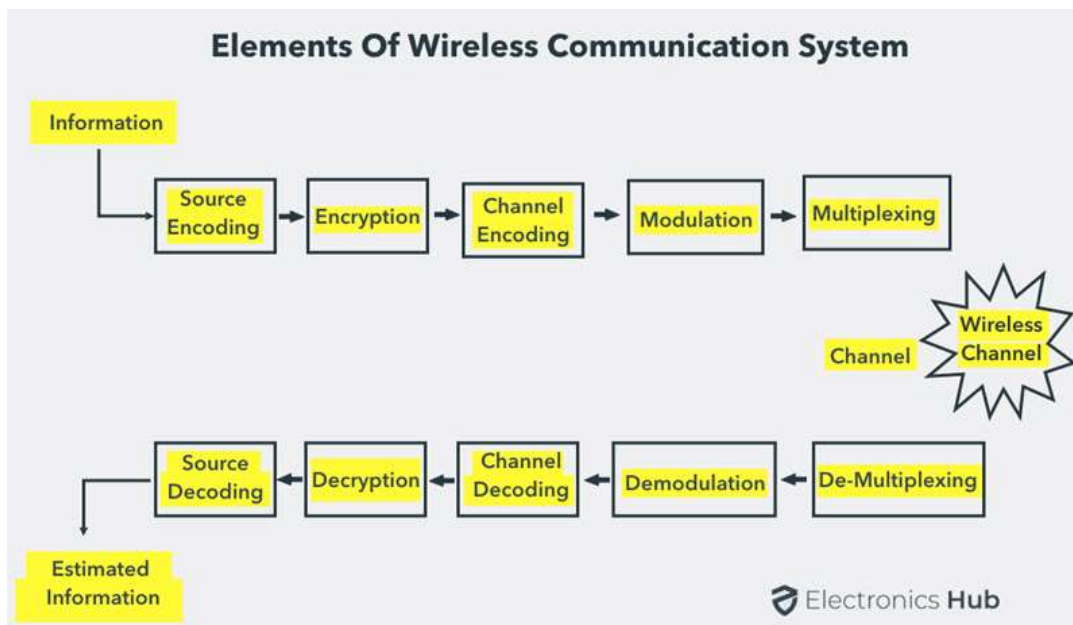


## Module 1

Wireless Communication is a method of transmitting information from one point to other, without using any connection like wires, cables or any physical medium.

A typical Wireless Communication System can be divided into three elements: the Transmitter, the Channel and the Receiver. The following image shows the block diagram of wireless communication system.



### The Transmission Path

A typical transmission path of a Wireless Communication System consists of Encoder, Encryption, Modulation and Multiplexing. The signal from the source is passed through a Source Encoder, which converts the signal in to a suitable form for applying signal processing techniques.

The redundant information from signal is removed in this process in order to maximize the utilization of resources. This signal is then encrypted using an Encryption Standard so that the signal and the

information is secured and doesn't allow any unauthorized access.

Channel Encoding is a technique that is applied to the signal to reduce the impairments like noise, interference, etc. During this process, a small amount of redundancy is introduced to the signal so that it becomes robust against noise. Then the signal is modulated using a suitable Modulation Technique (like PSK, FSK and QPSK etc.) , so that the signal can be easily transmitted using antenna.

The modulated signal is then multiplexed with other signals using different Multiplexing Techniques like Time Division Multiplexing (TDM) or Frequency Division Multiplexing (FDM) to share the valuable bandwidth.

### **The Channel**

The channel in Wireless Communication indicates the medium of transmission of the signal i.e. open space. A wireless channel is unpredictable and also highly variable and random in nature. A channel maybe subject to interference, distortion, noise, scattering etc. and the result is that the received signal may be filled with errors.

### **The Reception Path**

The job of the Receiver is to collect the signal from the channel and reproduce it as the source signal. The reception path of a Wireless Communication System comprises of Demultiplexing , Demodulation, Channel Decoding, Decryption and Source Decoding. From the components of the reception path it is clear that the task of the receiver is just the inverse to that of transmitter.

The signal from the channel is received by the Demultiplexer and is separated from other signals. The individual signals are demodulated using appropriate Demodulation Techniques and the original message signal is recovered. The redundant bits from the message are removed using the Channel Decoder.

Since the message is encrypted, Decryption of the signal removes the security and turns it into simple sequence of bits. Finally, this signal is given to the Source Decoder to get back the original transmitted message or signal

## **Advantages of Wireless Communication**

There are numerous advantage of Wireless Communication Technology, Wireless Networking and Wireless Systems over Wired Communication like Cost, Mobility, Ease of Installation, and Reliability etc.

## **Cost**

The cost of installing wires, cables and other infrastructure is eliminated in wireless communication and hence lowering the overall cost of the system compared to wired communication system. Installing wired network in building, digging up the Earth to lay the cables and running those wires across the streets is extremely difficult, costly and time consuming job.

In historical buildings, drilling holes for cables is not a best idea as it destroys the integrity and importance of the building. Also, in older buildings with no dedicated lines for communication, wireless communication like Wi-Fi or Wireless LAN is the only option.

## **Mobility**

As mentioned earlier, mobility is the main advantage of wireless communication system. It offers the freedom to move around while still connected to network.

## **Ease of Installation**

The setup and installation of wireless communication network's equipment and infrastructure is very easy as we need not worry about the hassle of cables. Also, the time required to setup a wireless system like a Wi-Fi network for example, is very less when compared to setting up a full cabled network.

## **Reliability**

Since there are no cables and wires involved in wireless communication, there is no chance of communication failure due to damage of these cables, which may be caused by environmental conditions, cable splice and natural diminution of metallic conductors.

## **Disaster Recovery**

In case of accidents due to fire, floods or other disasters, the loss of communication infrastructure in wireless communication system can be minimal.

## **Disadvantages of Wireless Communication**

Even though wireless communication has a number of advantages over wired communication, there are a few disadvantages as well. The most concerning disadvantages are Bandwidth Interference, Security and Health.

### **Bandwidth**

Bandwidth is still a limited resource in wireless environments. When transmitting data, users must sometimes send smaller bits of data to accommodate within the available bandwidth so that information

moves more quickly

## **Frequency Spectrum**

### **Interference**

Wireless Communication systems use open space as the medium for transmitting signals. As a result, there is a huge chance that radio signals from one wireless communication system or network might interfere with other signals.

The best example is Bluetooth and Wi-Fi (WLAN). Both these technologies use the 2.4GHz frequency for communication and when both of these devices are active at the same time, there is a chance of interference.

### **Security**

One of the main concerns of wireless communication is Security of the data. Since the signals are transmitted in open space, it is possible that an intruder can intercept the signals and copy sensitive information.

### **Health Concerns**

Continuous exposure to any type of radiation can be hazardous. Even though the levels of RF energy that can cause the damage are not accurately established, it is advised to avoid RF radiation to the maximum.

### **Types of Wireless Communications Systems**

Some of the important Wireless Communication Systems available today are:

Television and Radio Broadcasting

Satellite Communication

Radar

Mobile Telephone System (Cellular Communication)

Global Positioning System (GPS)

Infrared Communication

WLAN (Wi-Fi)

Bluetooth

ZigBee

Paging

Cordless Phones

Radio Frequency Identification (RFID)

## **Wireless Communication channel specification**

The method of wireless communication channel specification involves allocating the finite resource in two steps:

first the finite resource is allocated for the two directions of transmission and the second, the portion allocated for each direction is used to create multiple channels for the direction.

These two steps of subdividing the finite are referred to as:

1. Duplexing methods
2. Multiple access methods

### **Duplexing methods**

There are two main types of duplexing methods: **Frequency Division Duplexing and Frequency Division Duplexing**

#### **Frequency Division Duplexing**

Frequency division duplexing is employed in radio systems to provide an uplink and a downlink radio channel between the sender and the receiver, The frequencies are separated by a duplex spacing.

Users tune between the uplink and downlink frequencies to transmit and receive, respectively.

In wireless communication systems, the direction from user1 to user2 is referred to as the forward direction, and that from user2 to user1, the reverse direction. In the FDD method, the total available bandwidth  $W$  is first allocated separately for the forward and reverse directions of transmission. Let the total bandwidths allocated for the forward and reverse directions be  $W_f$  and  $W_r$  respectively

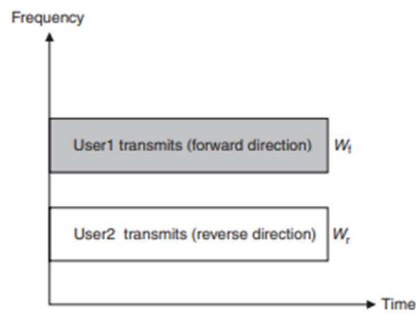


Figure 1.21 | Frequency division duplexing.

### Time Division Duplexing

In TDD, the directions of the transmission are created by alternating the transmission in time. The maximum bit rate  $B_{\max}$  supportable for a given bandwidth  $W$  is allocated between the two directions.

If this bit rate is equally divided between the two directions, each direction of transmission can support at most  $B_{\max}/2$ .

This method is also colloquially called as ping-pong method. Fig shows that for some time the bandwidth was used for user1 to user2 and for other time it was used for user2 to user1

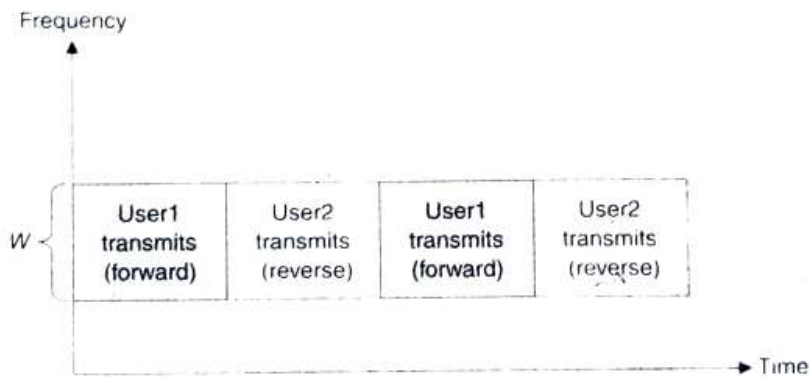


Figure 1.22 | Time division duplex

### Multiple access methods

The multiple access methods refer to the method of creating multiple channels for each transmission direction. There are three main types of multiple access methods:

1. Frequency division multiple access (FDMA)

2. Time division multiple access methods(TDMA)

3. Code division multiple access methods(CDMA)

### **Frequency Division Multiple Access**

FDMA is a channel access method used in multiple access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels, so that receivers can discriminate among them by tuning to the desired channel.

FDMA is a basic technology in the analog advanced mobile phone service(AMPS)

### **Time division Multiple Access**

TDMA is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot.

This allows multiple stations to share the same transmission medium(ex- RF channel) while using only a part of its channel capacity

TDMA is used in the digital 2G cellular system such as GSM

### **Code Division Multiple Access**

CDMA is a form of multiplexing where the transmitter encodes the signal using a pseudorandom sequence that the receiver also knows and can use to decode the received signal.

Each different random sequence corresponds to a different communication channel.

Mobile phones standard like wideband CDA use this media sharing technique

## **Wireless Communication problems**

**1. Shared Media:** The wireless media offers lower bandwidth in spite of the technique coming up to support Mbps wireless networks. Therefore, the effective utilization of bandwidth is necessary for wireless networks.

**2. Increased bit error rate (BER):** Wireless network media is more prone to errors due to obstacles coming in between the transmitter and the receiver, and the interference caused by neighboring transmitters.

One can observe frequent disconnections causing loss of data and annoying the user especially in voice and video communications

**3. Lower radio transmission power:** Mobile units are compact in size and work on battery with scarce energy resources. The mobile nodes limit transmission power to avoid interference. Signal Strength

decreases with inverse square of distance.

**4.Scattering:** Scattering occurs when the material through which the wave travels has objects with dimensions that are small compared to the wavelength and where the number of obstacles per unit volume is large.

Scattered waves are produced by rough surfaces, small objects, or other irregularities in the channel.

To provide proper functioning of radio devices in this kind of environment, it is necessary that the radio network design utilizes the correct deployment methodologies ( placement and antenna selection) to minimize this effect.

**5.Reflection:** Reflection occurs when a propagating electromagnetic wave strikes an object which has very large dimensions compared to the wavelength of the propagating wave for example, walls, furniture, building structure etc.

**6.Diffraction:** Diffraction occurs when the radio path between the transmitter and the receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle.

**7.Multiple propagation:** The multipath problem in mobile radio is caused by reflection and scattering from building, trees, and other obstacles along the radio path.

Multiple propagation can be a significant problem especially with indoor applications.

Wireless LAN manufacturers compensate for the effects of propagation by using special processing techniques, For ex- equalization and antenna diversity are methods that vendors use to reduce the problems arising from multipath propagation. If significant multipath propagation is present then it may be necessary to operate the wireless LAN at lower data rates.

**8.Fading:** Signal- fading phenomena can drastically affect the performance of a wireless communications system. Often caused by multipath conditions fading can degrade the BER performance of a digital communications system, resulting in the data loss.

Fading can occur in many forms, including a phenomenon called flat fading. In flat fading the same degree of fading takes place for all the frequency components transmitted through a radio channel and within the channel bandwidth.

In contrast, frequency selective fading causes different frequencies of an input signal to be attenuated and phase shifted differently in a channel.

## **Wireless Network**

Wireless network refers to any type of computer network that is "wireless" and is commonly associated with a telecommunication network whose interconnections between nodes are implemented without the use of wires.



With wireless networking a user can stay connected even when moving around within a given geographic area, and this is why the word "mobility" is sometimes used

Through the use of wireless networks, information could be sent overseas or behind enemy lines easily, efficiently and more reliably.

Wireless networks provide an inexpensive and rapid way connection to the internet in countries and regions where the telecom infrastructure is poor or there is a lack of resources as in most developing countries

### Classifications of Wireless Networks

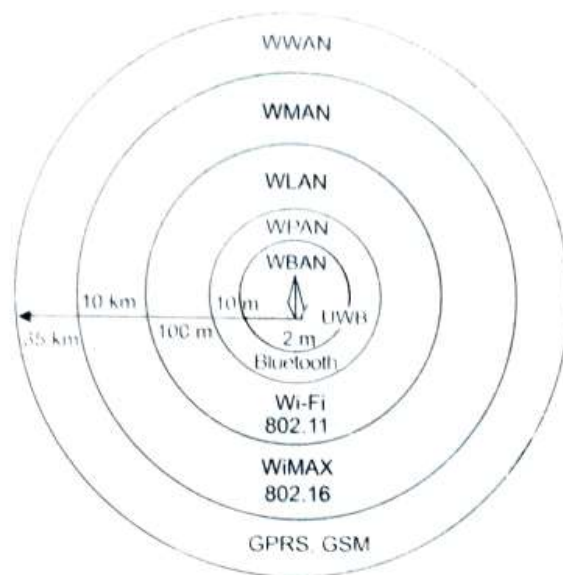


Figure 2.4 | Classification of wireless networks.

#### 1. Wireless Body area Network

WBAN consists of a set of mobile and compact intercommunication sensors, either wearable or implanted into the human body which monitors vital body parameters and movements.

These devices, communicating through wireless technologies transmit data from the body to a home base station, from where the data can be forwarded to a hospital clinic or elsewhere in real time.

Some of the technological requirements of WBAN are

1. use of broadband signaling scheme (possibly ultra wideband, UWB);

2. frequency range below 6GHz

3. support of heterogeneous multihop links to cope with high path loss through the human body

WBAN find application in supervising the health status of patients suffering from chronic diseases, such as diabetes, asthma, heart attacks etc where the long-term logging of patient data is necessary

## **2. Wireless LAN**

Wireless LAN (WLAN) technology provides internet access within a building or a limited outdoor area. WLAN uses spread spectrum or orthogonal frequency division multiplexing modulation technology based on radio waves to enable communication between devices in a limited area.

First used within offices and homes, WLAN technology is now also used in stores and restaurants. The use of home networks has greatly increased as the COVID-19 pandemic has forced office workers, students, teachers and others to work and study from home.

Most home network designs are simple. A modem connects to the cable or fiber from a local service provider. A wireless router is connected to the modem and receives the signal from the modem, which it then broadcasts using a wireless protocol, such as the 802.11 standards.

Office networks are more complicated. Access points (APs) are mounted on the ceiling, with each broadcasting a wireless signal to the surrounding area. Multiple APs are required in large offices, each connecting to the office backbone network via a wired connection to a switch.

## **3. Wireless MAN**

Wireless metropolitan area networks have been installed in cities worldwide to provide access for people outside an office or home network. These networks cover a wider area than office or home networks, but the principles are the same. APs are located on the sides of buildings or on telephone poles throughout the coverage area. APs are connected to the internet via a wired network and broadcast a wireless signal throughout the area. Users connect to their desired destination by connecting to the nearest AP, which forwards the connection through its internet connection.

## **4. Wireless PAN**

Wireless personal area networks cover a very limited area -- typically a maximum of 100 meters for most applications -- using protocols like Bluetooth and Zigbee. Bluetooth enables hands-free phone calls, connects a phone to earpieces or transmits signals between smart devices. Zigbee connects stations along an IoT network. Infrared technology is limited to line of sight, such as connecting TV remotes to televisions.

Wireless developers have constantly improved technology by discovering new ways to transmit signals to users. These advances enable higher data rates and increasing range for each of these wireless

technologies.

## 5. Wireless WAN

A WWAN is a computer network covering a broad geographical area. Wireless WANs use cellular technology to provide access outside the range of a wireless LAN or metropolitan network.

These networks enable users to make phone calls to others connecting either through a wireless WAN or a wired telephone system. Users can also connect to the internet to access websites or server-based applications.

Cell towers are located nearly everywhere within India and most other countries. A user connection is routed to the nearest cell tower which, in turn, is connected either to the wired internet or to another tower connected to wired internet.

### Wireless Switching technology

Packet switching is the basic type of wireless switching technology. Packet switching communication uses short bursts of information that use channels only for short periods of time.

Wireless devices are ON with a specific address assigned to them. Data are sent to and from the address routed using standardized protocols and are essentially an extension of the standardized protocol.

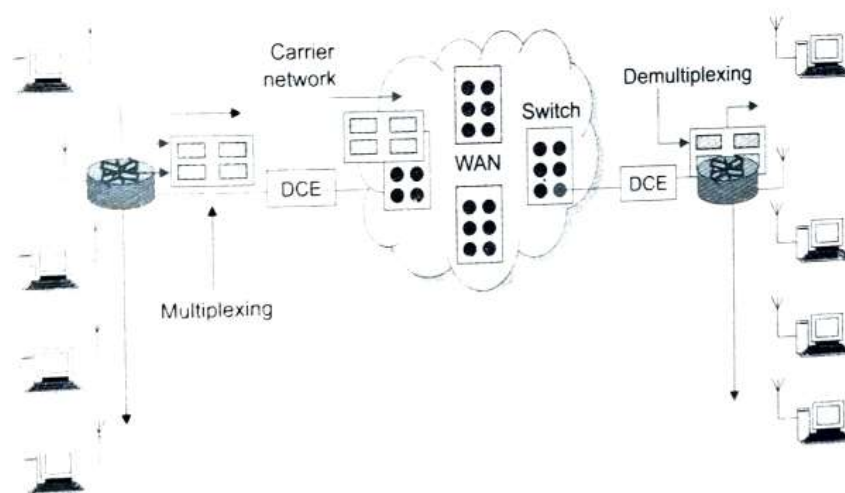


Figure 2.10 | Packet switching.

Fig shows the packet switching where the packets from all computer of a premise moves in a pipelined

fashion over the network

This network is connected to the switch of the WAN with the help of data circuit terminated equipment (DCE). Switch establishes a connection from one network to the other network. Whenever the computers generate the packets, they are routed to the carrier network and pipelined with the help of multiplexing technique.

At the receiving end, the packets are demultiplexed and delivered to the destination.

Packet switching is a more efficient system for transmitting data because it shares spectrum and bandwidth.

Another switching technology is based on virtual circuits. A virtual circuit is a logical circuit within a shared network between two network devices. The two types of virtual circuits exist: switched virtual circuits and permanent virtual circuits (PVC)

SVCs are virtual circuits that are dynamically established on demand and terminated when transmission is complete.

Communication over an SVC consists of three phases: circuit establishment, data transfer and circuit termination.

Establishment phase involves creating the virtual circuit between the source and destination devices, data transfer involves transmitting data between devices and circuit termination involves ending the virtual circuit between source and destination.

PVC is a permanently established virtual circuit that consists of one mode: data transfer. PVC are used in situations in which data transfer between devices is constant.

## **Wireless networking issues**

### **Traffic and resource allocation**

Each accepted connection has a certain traffic contract that describes the traffic type and resource requirements. A slot scheduler is responsible to assign slots in transmission frame according to the various traffic contracts.

### **Flow Control**

A connection involves buffering at several places on the path between the sender and receiver. Traffic type requirements concerning delay and implementation restrictions on the buffer capacity generally limit the amount of buffer space available to a connection.

Due to the dynamic character of wireless networks and user mobility, the stream of data might be hindered on the way from source to destination. Therefore flow control mechanisms are needed not only to prevent buffer overflow, but also to discard packets that have exceeded the allowable transfer

time.

## Security and Privacy

Network security refers to the protection of information and resources from loss corruption and improper use. Eavesdropper may listen to the traffic in real time or record it for future cryptanalysis.

This can be done on radio, link layer (MAC) or network (IP) level. As eavesdropping of the data bits is a real threat because they will be transmitted over wirelessair interface security, security and privacy are important issues in wireless systems.

## Power Management

Wireless devices have maximum utility when they can be used anywhere anytime. However the finite power supplies is one of the limitation to achieve this goal. As batteries provide limited power, a general constraint of wireless communication is the short continuous operation time of wireless terminals.

## Pricing

This deals with the pricing policies in wireless networks. The serice providers should charge the price based on the QOS requirements and the network situations.

## Wireless Network standards

Name	Frequency band	Bit rate	Signal range	Modulation	Applications
Bluetooth (IEEE 802.15)	2, 4 GHz	1, 2 Mbps	10 m	GMSK; device-to-device	Peer-to-peer
UWB (IEEE 802.15.3)	4, 8–10 GHz	480 Mbps	10 m	OFDM	Health monitoring
ZigBee (IEEE 802.15.4)	2, 4 GHz	250 kbps	10 m	O-QPSK	Control and automation
IEEE 802.11a	5 GHz	54 Mbps	100 m, outdoor; 30 m, indoor	OFDM, BPSK, QPSK, 16 QAM, 64 QAM	Wireless LAN
IEEE 802.11b	2, 4 GHz	11 Mbps	110 m, outdoor; 35 m, indoor	BPSK, QPSK, 64 QAM, CCK	Wireless LAN
IEEE 802.11g	2, 4 GHz	54 Mbps	110 m, outdoor; 35 m, indoor	OFDM, BPSK, QPSK, 16 QAM, 64 QAM	Military applications; example: high energy RADAR
IEEE 802.11n	2, 4/5 GHz	150 Mbps	160 m, outdoor, 70 m, indoor	MIMO	Wireless LAN
IEEE 802.16	10–66 GHz	134 Mbps	5 km	QPSK, 16 QAM, 64 QAM	Wireless MAN
IEEE 802.16a	2–11 GHz	75 Mbps	10 km	BPSK, QPSK, 16 QAM, 64 QAM	Network access for line- of-sight applications
IEEE 802.16d	2–11 GHz	75 Mbps	8 km	BPSK, QPSK, 16 QAM, 64 QAM	Last mile connectivity applications
IEEE 802.16e	2–6 GHz	30 bps; downlink/ uplink	5 km	BPSK, QPSK, 16 QAM, 64 QAM	Mobile and wireless applications, WMAN

## Sums-

**Problem 1.1**

In a communication channel, the channel bandwidth is 3.4 kHz and output S/N power ratio is 20 dB. Calculate the channel capacity.

**Solution:**

Given, channel bandwidth,  $B = 3.4$  kHz. Therefore

$$\begin{aligned} 10 \log_{10} S/N &= 20 \text{ dB} \\ \log_{10} S/N &= 2 \\ S/N &= 10^2 = 100 \end{aligned}$$

Channel capacity is

$$\begin{aligned} C &= B \log_2(1 + S/N) \\ &= 3.4 \times 10^3 \log_2(1 + 100) \\ &= 3.4 \times 10^3 (6.66) \\ C &= 22.644 \text{ bps} \end{aligned}$$

**Problem 1.2**

Calculate the minimum SNR required to support information transmission through the telephone channel of bandwidth 3.4 kHz at the data rate of 4800 bps.

**Solution:**

Given, channel data rate,  $C = 4800$  bps; bandwidth,  $B = 3.4$  kHz. Therefore channel capacity,

$$\begin{aligned} C &= B \log_2(1 + S/N) \\ 4800 &= 3.4 \times 10^3 \log_2(1 + S/N) \\ 1.411 &= \log_2(1 + S/N) \\ 1 + S/N &= 2^{1.411} \\ 1 + S/N &= 2.659 \\ S/N &= 1.659 \\ (S/N) \text{ (dB)} &= 10 \log_{10} 1.659 = 2.2 \text{ dB} \\ S/N &= 2.2 \text{ dB} \end{aligned}$$

**Problem 1.3**

In a communication channel, the bandwidth is 10 MHz and SNR is 100.

(a) Determine the channel capacity.

(b) If SNR drops to 10, how much bandwidth is needed to achieve the same channel capacity as in (a).

**Solution:**

Given, channel bandwidth = 10 MHz. Therefore

$$S/N = 100$$

Channel capacity is given by

$$\begin{aligned} C &= B \log_2(1 + S/N) \\ C &= 10 \times 10^6 \log_2(1 + 100) \\ C &= 66.6 \text{ Mbps} \end{aligned}$$

If the SNR drops to 10, that is,  $S/N = 10$ , the bandwidth is

$$\begin{aligned} B &= C / \log_2(1 + S/N) = C / \log_2(1 + 10) \\ B &= 66.6 \times 10^6 / 3.47 \\ B &= 19.19 \text{ MHz} \end{aligned}$$

### Problem 2.1

Find the transmitted power, if a transmitting node is operating at a frequency of 90 MHz and a mobile phone receiver at a distance of 650 m establishes the communication with the transmitting node. Assume the captured power at the mobile phone is  $1 \times 10^{-6}$  W.

#### Solution:

Given

Operating frequency,  $f = 90$  MHz

Distance,  $d = 650$  m

Receiver power,  $P_r = 1 \times 10^{-6}$  W

Transmitted power,  $P_t = ?$

Using Eq. (2.1) we get

$$P_t = P_r(4\pi d/\lambda)^2$$

$$\lambda = c/f = (3 \times 10^8)/(90 \times 10^6) = 3.33 \quad (\text{speed of light, } c = 3 \times 10^8 \text{ m/s})$$

$$P_t = 1 \times 10^{-6}[4\pi(650)/3.33]^2$$

$$P_t \approx 6 \text{ W}$$

### Problem 2.2

The transmitted power of a transmitter is 10 mW, operating at a frequency 85 MHz. A receiver captures data with the power, 0.1  $\mu$ W. Find the distance between transmitter and receiver.

#### Solution:

Given

Transmitter power,  $P_t = 10$  mW

Frequency,  $f = 85$  MHz

Captured power,  $P_r = 0.1$   $\mu$ W

Using Eq. (2.1) we get

$$P_r = P_t/(4\pi d/\lambda)^2$$

$$\lambda = c/f = (3 \times 10^8)/(85 \times 10^6) = 3.5 \quad (\text{speed of light, } c = 3 \times 10^8 \text{ m/s})$$

$$0.1 \times 10^{-6} = 10 \times 10^{-3}/(4\pi d/3.5)^2$$

$$d \approx 88 \text{ m}$$

### Problem 2.3

The transmitter power of a transmitter is 20 mW operating at a frequency of 75 MHz. At a distance of 500 m, a mobile phone establishes the communication with this transmitter. Find the captured power.

#### Solution:

It is given that transmitter power  $P_t = 20$  mW, frequency  $f = 75$  MHz, distance  $d = 500$  m, and speed of light  $c = 3 \times 10^8$  m/s. The wavelength of the signal is given by

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{75 \times 10^6} = 4$$

Using Eq. (2.1) we get

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} = \frac{20 \times 10^{-3}}{[(4 \times \pi \times 500)/4]^2} = 0.01 \mu\text{W}$$

**Problem 2.4**

For a mobile communication system, it is given that average noise power at the receiver is  $25 \mu\text{W}$  and the captured power is  $100 \text{ mW}$ . Calculate SNR in dB.

**Solution:**

Given

$$\text{Average noise power, } P_n = 25 \times 10^{-6} \text{ W}$$

$$\text{Received power, } P_r = 100 \times 10^{-3} \text{ W}$$

Using Eq. (2.2), SNR is given by

$$\text{SNR} = P_r/P_n = (100 \times 10^{-3})/(25 \times 10^{-6})$$

$$\text{SNR} = 4000$$

$$\text{SNR (dB)} = 10 \log_{10}(4000)$$

$$\text{SNR} \approx 36 \text{ dB}$$

**Problem 2.5**

A mobile receiver communicates at a distance of 5 km with the transmitter which is having the operating frequency of 750 MHz. Calculate the path loss in the system.

**Solution:**

Given transmitter operating frequency,  $f = 750 \text{ MHz}$

Distance between transmitter and receiver,  $d = 5 \text{ km}$ .

Using Eq. (2.3) we get

$$\text{Path loss, } L_p = (4\pi d/\lambda)^2$$

We know that  $\lambda = c/f = (3 \times 10^8)/(750 \times 10^6) = 0.4$ , therefore

$$L_p = [4\pi (5000)/0.4]^2$$

$$L_p = 2.46 \times 10^8$$

**Problem 2.6**

In a mobile communication system, path loss is  $10^9$ . The distance between the transmitter and the receiver is 3 km. Find the transmitter operating frequency.

**Solution:**

Given path loss,

$$L_p = 10^9$$

Distance between transmitter and receiver = 3 km

Using Eq. (2.3)

$$\text{Path loss, } L_p = (4\pi d/\lambda)^2$$

We know that  $\lambda = c/f$ , therefore

$$10^9 = (4\pi (3000) f/3 \times 10^8)^2$$

$$f = 251.6 \times 10^6$$

Transmitter operating frequency,  $f = 251.6 \text{ MHz}$



**Problem 2.7**

For a given communication system, transmitter operates at a frequency of 850 MHz with a power of 125 mW. This transmitter communicates with the receiver having the received power of 1  $\mu$ W. What is the distance between the transmitter and receiver?

**Solution:**

It is given that

$$P_t = 125 \text{ mW}$$

$$f = 850 \text{ MHz}$$

$$P_r = 1 \text{ } \mu\text{W}$$

Path loss is given by

$$L_p = \frac{P_t}{P_r} = \frac{125 \times 10^{-3}}{1 \times 10^{-6}} = 125 \times 10^3$$

The wavelength of the signal is

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{850 \times 10^6} = 0.3529$$

Using Eq. (2.3), we get the path loss as

$$L_p = \left( \frac{4\pi d}{\lambda} \right)^2 = \left( \frac{4 \times 3.14 \times d}{0.3529} \right)^2$$

$$125 \times 10^3 = \left( \frac{4 \times 3.14 \times d}{0.3529} \right)^2$$

$$d = 9.93 \text{ m}$$