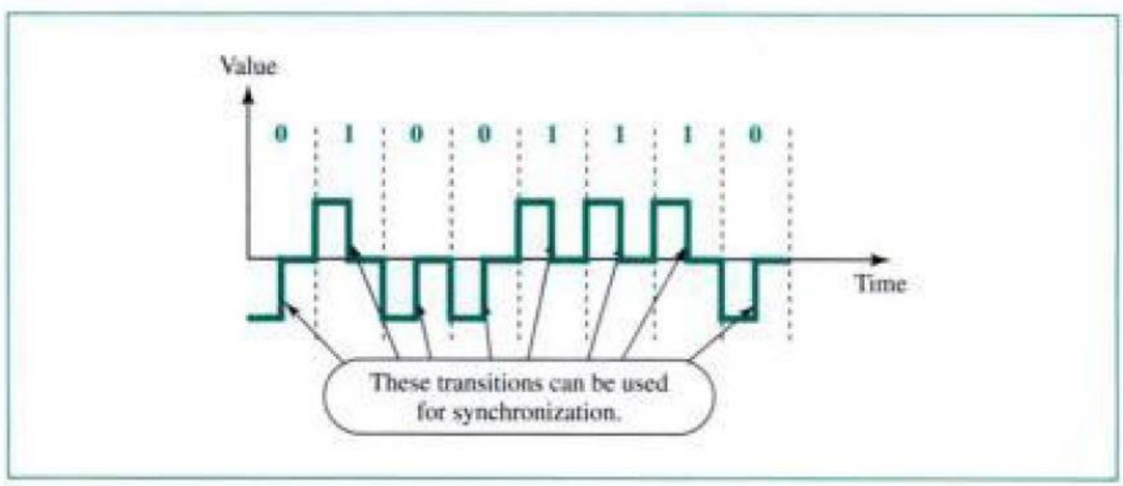


Return to Zero (RZ) :

RZ encoding uses three values, positive, negative and zero. In RZ the signal changes not between the bits but during each bit. A positive voltage means 1 and negative voltage means 0.halfway through each bit interval the signals returns to zero. A 1 bit is represented by positive-to-zero and a 0 bit represented by negative-to-zero. Fig (4.9)illustrate the concept.

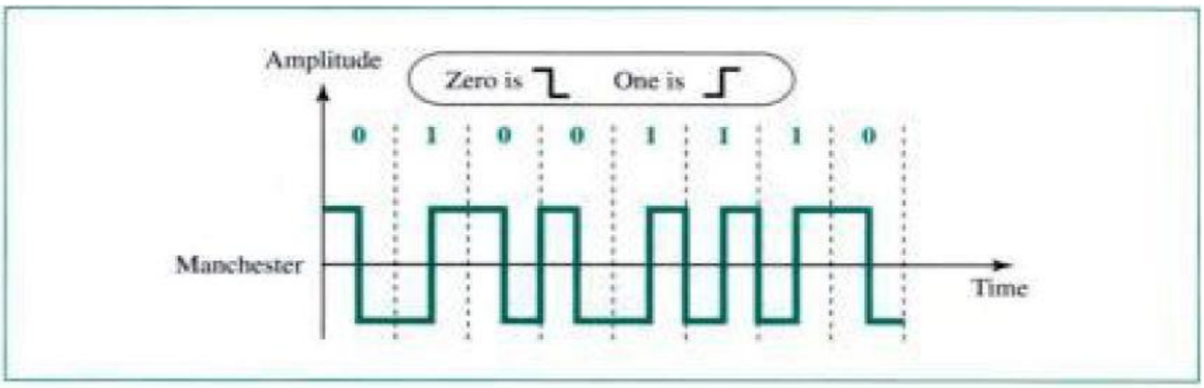
The main disadvantage of RZ encoding is that it requires two signals changes to encoded one bit and therefore occupies more bandwidth.

Figure 4.9 *RZ encoding*



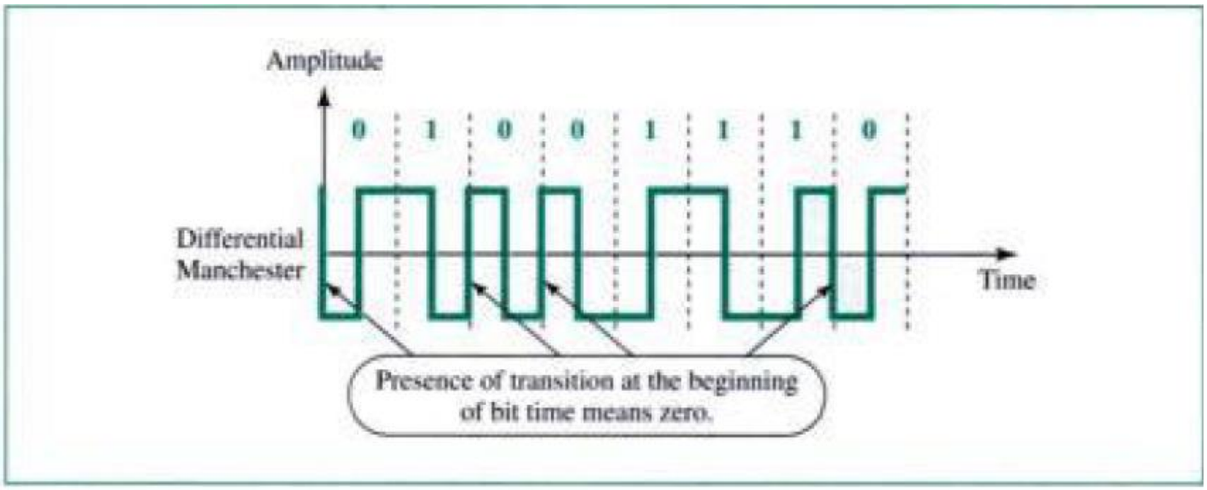
Manchester :

Manchester encoding uses an inversion at the middle of each bit interval for both synchronization and bit representation. A negative to positive transition represent binary 1, and a positive to negative transition represent binary 0. Figure (4.10) shows Manchester encoding .



Differential Manchester:

In differential Manchester encoding the inversion at the middle of bit interval is used for synchronization, but the presence or absence of an additional transition at the beginning of the interval is used to identify the bit, a transition means binary 0 and no transition means binary 1. Differential Manchester encoding requires two signal changes to represent binary 0 but only one to represent binary 1. figure (4.11) show Differential Manchester encoding.



Bipolar:

Bipolar encoding like RZ uses three voltage levels, positive , negative, and zero. The zero level in Bipolar encoding is used to represent binary 0 . the 1's are represented by alternating positive and negative voltages. If the first 1 bit is represented by the positive amplitude, the second will be represented by negative amplitude, the third by the positive amplitude and so on, and so on.

ANALOG -TO - DIGITAL CONVERSION

The techniques described in previous lecture convert digital data to digital signals. Sometimes, however, we have an analog signal such as one created by a microphone or camera. We have seen that a digital signal is superior to an analog signal. The tendency today is to change an analog signal to digital data. In this section we describe pulse code modulation techniques (PCM). After the digital data are created (digitization), we can use one of the techniques described to convert the digital data to a digital signal.

Pulse Code Modulation (PCM)

The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (**PCM**). A **PCM** encoder has three processes:

1. The analog signal is sampled.

2. The sampled signal is quantized.

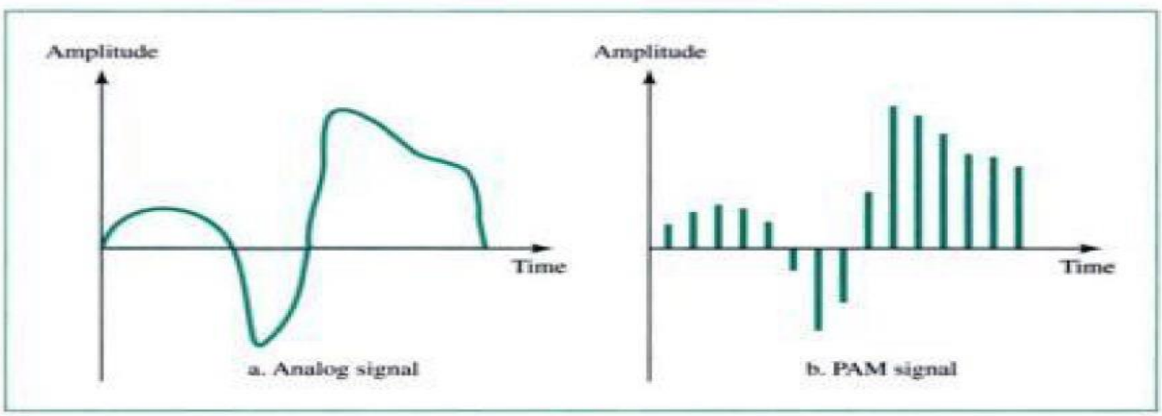
3. The quantized values are encoded as streams of bits.

Sampling

The first step in PCM is **sampling**. The term sampling means **measuring the amplitude of the signal at equal intervals**. The analog signal is sampled every **Ts** **s**, where **Ts** is the sample interval or period.

The sampling process is sometimes referred to as **pulse amplitude modulation** (**PAM**). We need to remember, however, that the result is still an analog signal with nonintegral values. In **PAM** , the original signal is sampled at equal intervals as shown in figure below .

Figure 4.18 *PAM*

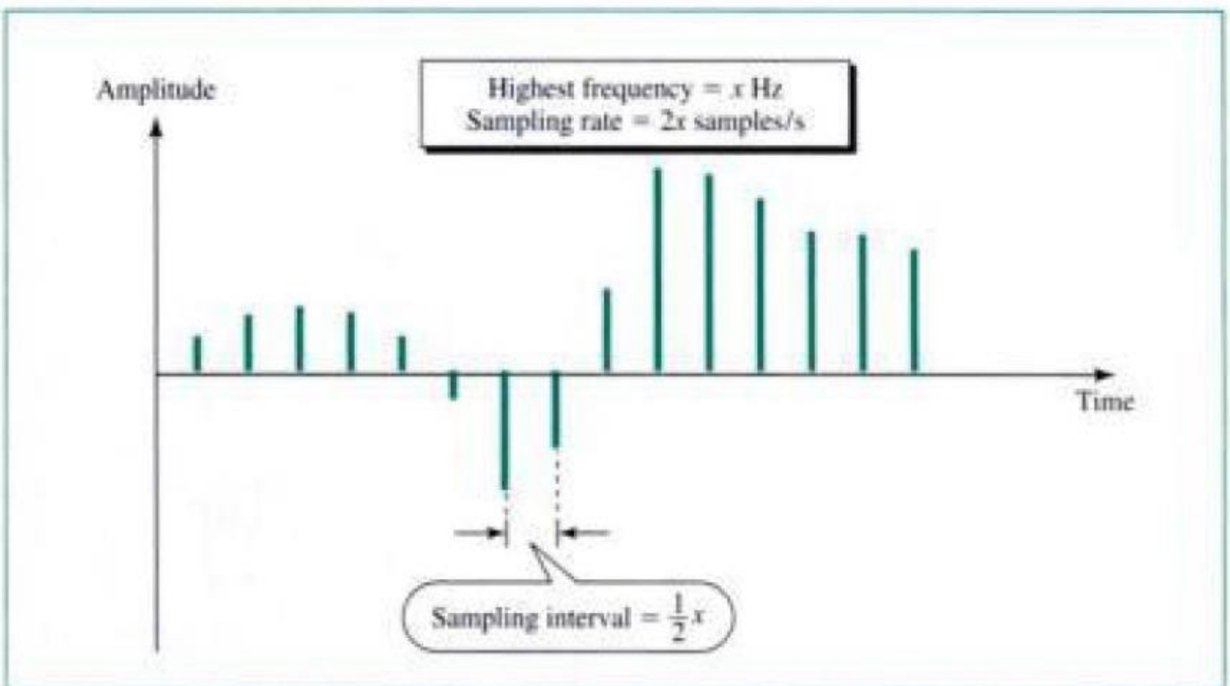


Sampling Rate

One important consideration is the sampling rate or frequency. What are the restrictions on Ts?. According to the **Nyquist theorem**, to reproduce the original analog signal, one necessary condition is that **the sampling rate must be at least twice the highest frequency in the original signal**. So if we want to sample telephone voice with a maximum frequency (4000 Hz) , we need sampling rate at (8000) sample per second.

A sampling rate of twice the frequency of x Hz means that the signal must be sampled every $1/2x$ seconds. Using the voice-over-phone-lines example above, that means one sample every 1/8000 s. Figure 4.23 illustrates the concept.

Figure 4.23 *Nyquist theorem*



Example: What a sampling rate is needed for a signal with a bandwidth of (10000 Hz) (1000 to 11000 Hz)?

Sol :

The sampling rate must be twice the highest frequency in the signal :

Sampling rate = 2 * (11000) = 22000 samples/s.

Example :

A complex low-pass signal has a bandwidth of 200 kHz. What is the minimum sampling rate for this signal?

Solution

The bandwidth of a low-pass signal is between 0 and f, where f is the maximum frequency in the signal. Therefore, we can sample this signal at 2 times the highest frequency (200 kHz). The sampling rate is therefore 400,000 samples per second.

Example

A complex bandpass signal has a bandwidth of 200 kHz. What is the minimum sampling rate for this signal?

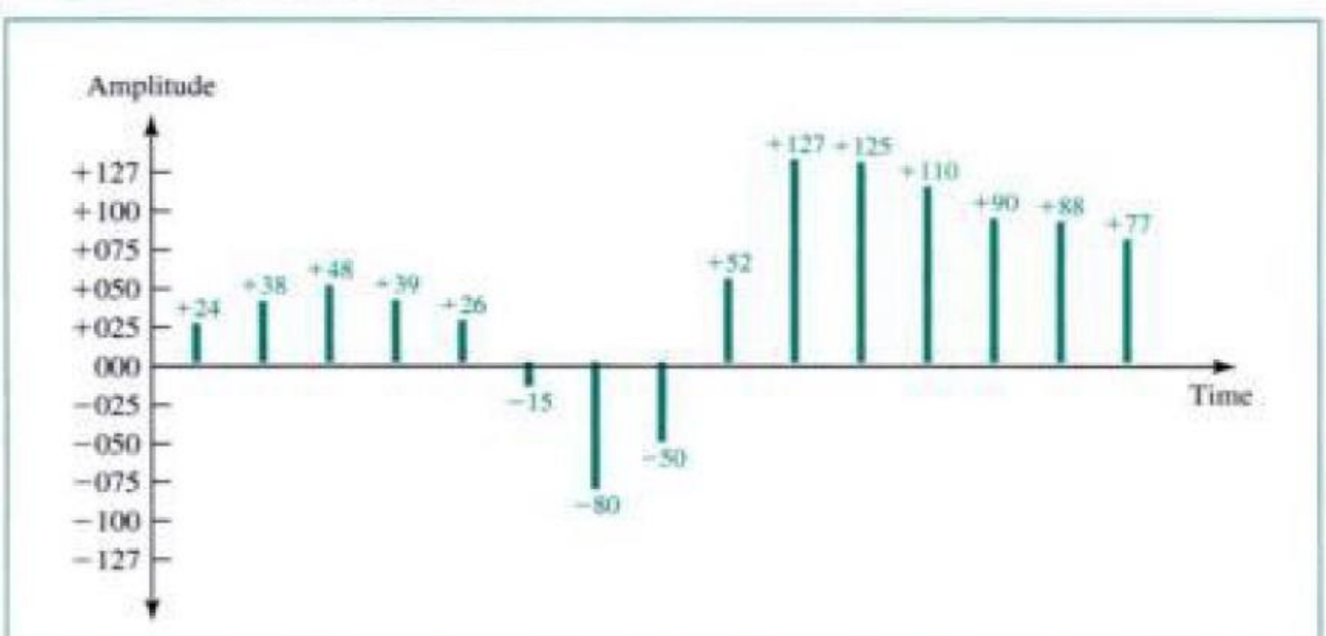
Solution

We cannot find the minimum sampling rate in this case because we do not know where the bandwidth starts or ends. We do not know the maximum frequency in the signal.

Quantization

The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal. PCM quantized the PAM pulses. **Quantization is a method of assigning integral values in a specific range to sampled instances**, the result of quantization is shown in figure below .

Figure 4.19 *Quantized PAM signal*



Encoding

The last step in PCM is encoding. After each sample is quantized and the number of bits per sample is decided, each sample translated to its binary equivalent.

Figure 4.20 shows a simple method of assigning sign and magnitude to quantized samples. Each value is translated into its 7-bit binary equivalent. The eighth bit indicates the sign.

Figure 4.20 *Quantizing by using sign and magnitude*

+024	00011000	−015	10001111	+125	01111101
+038	00100110	−080	11010000	+110	01101110
+048	00110000	−050	10110010	+090	01011010
+039	00100111	+052	00110110	+088	01011000
+026	00011010	+127	01111111	+077	01001101

Sign bit
+ is 0   − is 1

How many Bits per sample?

After we found the sampling rate, we need to determine the number of bits to be transmitted for each sample. This depends on the level of precision needed. The choice of **L**, the number of levels, depends on the range of the amplitudes of the analog signal and how accurately we need to recover the signal. If the amplitude of a signal fluctuates between two values only, we need only two levels; if the signal, like voice, has many amplitude values, we need more quantization levels.

Example:

A signal is sampled, each sample requires at least 12 levels of precision (+0 to +5 , - 0 to - 5), how many bits should be sent for each sample?

Sol:

We need 4 bits, 1 bit for the sign and 3 bits for the value; a 3 bits value can represent 2^3 = 8 levels (000 to 111) Which is more than what We need. A 2 bits value is not enough since (2^2 = 4). A 4 bits value is too much because (2^4 = 16).

Bit Rate

After finding the number of bits per sample, we can calculate the bit rate by using the following formula:

$$\text{Bit rate} = \text{sampling rate} \times \text{number of bits per sample}$$

Example 6

We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?

Solution

The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate is

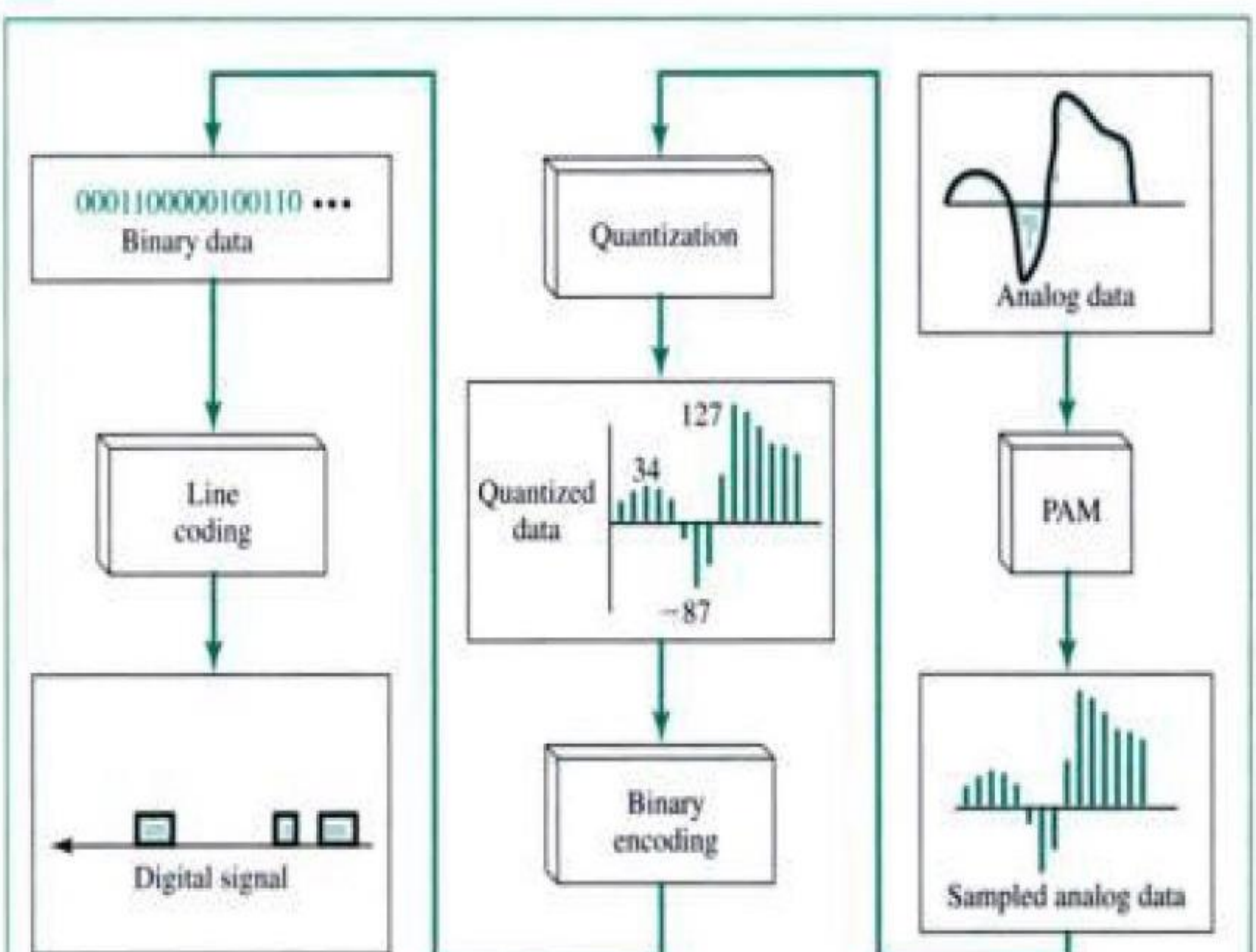
$$\text{Sampling rate} = 4000 \times 2 = 8000 \text{ samples/s}$$

The bit rate can be calculated as

$$\text{Bit rate} = \text{sampling rate} \times \text{number of bits per sample} = 8000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ Kbps}$$

PCM is actually made up from four separate processes, **PAM**, **Quantization**, **binary encoding** and **Line encoding**. figure below shows the entire process.

Figure 4.22 *From analog signal to PCM digital code*

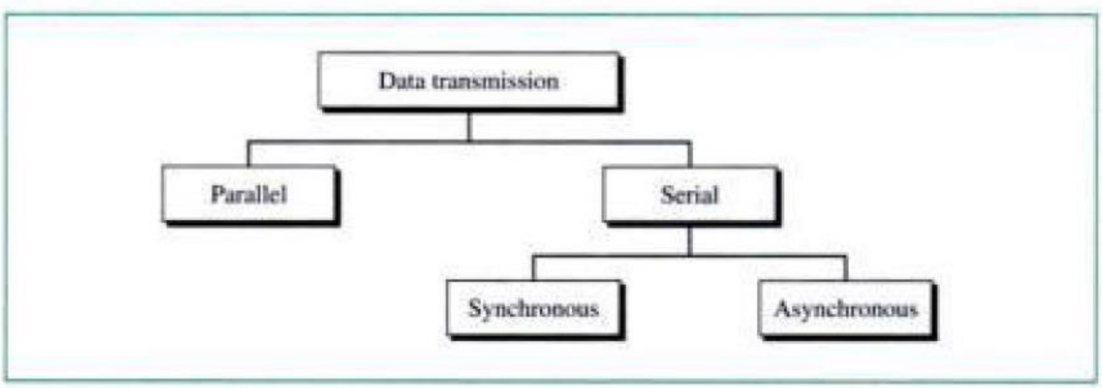


Transmission Modes

Of primary concern when we are considering the transmission of data from one device to another is the wiring, and of primary concern when we are considering the wiring is the data stream. Do we send 1 bit at a time; or do we group bits into larger groups and, if so, how? The transmission of binary data across a link can be accomplished in either parallel or serial mode. In parallel mode, multiple bits are sent with each clock tick.

In serial mode, 1 bit is sent with each clock tick. While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous (see Figure below).

Figure 4.24 *Data transmission*



Parallel Transmission

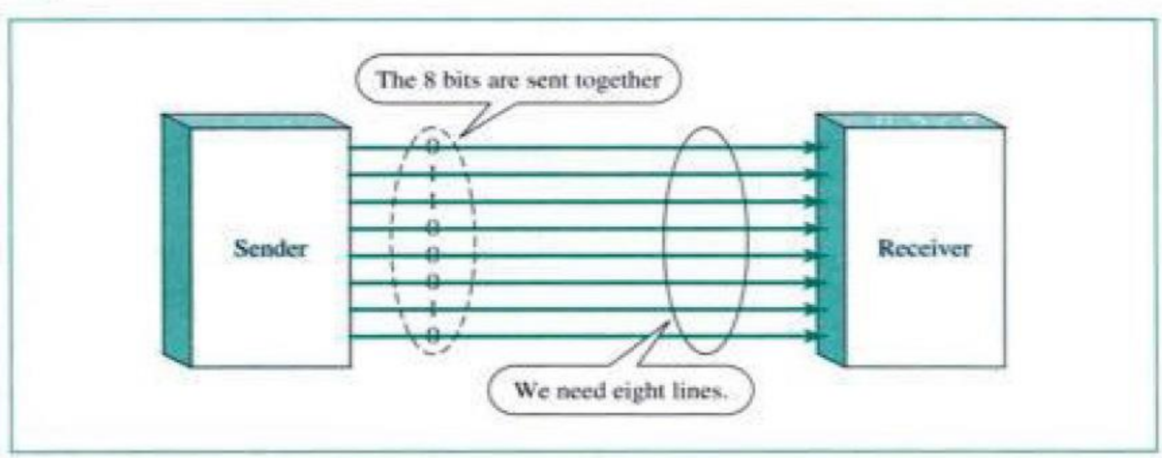
Binary data, consisting of 1s and 0s, may be organized into groups of n bits each. Computers produce and consume data in groups of bits much as we conceive of and use spoken language in the form of words rather than letters. By grouping, we can send data n bits at a time instead of 1. This is called parallel transmission.

The mechanism for parallel transmission is a conceptually simple one: Use n wires to send n bits at one time. That way each bit has its own wire, and all n bits of one group can be transmitted with each clock tick from one device to another. Figure 4.25 shows how parallel transmission works for n =8. Typically, the eight wires are bundled in a cable with a connector at each end.

The advantage of parallel transmission is speed. All else being equal, parallel

transmission can increase the transfer speed by a factor of n over serial transmission.

Figure 4.25 *Parallel transmission*

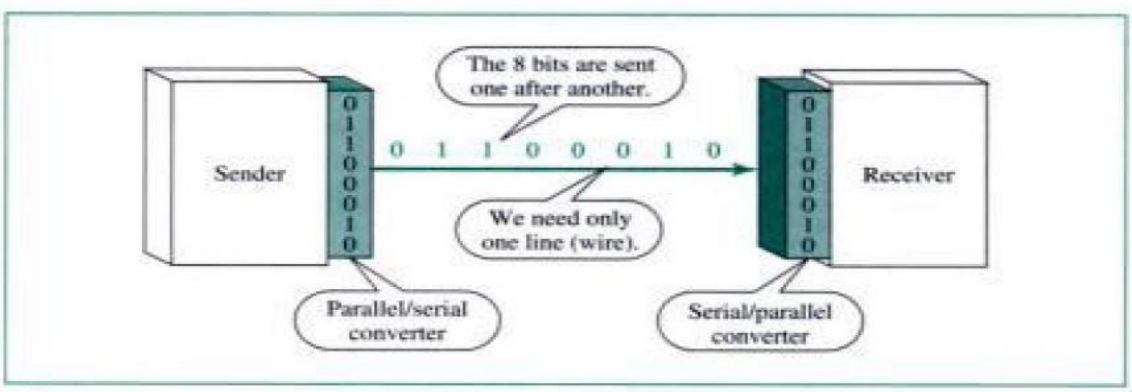


But there is a significant disadvantage: cost. Parallel transmission requires n communication lines (wires in the example) just to transmit the data stream. Because this is expensive, parallel transmission is usually limited to short distances.

Serial Transmission

In serial transmission one bit follows another, so we need only one communication channel rather than n to transmit data between two communicating devices (see Figure below).

Figure 4.26 *Serial transmission*



The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of n.

Since communication within devices is parallel, conversion devices are required at the interface between the sender and the line (parallel-to-serial) and between the line and the receiver (serial-to-parallel).

Serial transmission occurs in one of three ways: asynchronous, synchronous, and isochronous.

Asynchronous Transmission

Asynchronous transmission is so named because the timing of a signal is unimportant. Instead, information is received and translated by agreed upon patterns. As long as those patterns are followed, the receiving device can retrieve the information without regard to the rhythm in which it is sent. Patterns are based on grouping the bit stream into bytes. Each group, usually 8 bits, is sent along the link as a unit. The sending system handles each group independently, relaying it to the link whenever ready, without regard

to a timer. Without synchronization, the receiver cannot use timing to predict when the next group will arrive. To alert the receiver to the arrival of a new group, therefore, an extra bit is added to the beginning of each byte. This bit, usually a 0, is called the start bit.

To let the receiver know that the byte is finished, 1 or more additional bits are appended to the end of the byte. These bits, usually I s, are called stop bits. By this method, each byte is increased in size to at least 10 bits, of which 8 bits is information and 2 bits or more are signals to the receiver. In addition, the transmission of each byte may then be followed by a gap of varying duration. This gap can be represented either by an idle channel or by a stream of additional stop bits.

The start and stop bits and the gap alert the receiver to the beginning and end of each byte and allow it to synchronize with the data stream. This mechanism is called asynchronous because, at the byte level, the sender and receiver do not have to be synchronized.

But within each byte, the receiver must still be synchronized with the incoming bit stream. That is, some synchronization is required, but only for the duration of a single byte. The receiving device resynchronizes at the onset of each new byte.

When the receiver detects a start bit, it sets a timer and begins counting bits as they come in. After n bits, the receiver looks for a stop bit. As soon as it detects the stop bit, it waits until it detects the next start bit.

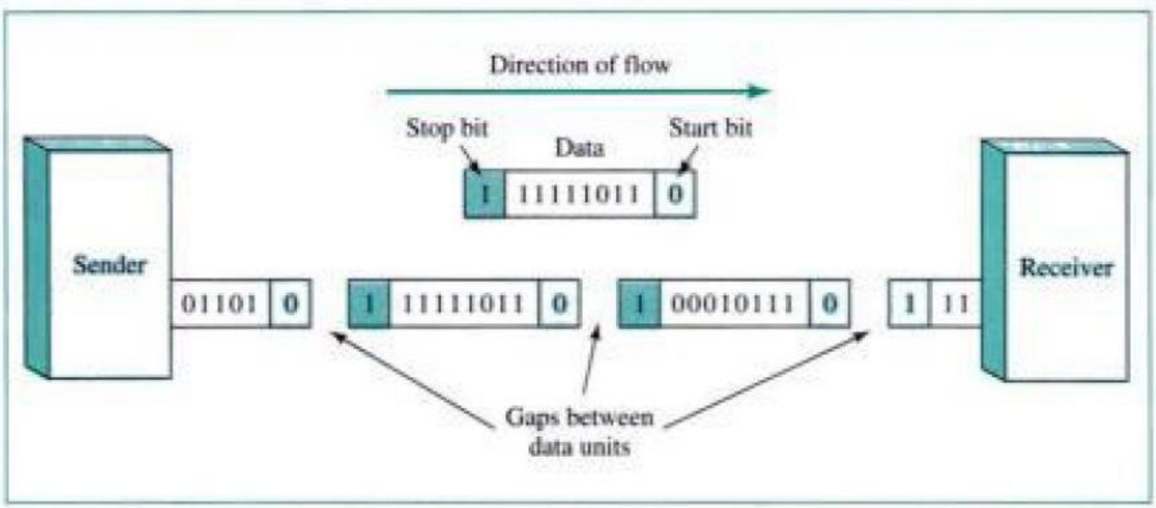
Figure 4.27 is a schematic illustration of asynchronous transmission. In this example, the start bits are as, the stop bits are 1s, and the gap is represented by an idle line rather than by additional stop bits.

The addition of stop and start bits and the insertion of gaps into the bit stream

make asynchronous transmission slower than forms of transmission that can operate without the addition of control information. But it is cheap and effective, two advantages that make it an attractive choice for situations such as low-speed communication.

For example, the connection of a keyboard to a computer is a natural application for asynchronous transmission. A user types only one character at a time, types extremely slowly in data processing terms, and leaves unpredictable gaps of time between each character.

Figure 4.27 *Asynchronous transmission*



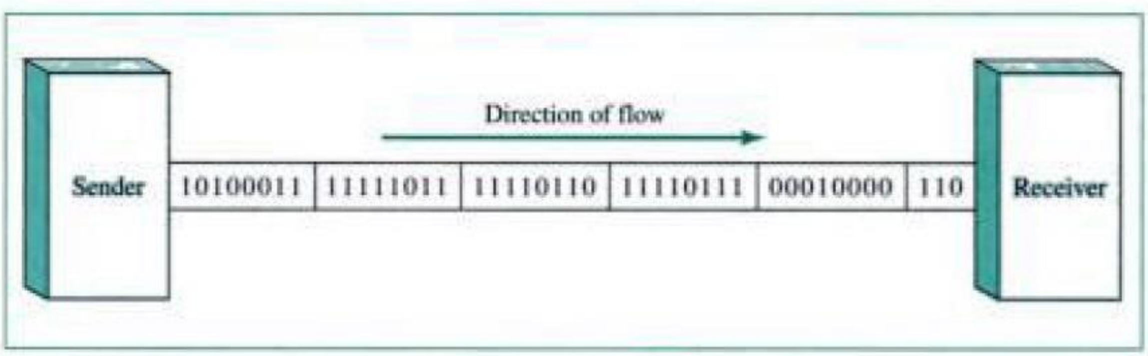
Synchronous Transmission

In synchronous transmission, the bit stream is combined into longer "frames," which may contain multiple bytes. Each byte, however, is introduced onto the transmission link without a gap between it and the next one. It is left to the receiver to separate the bit stream into bytes for decoding purposes. In other words, data are transmitted as an unbroken string of 1s and Os, and the receiver separates that string into the bytes, or characters, it needs to reconstruct the information.

Figure 4.28 gives a schematic illustration of synchronous transmission. We have

drawn in the divisions between bytes. In reality, those divisions do not exist; the sender puts its data onto the line as one long string. If the sender wishes to send data in separate bursts, the gaps between bursts must be filled with a special sequence of 0s and 1s that means idle. The receiver counts the bits as they arrive and groups them in 8-bit units.

Figure 4.28 *Synchronous transmission*



Without gaps and start and stop bits, there is no built-in mechanism to help the

receiving device adjust its bit synchronization midstream. Timing becomes very important, therefore, because the accuracy of the received information is completely dependent on the ability of the receiving device to keep an accurate count of the bits as they come in.

The advantage of synchronous transmission is speed. With no extra bits or gaps to introduce at the sending end and remove at the receiving end, and, by extension, with fewer bits to move across the link, synchronous transmission is faster than asynchronous transmission. For this reason, it is more useful for high-speed applications such as the transmission of data from one computer to another. Byte synchronization is accomplished in the data link layer.

We need to emphasize one point here. Although there is no gap between characters in synchronous serial transmission, there may be uneven gaps between frames.

Isochronous

In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails. For example, TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate. If each image is sent

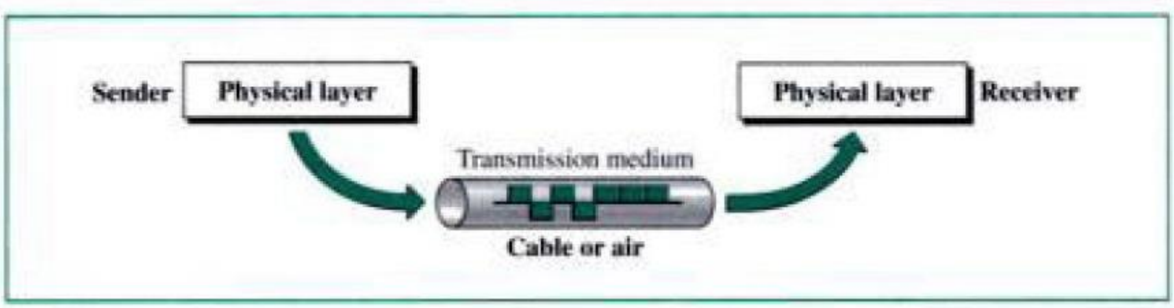
by using one or more frames, there should be no delays between frames. For this type of application, synchronization between characters is not enough; the entire stream of bits must be synchronized. The isochronous transmission guarantees that the data arrive at a fixed rate.

Transmission Media

Introduction:

You could say that transmission media belong to layer zero. Figure 7.1 shows the position of transmission media in relation to the physical layer.

Figure 7.1 *Transmission medium and physical layer*



A transmission medium can be broadly defined as anything that can carry information from a source to a destination.

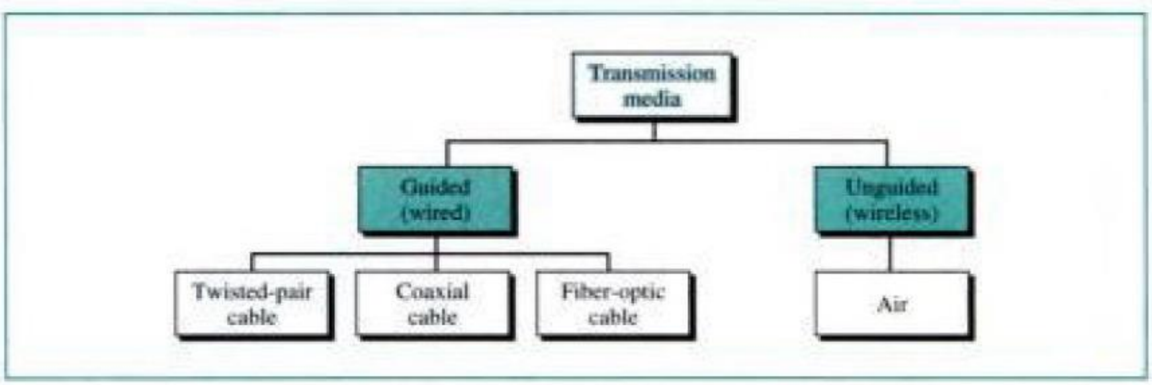
In data communications the definition of the information and the transmission

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

In telecommunications, transmission media can be divided into two broad categories:

guided and unguided. Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable. Unguided medium is free space. Figure 7.2 shows this taxonomy.

Figure 7.2 *Classes of transmission media*



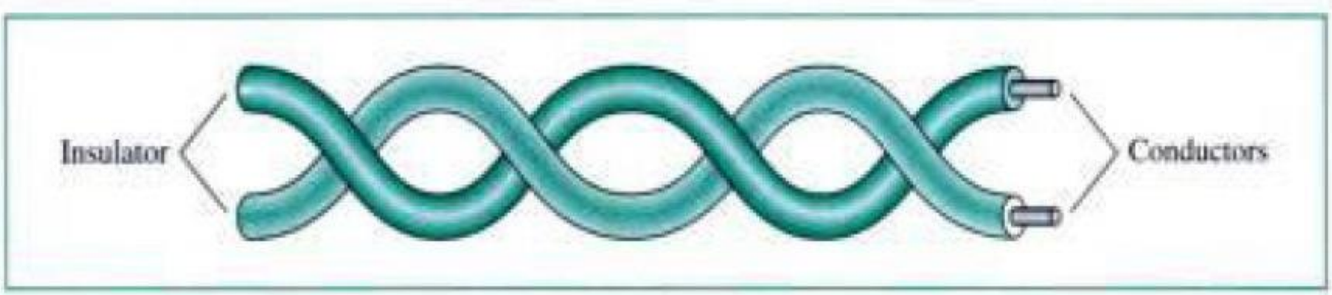
7.1 GUIDED MEDIA

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable. A signal traveling along any of these media is directed and contained by the physical limits of the medium. Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current. Optical fiber is a cable that accepts and transports signals in the form of light.

Twisted-Pair Cable

A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure 7.3.

Figure 7.3 *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.

If the two wires are parallel, the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources (e,g., one is closer and the other is farther). This results in a difference at the receiver. By twisting the pairs, a balance is maintained. For example, suppose in one twist, one wire is closer to the noise source and the other is farther; in the next twist, the reverse is true.

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 canceled out.

From the above discussion, it is clear that the number of twists per unit of length

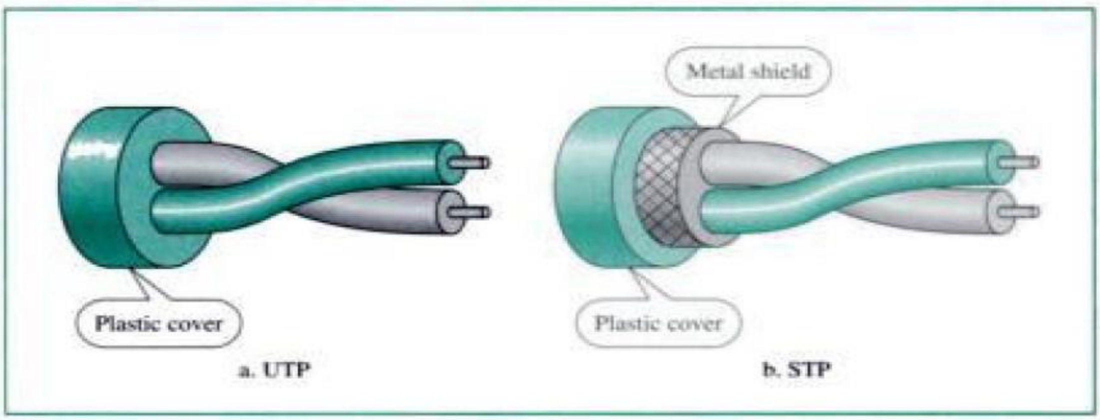
(e.g., inch) has some effect on the quality of the cable.

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 braidedmesh covering that encases each pair of insulated conductors. Although metal casing improves the quality of cable by preventing the penetration of noise or crosstalk, it is bulkier and more expensive. Figure 7.4 shows the difference between UTP and STP.

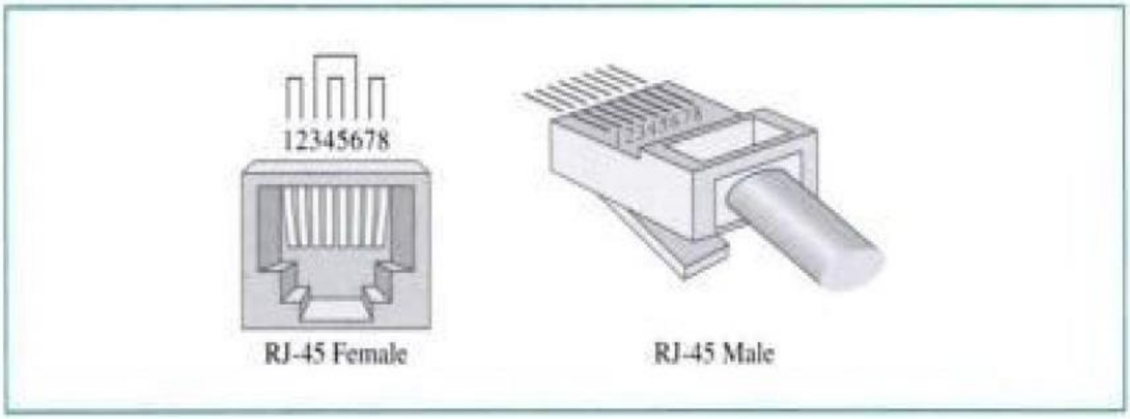
Figure 7.4 *UTP and STP*



Connectors

The most common UTP connector is RJ45 (RJ stands for registered jack), as shown in Figure 7.5. The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.

Figure 7.5 *UTP connector*



Applications

Twisted-pair cables are used in telephone lines to provide voice and data channels.

The local loop-the line that connects subscribers to the central telephone office---commonly consists of unshielded twisted-pair cables.

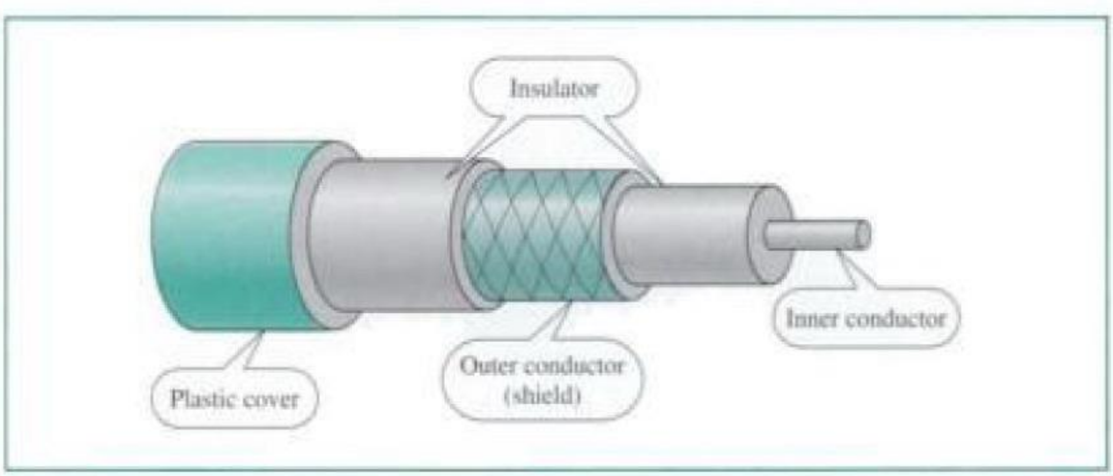
The DSL lines that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables. Local-area networks, such as l0Base-T and l00Base-T, also use twisted-pair cables.

Coaxial Cable

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted pair cable, in part because the two media are constructed quite differently. Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two. The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit.

This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover (see Figure 7.7).

Figure 7.7 *Coaxial cable*



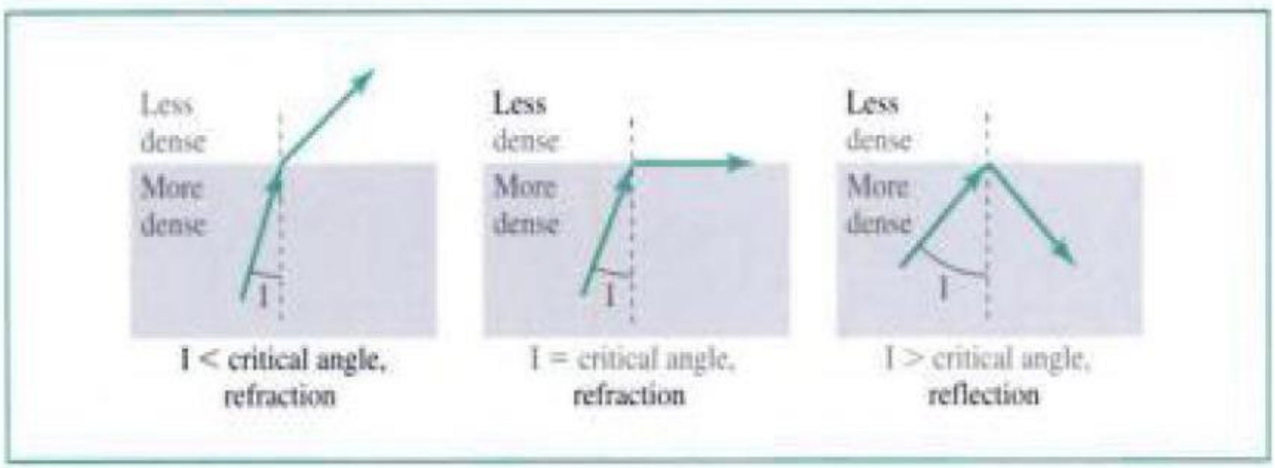
Applications

Coaxial cable was widely used in analog telephone networks where a single coaxial network could carry 10,000 voice signals. Later it was used in digital telephone networks where a single coaxial cable could carry digital data up to 600 Mbps. However, coaxial cable in telephone networks has largely been replaced today with fiber-optic cable. Cable TV networks also use coaxial cables.

Fiber-Optic Cable

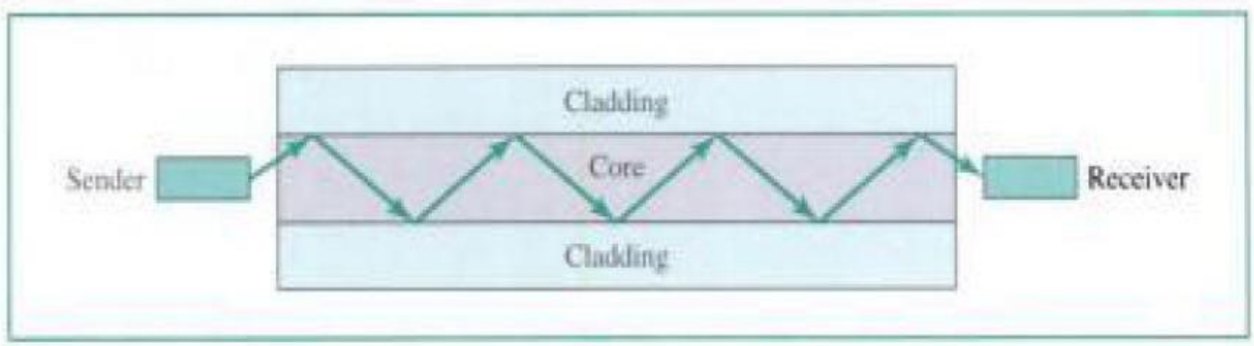
A fiber-optic cable is made of glass or plastic and transmits signals in the form of light. To understand optical fiber, we first need to explore several aspects of the nature of light. Light travels in a straight line as long as it is moving through a single uniform substance. If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction. Figure 7.10 shows how a ray of light changes direction when going from a more dense to a less dense substance.

Figure 7.10 *Bending of light ray*



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 7.11.

Figure 7.11 *Optical fiber*



Applications

Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective.

Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network. Optical fiber provides the backbone structure while coaxial cable provides the connection to the user premises.

Local-area networks such as 100Base-FX network (Fast Ethernet) and 1000Base-X also use fiber-optic cable.

Advantages and Disadvantages of Optical Fiber

Advantages Fiber-optic cable has several advantages over metallic cable (twistedpair or coaxial).

1- Higher bandwidth. Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.

2- Less signal attenuation. Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.

3- Immunity to electromagnetic interference. Electromagnetic noise cannot affect fiber-optic cables.

4- Resistance to corrosive materials. Glass is more resistant to corrosive materials than copper.

5- Light weight. Fiber-optic cables are much lighter than copper cables.

6- Greater immunity to tapping. Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages

There are some disadvantages in the use of optical fiber.

1- Installation and maintenance. Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.

2- Unidirectional light propagation. Propagation of light is unidirectional. If we

need bidirectional communication, two fibers are needed.

3- Cost. The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber

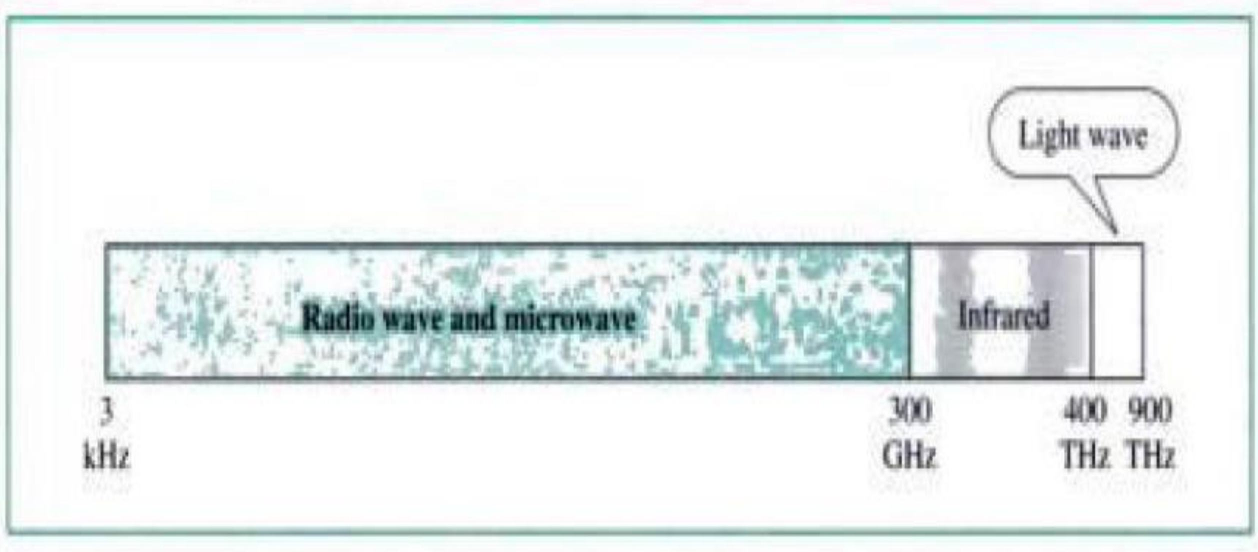
cannot be justified.

Unguided Media: Wireless

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

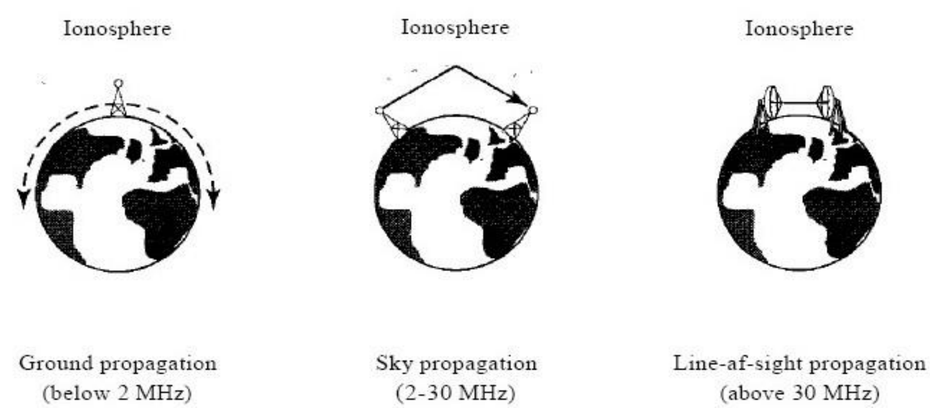
Figure 7.17 shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication.

Figure 7.17 *Electromagnetic spectrum for wireless communication*



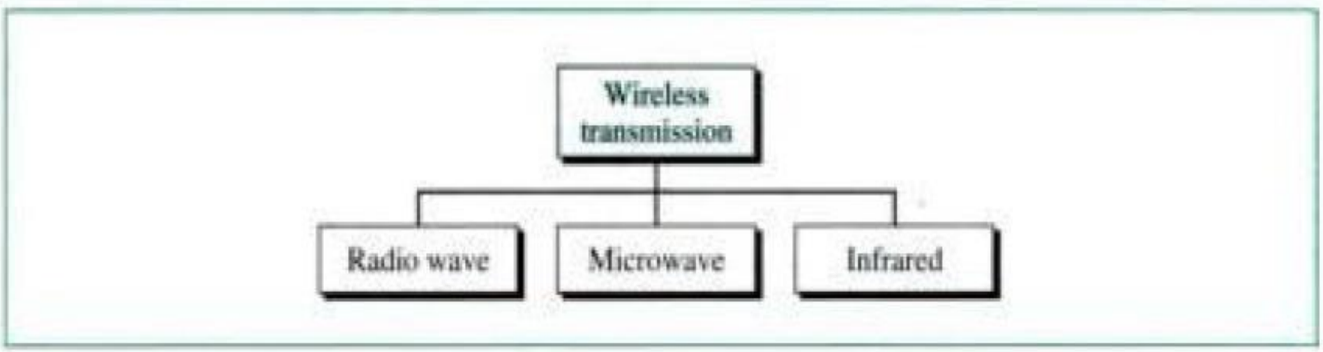
Unguided signals can travel from the source to destination in several ways: ground propagation, sky propagation, and line-of-sight propagation, as shown in Figure 7.18.

Figure 7.18 *Propagation methods*



We can divide wireless transmission into three broad groups: radio waves, microwaves, and infrared waves. See Figure 7.19.

Figure 7.19 *Wireless transmission waves*



Radio Waves

Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves; 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. A sending antenna sends waves that can be received by any receiving antenna. The omnidirectional property has a disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.

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.

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, cordless phones, and paging are examples of multicasting.

Microwaves

Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves. Microwaves are unidirectional. When an antenna transmits microwave waves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.

The unidirectional property has an obvious advantage. A pair of antennas can be aligned without interfering with another pair of aligned antennas. The following describes some characteristics of microwave propagation:

1- Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvature of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for long distance communication.

2- Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside buildings.

3- The microwave band is relatively wide, almost 299 GHz. Therefore wider sub bands can be assigned, and a high data rate is possible

4- Use of certain portions of the band requires permission from authorities.

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.

Microwaves are used for unicast communication such as cellular telephones,

satellite networks, and wireless LANs.

Infrared

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; a short-range communication system in one room cannot be affected by another system in the next room. When we use our infrared remote control, we do not interfere with the use of the remote by our neighbors. However, this same characteristic makes infrared signals useless for long-range communication. In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.

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. Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.