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Cellular Networks

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Cellular Networks

Chapter 1 : Introduction to Wireless Channel

Q. 1 Define wireless communication. State some examples of wireless communication systems.

Ans. :

Wireless communication :

- Wireless communication is defined as the communication by radio waves. The term wireless explains the communications other than the broadcast communication, between individuals who often use portable or mobile equipment.

Examples :

- Some of the wireless communication systems are as follows :
  1. Wireless LAN.
  2. Cordless telephone.
  3. Walkie-Talkie.
  4. Pagers.
  5. AC remote control.
  6. TV remote control.
  7. Cellular phones.
  8. Satellite communication systems.

Q. 2 Explain the need of wireless communication.

Ans. :

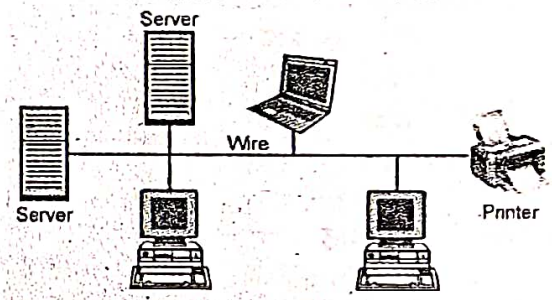
- The wireless communication is needed because of the reasons mentioned below :
  1. Long distance communication is difficult using wired media due to the length of wire, maintenance problems etc.
  2. One user to multiuser communication system becomes complicated using wired media. This becomes easy with wireless links.
  3. Broadcasting applications such as radio, TV etc are possible only through wireless communication due to a large number of users. Wired communication is not possible for such application.
  4. It is easy to add new users without any additional wiring.
  5. Wireless communication is possible even if the user is moving.
  6. Using wireless LANs or wireless communication between computer and peripherals avoid wiring and improve reliability.

Q. 3 Write a short note on : Wired and wireless networks.

Ans. :

Wired network :

- A network is defined as the collection of computers, terminals, servers and various components connected to each other, to allow easy flow of data and use of resources.
- Fig. 1.1 shows a wired network in which various devices are interconnected with wires.



(O-921) **Fig. 1.1 : A wired network**

Wireless network :

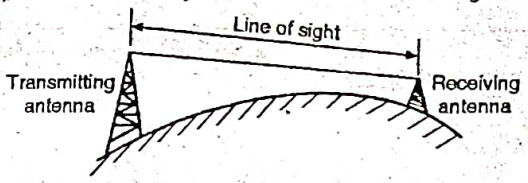
- A wireless network is defined as the collection of computers, servers, terminals and various other components, connected to each other by wireless links instead of connecting wires.
- Wireless networks use radio waves to connect one device in the network to the others. All the devices in a wireless network can be moved within the range or coverage area of the network.

- This makes the wireless networks extremely portable. In wireless networks air is used as a medium to transfer the data.
- A computer needs to have the wireless network card to be a part of a wireless network. It will have the same functionality, as that of a wired computer but its speed will reduce.

Q. 4 What is LOS communication ?

Ans. :

- Line of sight in the space wave propagation is defined as the straight path between transmitting antenna and a receiving antenna, when unobstructed by the horizon as shown in Fig. 1.2.



(B-2976) **Fig. 1.2 : Concept of line of sight**

Q. 5 List and explain different radio propagation mechanism with suitable example. March 20

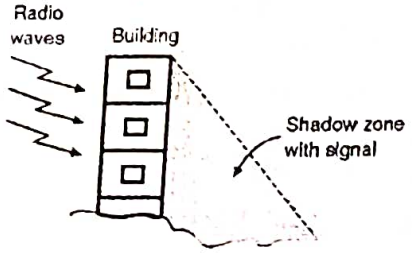
Ans. :

Radio propagation mechanisms :

1. *Blocking or shadowing.*
2. *Reflection.*
3. *Refraction.*
4. *Scattering.*
5. *Diffraction.*

Blocking or Shadowing :

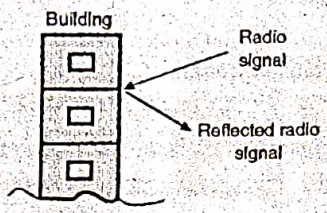
- *At very high frequencies the radio frequency signal behave like light. Hence small obstacles like walls, trees, cars etc. can block the signal.*
- *Blocking or shadowing is defined as the extreme form of attenuation of radio signals due to large objects. (See Fig. 1.3(a)).*



(G-2446) **Fig. 1.3(a) : Blocking or shadowing**

Reflection :

- Another important effect is of radio signals which takes place if the size of the obstacle (hill, building) is much larger than the wavelength of the radio signals (Fig. 1.3(b)).
- If a propagating radio wave hits an object the size of which is very large as compared to its wavelength then the wave gets reflected by the object.

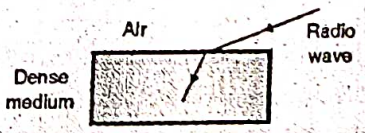


(G-2446) **Fig. 1.3(b) : Reflection**

- The example of such a large object is a large building, furniture, wall, a hill etc. The phase shift between the incident and reflected wave is 180°.
- The reflected signal is not as strong as the original one because the object absorbs some energy.
- In big cities, the reflection helps signal transmission where no line of sight communication is possible.

Refraction :

- It is defined as the change in direction of radio signal when it passes obliquely from a medium of lower density to the other medium of higher density. That is why radio signal bend towards earth.
- The refraction takes place when the two mediums involved have different densities. This is because the velocity of radio signals is inversely proportional to the density of medium.
- The principle of refraction is illustrated in Fig. 1.3(c).

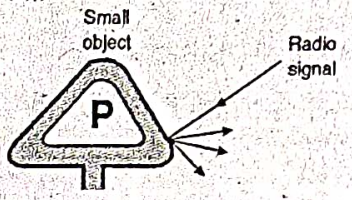


(G-2447) **Fig. 1.3(c) : Refraction**

Scattering :

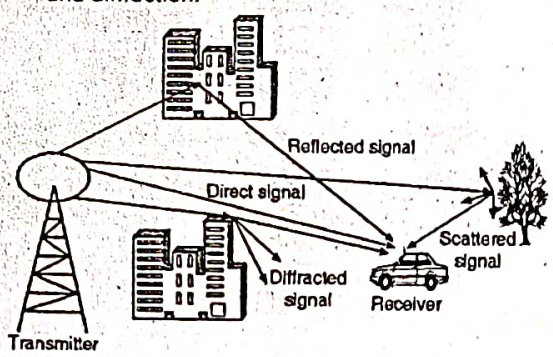
- Blocking and reflection happen when an obstacle is large in size.

- But scattering of a radio signal takes place if the object is small in size (typically equal to or smaller than the wavelength of the radio signal (See Fig. 1.3(d))).



(G-2447) **Fig. 1.3(d) : Scattering**

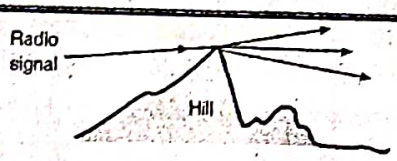
- The scattering of an EM wave takes place when the wave travels through a medium containing many objects which are smaller than the wavelength of the wave.
- The examples of such objects are lamp posts, street signs etc. Due to this phenomenon, the wave gets scattered in several weak outgoing signals.
- Scattering is also produced by rough surfaces, small objects, or other irregularities in the channel.
- In order to ensure a proper functioning of devices in such an environment, the radio network design must utilize the correct methods of deployment (placement and antenna selection) to minimize this effect.
- Fig. 1.4 illustrates the three propagation mechanisms for EM waves, reflection, refraction and diffraction.



(G-2095) **Fig. 1.4 : Reflection, refraction and scattering**

Diffraction :

- Diffraction is very similar to scattering. As shown in Fig. 1.5, in diffraction, the radio waves get deflected at the edges of a large object and will travel in different directions.



(G-2448) **Fig. 1.5 : Diffraction**

- A propagating wave gets diffracted when it hits an object or surface which cannot be penetrated, and has sharp irregularities i.e. edges.
- Therefore it is very difficult to precisely predict the signal strength at any given point.
- At the edges of such object, the incident wave bends and starts propagating in different directions.
- This is known as diffraction. The diffracted waves are present throughout the space and even behind the obstacle.
- The diffraction of a wave takes place when the size of the object is comparable with the wavelength of the wave.
- Due to diffraction, a wave can reach places behind the object where it could not have otherwise reached.
- The amount of diffraction is dependent on the frequency of the wave being diffracted. It is more for low frequency waves.

Q. 6 Explain the concept of fading. State different reasons for fading.

Ans. :

Definition :

- Fading is defined as the variations or fluctuations in the signal strength at the receiver. The ISI, delay spreading and continuous movement of the sender and receiver result in signal fading.
- The fading of any type, takes place due to the interference between two waves which follow different paths to travel from transmitter to receiver.
- Thus fading takes place due to multipath reception of the signal.

- Due to different path lengths, the two signals will undergo different phase shifts.
- At the receiver the vector sum of them will take place.
- Therefore alternate cancellation and reinforcement will take place if the path difference is as large as $\lambda/2$.
- Such fluctuations are therefore more likely to occur at lower wavelengths or higher frequencies.

Types of fading :

1. **Short term fading :**

- The quick changes taking place in the received signal power is known as short term fading.
- The receiver has to continuously adapt to the changing signal strength.

2. **Long term fading :**

- The variations in average received signal power over a long time is known as long term fading.

Flat fading :

- A received radio signal is said to have undergone flat fading if the channel bandwidth is greater than the signal bandwidth.
- Flat fading channels are also known as the **narrow band channels.**
- In flat fading all the frequency components in a signal fade in the same proportion simultaneously.
- Flat fading is also called as non-selective fading.

Frequency selective fading :

- In frequency selective fading, different frequency components in the received signal undergo unequal fading.
- If the channel bandwidth is less than the signal bandwidth then the frequency selective fading will take place.

Different reasons for fading :

1. The fading can take place due to interference between the lower and upper rays of the sky wave.
2. It can take place due to interference between waves arriving by different number of hops or paths.
3. Due to interference between the ground waves and sky waves.
4. Due to fluctuations of height or density in ionosphere layers.
5. As the fading is a frequency selective process, the signals very close to each other in the frequency domain will fade to a different extent.
6. The AM signal is very badly distorted due to such a frequency selective fading. The SSB signal is not affected to such an extent.
7. One way to counteract the problem of fading is to use space or frequency diversity reception system. The other way is to use the automatic gain control (AGC) for the receiver.

Q. 7 State the merits and demerits of Wireless Communication.

Ans. :

Merits :

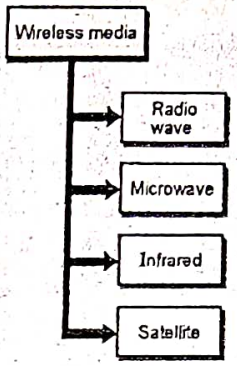
1. No wires are required to be used.
2. Wireless transmission has a larger coverage area than that of wired transmission.
3. Wireless media has large bandwidth.
4. Mobility.
5. Increased reliability.
6. Rapid disaster recovery.
7. Lower cost.

Demerits :

1. Small objects such as walls can obstruct the signal.
2. Weather conditions such as rain, fog, moisture can increase signal attenuation and disrupt the communication.

Q. 8 What are different wireless media ?

Ans. :



(G-119) **Fig. 1.6 : Classification of wireless media**

Q. 9 State and explain various properties of RF waves.

Ans. :

Properties of RF waves :

1. They can propagate through the buildings.
2. They can travel long distances.
3. There is no need to physically align the transmitter and receiver as RF waves are omnidirectional.
4. Many characteristics of RF waves are dependent on their frequency.
5. The low frequency waves can pass through very easily but their power drops drastically with increased distance. Thus they cannot travel longer distances.
6. On the other hand the high frequency waves can travel longer distances but they are more prone to absorption due to raindrops or they get easily reflected by obstacles and the interference problem is grave.

Q. 10 Explain the 1G cellular system and state its features and drawbacks.

Ans. :

1G cellular system :

- The first generation of cellular telephony was suitable only for voice communication using analog signals. Now cellular technology is in the fourth generation.
- One of the important first generation mobile system used in North America is AMPS.
- The first generation of wireless mobile system was implemented in 1980's.
- The modulation scheme used was frequency modulation (FM).
- Long form of AMPS is Advanced Mobile Phone System. It is one of the leading analog cellular system in North America.
- It makes use of FDMA (Frequency Division Multiple Access) to separate channels in a link.

Features of First Generation :

- Table 1.1 presents the features of first generation.

Table 1.1 : Features of 1G systems

Sr. No.	Feature	Value / Description
1.	Generation	1-G (1970 – 1984)
2.	Technology	Analog cellular
3.	Standard	AMPS
4.	Switching	Circuit switching
5.	Frequency band	824-894 MHz
6.	Modulation	FM
7.	Data speed	2.4 kbps
8.	Multiplexing	FDMA
9.	Core network	PSTN
10.	Service	Only voice or only message

Drawbacks of 1-G Systems :

1. Poor voice quality.
2. No security.

Q. 11 Explain the 2G cellular system and state its features.

Ans. :

2G cellular system :

- The second generation of cellular telephony was developed in order to improve the quality of communication.
- The second generation was designed for digital voice.
- 2G networks began to emerge around 1980's but their actual implementation started by 1990's.

- Due to different path lengths, the two signals will undergo different phase shifts.
- At the receiver the vector sum of them will take place.
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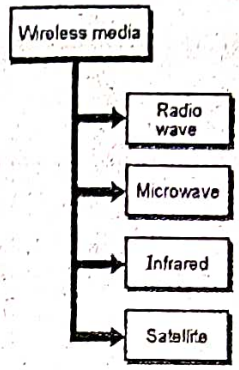

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10.	Service	Only voice or only message

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2. No security.

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Ans. :

2G cellular system :

- The second generation of cellular telephony was developed in order to improve the quality of communication.
- The second generation was designed for digital voice.
- 2G networks began to emerge around 1980's but their actual implementation started by 1990's.

- The second generation mobile systems are digital systems and it has the following types of developments :
  1. IS-54 (TDMA) in 1991.
  2. IS-95 (CDMA) in 1993.
  3. IS-136 in 1996.
  4. GSM (TDMA).
- Out of these the GSM (Global system for mobile communications) is by far the most consistent 2G standard. 2.5G and 2.75G are the upgraded versions of 2G.

Features of 2G Systems :

- Some of the important features of the 2G-mobile systems are as follows :

Table 1.2 : Features of 2G systems

Sr. No.	Feature	Value / Description
1.	Generation	2-G (1990)
2.	Technology	Digital Cellular Technology
3.	Standard	CDMA, TDMA and GSM
4.	Switching	Circuit/ Packet switching
5.	Frequency band	850 - 1900 MHz (GSM)
6.	Data speed	9.6 kbps.
7.	Multiplexing	CDMA, TDMA
8.	Modulation	GMSK
9.	Core network	PSTN
10.	Services	Digital voice, data and SMS facility
11.	Handoff	Horizontal

Q. 12 State any four features of third generation (3G) standard systems and list various 3G standards.

Ans. :

Features of Third Generation :

- Some of the important features of 3G mobile systems are as follows :

Table 1.3 : Features of 3G systems

Sr. No.	Feature	Value / Description
1.	Generation	3G (2001)
2.	Technology	Broadband/IP, FDD, TDD
3.	Standards	CDMA, W-CDMA, UMTS.
4.	Switching	Circuit/Packet switching
5.	Frequency band	1.6 GHz to 2.5 GHz
6.	Data speed	2 Mbps
7.	Multiplexing	CDMA
8.	Core network	Packet network
9.	Services	High speed data, voice, video
10.	Handoff	Horizontal

3G standards :

- The well known examples of 3G systems are :
  1. W – CDMA.
  2. CDMA – 2000. 3. TD – SCDMA.

Q. 13 Explain the 4G cellular system and state its applications and features.

Ans. :

4G cellular system :

- The 4G wireless systems were designed to fulfill the requirements of International Mobile Telecommunications Advanced (IMT-A) using IP (Internet Protocol) for all the services.

Applications of 4G :

- The 4G is developed to support the QoS and data rate requirements of the advanced applications such as :
  1. Wireless broadband access.
  2. Multimedia Messaging Service (MMS).
  3. Video chat.
  4. Mobile TV.
  5. HDTV.

6. Digital Video Broadcasting (DVB).
7. Voice and data.
8. Other services which need large bandwidth.

- In 4G systems, an advanced radio interface is used with Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO) and the link adaptation technologies.
- 4G standards also includes Long Term Evolution (LTE) and IEEE 802.16 (Wi-Max).
- The 4G systems provide very high data rates as compared to 3G.
- But the major problem with 4G systems is security because of its IP address system.

Features of 4G Systems :

- The important features of 4G mobile systems are as follows :

Table 1.4 : Features of 4G systems

Sr. No.	Feature	Value / Description
1.	Generation	4G (2010)
2.	Technology	IP-Broadband, Wi-Fi, MIMO
3.	Standard	Wi Max and LTE
4.	Switching	Packet switching
5.	Frequency band	2 GHz – 8 GHz
6.	Data speed	50 Mbps
7.	Multiplexing	MC-CDMA and OFDM
8.	Core network	Internet
9.	Service	Dynamic Information Access
10.	Handoff	Vertical

Q. 14 State the features of 5G cellular system.

Ans. :

Features of Fifth Generation :

Table 1.5 : Features of Fifth Generation

Sr. No.	Feature	Value / Description
1.	Generation	5G (2020)
2.	Technology	WWWW, IPv6
3.	Standard	Yet to be finalized
4.	Switching	Packet
5.	Frequency	15 GHz
6.	Data speed	> 1 Gbps
7.	Multiplexing	MC-CDMA, LAS-CDMA, OFDM
8.	Core network	Internet
9.	Services	Interactive multimedia, Voice over IP, Virtual reality, Augmented reality, IOT etc.
10.	Handoff	Horizontal and vertical

Q. 15 What are the advantages and applications of 5G cellular system.

Ans. :

Advantages :

- Following are the advantages of 5G :
  1. 5G technology can gather all networks on one platform.
  2. It is more effective and efficient.
  3. 5G technology will provide a huge broadcasting data (in Gigabit), which will support more than 60,000 connections.
  4. 5G is compatible with the previous generations.
  5. It can offer uniform, uninterrupted, and consistent connectivity across the world.

Applications :

- The 5G technology can be used in the following applications :
  1. Entertainment and multimedia
  2. Internet of Things – Connecting everything
  3. Smart Home
  4. Logistics and shipping
  5. Smart cities
  6. Smart farming
  7. Healthcare and mission critical applications

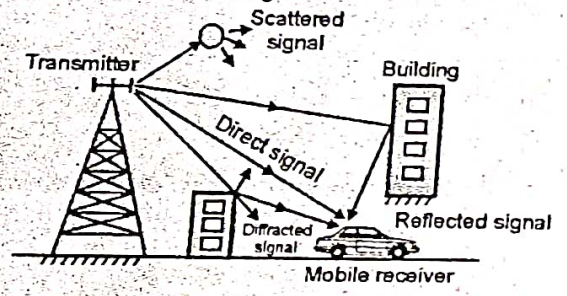
8. Drone operation
9. Security and surveillance

Q. 16 Explain the concept of multipath signal Propagation.

Ans. :

Multipath Propagation :

- When the electromagnetic waves leave the transmission antenna, they do not only follow the direct path from transmitter to receiver.
- Instead, they undergo reflection, refraction and scattering from various objects such as tall buildings, hills etc, while travelling.
- Due to this, multiple copies of the same EM signal are produced which are small in strength and have different phase shifts as compared to the direct wave as shown in Fig. 1.7.



(O-903) **Fig. 1.7 : Concept of multipath propagation**

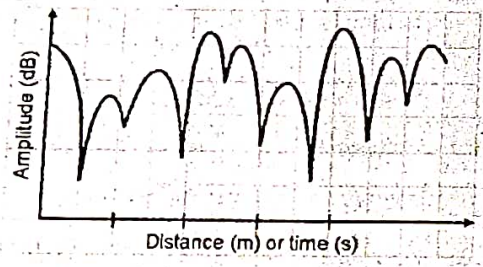
- Thus the transmitted signal gets propagated via multiple roots while travelling from transmitter to receiver. This is called as multipath propagation.
- The power of the signal received by a receiver is always less than the power of the signal transmitted by the transmitter.
- This reduction in the signal strength is known as attenuation and it is due to various factors.
- The signal reaching a receiver follows multiple paths instead of just the direct path between a transmitter and a receiver as shown in Fig. 1.7.
- This is called as the multipath reception.
- It takes place when a receiver receives the direct path transmitted signal along with the reflected and scattered versions of the same signal.
- The reflection and scattering occurs from buildings, trees, and other obstacles along the radio path.

Q. 17 Explain the concept of multipath fading.

Ans. :

Concept of multipath fading :

- Due to this the radio waves arrive at a mobile receiver from many different directions, with different time delays.
- Due to different path lengths, each signal undergoes a different phase shift while reaching the receiver. The net signal strength at the receiver is equal to the vector sum of all these signals.
- With a moving receiver the signal strength at the receiver fluctuates continuously. This is known as multipath fading as shown in Fig. 1.8.



(G-2807) **Fig. 1.8 : Fading / Multipath**

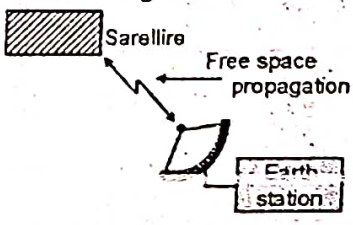
- The effects of multipath propagation can be reduced, by using some special processing techniques such as equalization and antenna diversity.

Q. 18 With necessary equations explain free space propagation model in detail.

Ans. :

Free space propagation model :

- This model is used for predicting the received signal strength when the transmitter and receiver have a clear Line-Of-Sight (LOS) path between them as shown in Fig. 1.9.



(G-2622) **Fig. 1.9 : Free space communication**

- The examples of LOS communication are :
  1. Microwave communication
  2. Satellite communication

Function of the model :

- The function of the free-space model is to predict the received signal strength as a function of the separation (d) between the transmitter and receiver.

Friis Free Space Equation :

- The free space power received by a receiving antenna is given by Friis frees space equation as follows :

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$= \frac{P_t G_t G_r}{L}\left(\frac{\lambda}{4\pi d}\right)^2 \quad ...(1)$$

- Where,

  $P_r(d)$ = Received power,

  P_t = Transmitted power

  G_t, G_r = Transmitter and receiver antenna gains

  d = T-R separation in m,

  L = System loss factor not related to propagation

  λ = Wavelength

- The value of L is greater than or equal to 1.
- The gain of an antenna is related to its effective area A_e with the following expression,

$$G = \frac{4\pi A_e}{\lambda^2} \quad ...(2)$$

Where $\lambda = \frac{C}{f}$ and

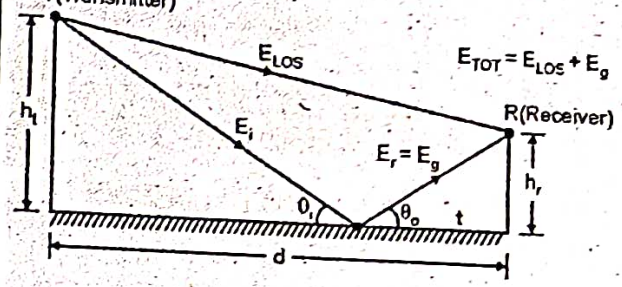
f = Carrier frequency in Hz.

- The losses L ($L \geq 1$) are generally corresponding to the attenuation due to transmission line, filter losses, and antenna losses.
- If L = 1, there are no losses in the system.

Q. 19 Derive an expression for a ground reflection model assuming distance between transmitter and receiver antenna is very large compare to heights of the antennas.

Ans. :

- The two ray model is also called as ground reflection model or two ray ground reflection model and it is as shown in Fig. 1.10.



(G-2824) **Fig. 1.10 : Two ray ground reflection model**

- It considers the direct path as well as ground reflected path between the transmitter and receiver.
- This model gives accurate results in predicting large scale signal strength over long distances.

Assumptions :

1. The earth's surface is flat, and the maximum distance d between the transmitter and receiver (T – R) is only a few tens of km.
2. The total E-field at the receiver E_{TOT} is vector sum of direct line-of-sight component E_{LOS} and the ground reflected component E_g.
3. Let h_t be the height of the transmitter and h_r be the height of the receiver.

Expression for total received E-field :

- If the free space E-field is E_0 (V/m) at a distance d_0 from the transmitter then for $d > d_0$, the E-field is given by,

$$E(d, t) = \frac{E_0 d_0}{d} \cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) \text{.....}(d > d_0) \quad ...(1)$$

Where, $|E(d, t)| = \frac{E_0 d_0}{d}$ represents the envelop of E- field at a distance d from the transmitter.

- The direct wave travels a distance d' and reflected wave that travels at a distance d'' before reaching the receiver.

- The E-field produced by the direct component at the receiver is given by,

$$E_{LOS}(d', t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) \quad ...(2)$$

- And the E-field produced by the ground reflected wave is given by,

$$E_g(d'', t) = \frac{\tau E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right) \quad ...(3)$$

- The laws of reflection in dielectrics states that,

$$\theta_i = \theta_0 \quad ...(4)$$

$$\text{and } E_g = \tau E_i \quad ...(5)$$

$$E_t = (1 + \tau) E_i \quad ...(6)$$

- Where τ is the reflection coefficient for ground.
- Assume that the E-field polarization is perfectly horizontal and a perfect ground reflection ($\tau_I = -1$, $E_t = 0$), to obtain the total E- field $E_{TOT}(d, t)$ at the receiver as follows,

$$|E_{TOT}| = |E_{LOS} + E_g| \quad ...(7)$$

- Substituting values of E_{LOS} and E_g from Equations (2) and (3) we get,

$$E_{TOT}(d, t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right) \quad ...(8)$$

- The geometry of Fig. 1.11 shows the use of method of images to find out the path difference Δ between the direct and the ground reflected paths as follows :
- The path difference Δ is,

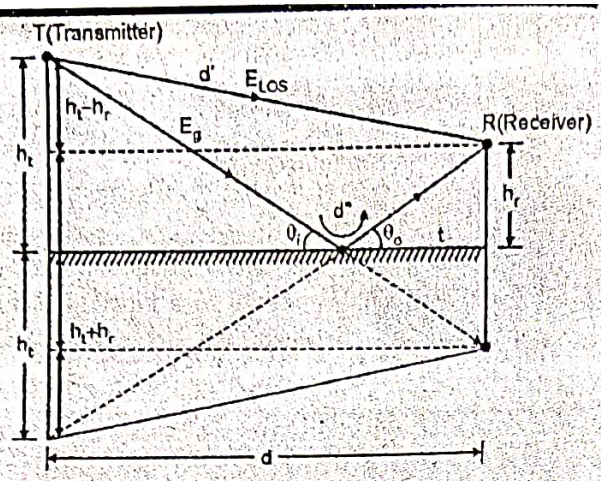
$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2} \quad ...(9)$$

- If $d >> (h_t + h_r)$ then simplify the above expression using Taylor series approximation to get,

$$\Delta = d'' - d' = \frac{2h_t h_r}{d} \quad ...(10)$$

- Also the phase difference θ_Δ between the two E-field components is given by,

$$\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta\omega_c}{c} \quad ...(11)$$



(G-2813) **Fig. 1.11 : Method of images to find the path difference between the line-of sight and ground reflected paths**

- And the time delay τ_d between the arrival of these two components is given by,

$$\tau_d = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c} \quad ...(12)$$

- For large values of distance d, the difference between the direct path distance d' and ground reflected path d'' becomes very small.
- Therefore the amplitudes of E_{LOS} and E_g are virtually identical but there will be a phase difference between them. That means,

$$\left|\frac{E_0 d_0}{d}\right| \approx \left|\frac{E_0 d_0}{d'}\right| \approx \left|\frac{E_0 d_0}{d''}\right| \quad ...(13)$$

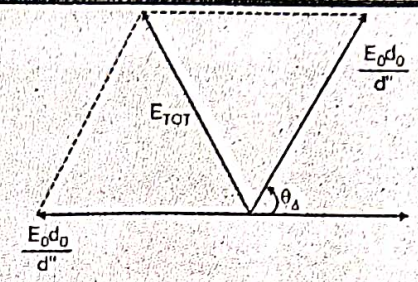
- The value of received electric field at time $t = \frac{d''}{c}$, can be evaluated as,

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_0 d}{d'} \cos\left(\omega_c\left(\frac{d'' - d'}{c}\right)\right) - \frac{E_0 d_0}{d''} \cos 0° \quad ...(14)$$

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_0 d_0}{d'} \angle\theta_\Delta - \frac{E_0 d_0}{d''}$$

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) \approx \frac{E_0 d_0}{d} [\angle\theta_\Delta - 1]$$

- Fig. 1.12 shows the phasor diagram that shows how to combine the electric field components of line-of-sight, ground reflected waves to obtain total received E-field.



(G-2825) **Fig. 1.12 : Phasor diagram**

- The electric field (at the receiver) at a distance d from the transmitter is,

$$|E_{TOT}(d)| = \sqrt{\left(\frac{E_0 d_0}{d}\right)^2 (\cos\theta_\Delta - 1)^2 + \left(\frac{E_0 d_0}{d}\right)^2 \sin^2\theta_\Delta} \quad ...(15)$$

$$|E_{TOT}(d)| = \frac{E_0 d_0}{d}\sqrt{2 - 2\cos\theta_\Delta} \quad ...(16)$$

- Solving using trigonometric identities we get,

$$|E_{TOT}(d)| = \frac{2 E_0 d_0}{d} \sin\left(\frac{\theta_\Delta}{2}\right) \quad ...(17)$$

- This is the exact expression for the total received E-field for the two ray ground reflection model.

Q. 20 State advantages and disadvantages of two ray model.

Ans. :

Advantages :

- The major advantages of the two ray model are as given below :
  1. It is a useful propagation model, because it considers both the direct path and the ground reflected propagation path between the transmitter and receiver to calculate the path loss.
  2. It can predict the large scale signal strength for large values of d in the mobile systems and for the LOS microwave channels.

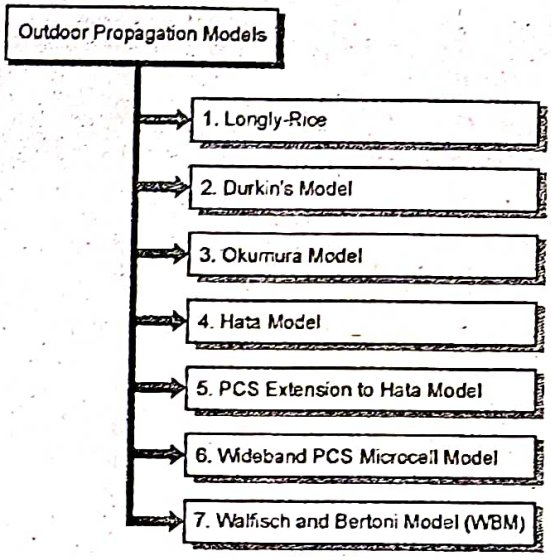
Disadvantage :

- The major disadvantage of the two ray model is given below :
  1. This is an oversimplified model and errors are introduced due to the fact that the effects of factors like buildings, terrain profile etc. are not considered while calculating the signal strength.

Q. 21 State various outdoor propagation models.

Ans. :

Outdoor propagation models :



(G-2830) **Fig. 1.13 : Outdoor propagation models**

Q. 22 Discuss the Okumura's prediction method with necessary equations.

Ans. :

Okumura's prediction method :

- The Okumura propagation model is suitable for large cell coverage with distances up to 100 km in urban areas, and it can extrapolate predictions up to 3 GHz.
- Use this model for effective base-station antenna heights in the range from 30 m to 1000 m, whereas the effective mobile receiver antenna height is taken as 3 m.
- The Okumura propagation model is very accurate in its predictions and is used by computer simulation tools.
- A simplified version of the Okumura path loss model, for propagation in an urban mobile environment, is expressed as follows :

$$L_{PO}(dB) = L_f(dB) + \alpha_m(f_c, r) - \alpha_t - \alpha_r - \sum \alpha_c \quad ...(1)$$

- Where L_f is the free-space propagation path loss expressed in dB
- α_m represents the median attenuation relative to free space, and is a function of f_c and r.

- α_t is the effective base station antenna height (h_t) gain factor, which varies at a rate of 20 dB/decade, and expressed mathematically as follows :

$$\alpha_t = 20 \log (0.005 \times h_t) \quad ...(2)$$

- Note that the above expression is valid for the range 1000 m > h_t > 30 m.
- Next, α_r is the effective mobile receiver antenna height (h_r) gain factor, which varies at a rate of 10 dB/decade for heights less than 3 m, and it is mathematically expressed as follows :

$$\alpha_r = 20 \log (0.33 \times h_r) \text{ for } 10 \text{ m} > h_r > 3 \text{ m} \quad ...(3)$$

$$\text{And} \quad \alpha_r = 10 \log (0.33 \times h_r) \quad \text{for } h_r \leq 3 \text{ m} \quad ...(4)$$

- α_c is the correction factor gain which depends on the type of environment (suburban area, open area), water surfaces, isolated , obstacle, etc.
- The Okumura model prepared based on the data collected in different terrains with specified system parameters.
- The standard deviation between the measured path loss and predicted path loss using this model is about 10-14 dB.
- This model is ideally suitable for use in cities with many urban structures but not many tall building structures. The Hata propagation model is based on the Okumara model.

Q. 23 Discuss the Hata model.

Ans. :

Hata model :

- The Hata model is an empirical formulation of the graphical path loss data obtained from the Okumura model. It is valid in the frequency range from 150 - 1500 MHz only.
- In this model Hata presented the propagation loss in the urban area in the form of a standard formula and provided correction equations for its application to other situations.
- The standard formula for median path loss in urban areas is given by the following equation.

$$L \text{ (urban) (dB)} = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d \quad ...(5)$$

Where,

f_c = Frequency in (MHz) from 150 MHz to 1500 MHz

h_{te} = Effective transmitter (base station) antenna height ranging from 30 m to 200 m.

h_{re} = Effective receiver (mobile) antenna height ranging from 1 m to 10 m.

d = Tx – Rx separation distance in km.

$a(h_{re})$ = Correction factor for effective mobile antenna height that is a function of the size of the coverage area.

- The mobile antenna correction factor $a(h_{re})$ for small to medium city is given by,

$$a(h_{re}) = (1.1 \log f_c - 0.7) h_{re} - (1.56 \log f_c - 0.8) \text{ dB} \quad ...(6)$$

- And the value of $a(h_{re})$ for large city is,

$$a(h_{re}) = 8.29 (\log 1.54 h_{re})^2 - 1.1 \text{ dB} \quad \text{for } f_c \leq 300 \text{ MHz}$$

$$a(h_{re}) = 3.2 (\log 11.75 h_{re})^2 - 4.97 \text{ dB} \quad \text{for } f_c \geq 300 \text{ MHz} \quad ...(7)$$

- Modify the standard Hata formula of Equation (5) as follows to calculate the path loss in suburban area.

$$L \text{ (dB)} = L \text{ (urban)} - 2 \log \left(\frac{f_c}{28}\right)^2 - 5.4 \quad ...(8)$$

- For path loss in open rural areas, the standard Hata formula is modified as follows,

$$L \text{ (dB)} = L \text{ (urban)} - 4.78 \log f_c^2 + 18.33 \log f_c - 40.94 \quad ...(9)$$

Q. 24 With the help derivation explain the concept of channel estimation in wireless systems.

Ans. :

Channel estimation in wireless systems :

- Consider the wireless channel model given in Equation (1), where h is the flat-fading channel coefficient.

$$y(k) = hx(k) + n(k) \quad ...(1)$$

- In this expression, y(k) represents the output or response of the channel, x(k) is its input and n(k) is the channel noise.
- Obtain the estimate $\hat{x}(k)$ of the symbol x(k) from y(k) simply as $\hat{x}(k) = \frac{1}{h} y(k)$. This is known as the zero-forcing receiver in wireless system.

- This shows that in order to detect the transmitted symbol x(k) at the receiver, we must know the channel coefficient "h".

Definition of channel estimation :

- The channel estimation is defined as the process of computing the channel coefficient " h" at the wireless receiver which is an important procedure in every wireless communication system.
- A popular scheme for estimating the wireless channel is with the help of transmission of pilot or training symbols.
- Pilot symbols are predetermined fixed symbols which are transmitted over the wireless channel. The pilot symbols are known to the wireless receiver.
- The receiver observes the outputs corresponding to the transmitted pilot symbols and with the help of knowledge of the transmitted pilot symbols, estimates the unknown fading channel coefficient.
- This procedure for pilot-based channel estimation is as follows :
- Let the transmitted $L^{(p)}$ pilot symbols be denoted as $x^{(p)}(1), x^{(p)}(2), \ldots, x^{(p)}(L^{(p)})$ for the purpose of channel estimation.
- Let the corresponding received outputs be $y^{(p)}(1), y^{(p)}(2), \ldots, y^{(p)}(L^{(p)})$, i.e., each $y^{(p)}(k)$, $1 \le k \le L^{(p)}$ is the output corresponding to the transmitted pilot symbol $x^{(p)}(k)$.
- The channel model for these received pilot symbols is given as follows :

$$y^{(p)}(k) = hx^{(p)}(k) + n(k)$$

- In order to simplify the derivation, assume that all the quantities $y^{(p)}(k)$, $x^{(p)}(k)$, $n(k)$ and the channel coefficient h are real.
- Due to the presence of the noise term n (k) in the above system, it is clear that $y(k) \neq hx(k)$ for any k.
- Thus, we have to determine an estimate of h from the noisy observation samples y (k).
- Intuitively then, a reasonable estimate $\hat{h}$ of h can be derived as a minimizer of the cost function as follows :

$$\hat{h} = \arg\min_{h} \{(y^{(p)}(1) - hx(p)(1))^2 + (y^{(p)}(2) - hx^{(p)}(2))^2 + \ldots + (y^{(p)}(L^{(p)}) - hx^{(p)}(L^{(p)})^2\}$$

$$= \underbrace{\sum_{k=1}^{L} (y^{(p)}(k) - hx^{(p)}(k))^2}_{\xi(h)}$$

- The above minimization is aimed at finding the best estimate of h which corresponds to the lowest observation error ξ (h) and therefore it is termed as the least-squares estimate.
- The most convenient way to minimize the error function ξ (h), is to differentiate it and set it equal to zero.
- Differentiate the error function to get,

$$\frac{d\xi(h)}{dh} = \sum_{k=1}^{L} 2(y^{(p)}(k) - hx^{(p)}(k)(x^{(p)}(k))$$

- Equate the differentiated error function to zero to get,

$$0 = \sum_{k=1}^{L} x^{(p)}(k)(y^{(p)}(k) - \hat{h}\, x^{(p)}(k))$$

$$\Rightarrow \hat{h} = \frac{\sum_{k=1}^{L} y^{(p)}(k)\, x^{(p)}(k)}{\sum_{k=1}^{L} (x^{(p)}(k))^2} \quad \ldots(2)$$

- In this way, compute the channel estimate $\hat{h}$ of the fading channel coefficient h.
- This is the desired expression for the channel coefficient estimate.

Q. 25 Explain the concept of diversity reception in wireless systems.

Ans. :

Diversity reception in wireless systems :

- Diversity reception is used in order to minimize the effects of fading.
- The theory of diversity lies at the heart of all modern wireless communication theory and technologies.

- It is by far the best tool available to combat the effects of multipath fading in a wireless channel and thereby ensure reliable communication.
- Diversity techniques can be employed in such scenarios to substantially improve the reliability of wireless communication, while reducing the BER.
- The principle of diversity reception is based on the fact that the signal at different points on the earth or different frequency signals do not fade simultaneously.
- There are two fundamental types of diversity reception systems :
  1. Space diversity system
  2. Frequency diversity system

1. Space diversity :

- In this system two or more receiving antennas are used. They are placed at points which are separated by about nine or more wavelengths.
- Receivers equal to the number of antennas are employed. The output stage of all the receivers is made common.
- As all the receivers receive the signal, the AGC from the receiver with the strongest signal at that moment is used to cut off all the other receivers.
- Thus, only the signal from the strongest receiver is passed to the common output stage.

2. Frequency diversity :

- This system works on the similar principle of the space diversity. The signal is transmitted simultaneously at two or three different frequencies.
- Out of the signals received by different receivers which are tuned to different frequencies, only the strongest signal at a particular frequency is selected.
- Due to the use of two or three frequencies for transmitting the same signal more bandwidth is required and the frequency spectrum is wasted.
- Therefore frequency diversity system is used only when it is not possible to use the space diversity.

Q. 26 How do diversity techniques help in improving SNR?

Ans. :

- Diversity techniques provide wireless link improvement at low cost.
- It is a powerful communication receiver technique.
- Diversity requires no training overhead because the transmitter does not require training sequence. There are a wide range of diversity implementations.
- Many diversity implementations are very practical and they provide significant link improvement with some additional cost.
- Diversity techniques exploit the random nature of radio propagation by searching independent or at least highly uncorrelated signal paths for communication.
- Practically, the receiver makes diversity decisions and that decisions are unknown to the transmitter.
- If one radio path experiences a deep fade, another independent path can have a strong signal.
- On order to select one path from more than one paths, both the instantaneous and average SNRs at the receiver can be improved.
- They can be always improved by as much as 20 dB to 30 dB.
- We have already seen the two types of fading-small-scale and large-scale fading.

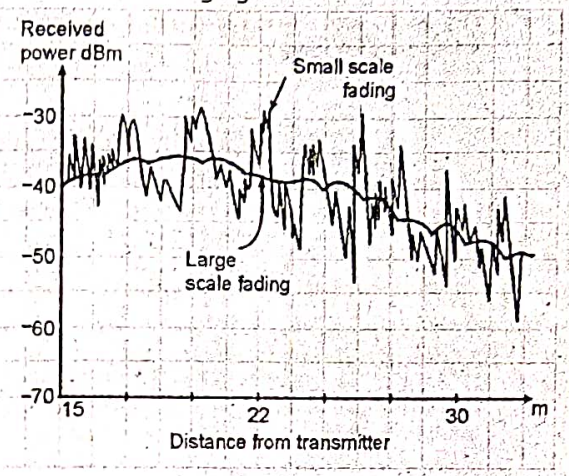
Q. 27 Explain the concept of microscopic diversity reception in wireless systems.

Ans. :

Microscopic diversity reception :

- The small scale or fading models are the models that characterize the rapid fluctuations of received signal strength over either very short distances or very short time durations.
- These models are useful for the mobile radio communications.
- A mobile station, when moves over a short distance, gives rise to the small scale fading.
- Main cause of small scale fades is multiple reflections from the surroundings in the area of the mobile.
- Small-scale fading for narrowband signals results in a Rayleigh fading distribution of signal strength over small distances.
- The microscopic diversity techniques can be used to exploit the rapidly changing signal in order to prevent the occurrence of deep fades.

- The small-scale fading in Fig. 1.14 reveals that if two antennas are separated by a small part of a meter, one can receive a null signal while other receives a strong signal.



(G-2678) **Fig. 1.14 : Two types of fading**

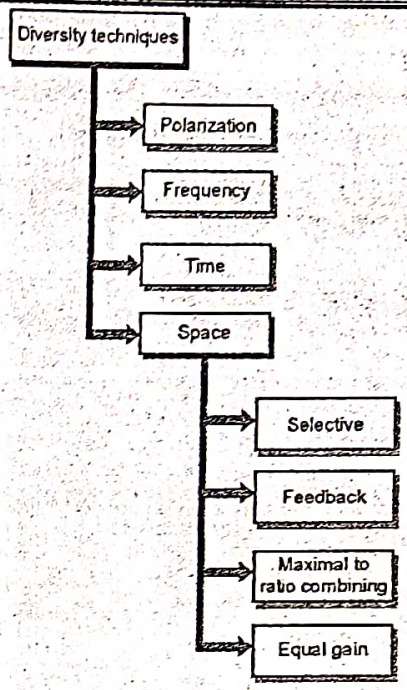
- A receiver can mitigate small scale fading effects by choosing the best signal at all times, this is known as antenna or space diversity.

Q. 28 Explain the concept of macroscopic diversity reception in wireless systems.

Ans. :

Macroscopic diversity reception :

- Large scale fading is caused by shadowing. The shadowing occurs due to variations in both the terrain profile and the nature of surroundings.
- The received signal in deeply shadowed conditions, can improve the average signal-to-noise ratio on the forward link. This type of diversity is known as called macroscopic diversity.
- In the macroscopic diversity technique, the mobile takes the advantage of large separations between the serving base stations.
- This technique is useful at the base station receiver.
- The base station can improve the reverse link with the use of the base station antennas separated in space. In order to improve the reverse link, a base station selects the antenna with the strongest signal from the mobile.
- Fig. 1.15 shows the types of the Diversity techniques.



(G-2828) **Fig. 1.15 : Types of Diversity Techniques**

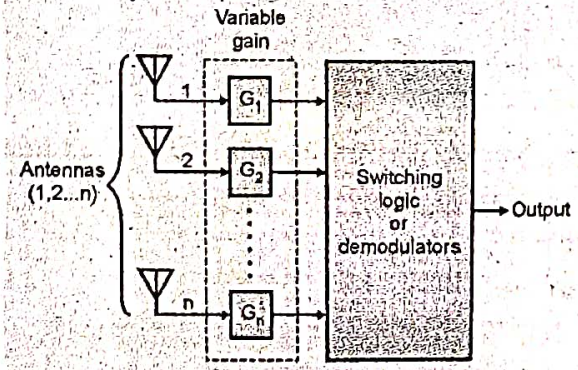
- The functionality of each diversity method is different.
- A common goal of all diversity techniques is to decrease the large scale fading effects observed in the multipath receiver circuits.

Q. 29 Explain the Space diversity technique briefly.

Ans. :

Space diversity technique :

- The space diversity technique is also known as antenna diversity.
- This is one of the most popular diversity technique used in the wireless systems.
- Fig. 1.16 shows the block diagram of a space diversity technique.



(G-2829) **Fig. 1.16 : Block diagram of space diversity**

- The block diagram consists of 'n' number of antennas with separate gain values G_1, G_2, G_3, ...G_n and a set of demodulators. The demodulators are used to generate the required output.

Q. 30 Explain the concept of frequency diversity reception in wireless systems.

Ans. :

Frequency diversity reception :

- An information in this diversity technique is transmitted on more than one carrier frequency.
- The frequencies are separated by more than the coherence bandwidth of the mobile channel.
- These will be uncorrelated with each other and will not experience the same fades.
- In case of uncorrelated channels are, the occupancy of simultaneous fading will be the multiple of the individual fading probabilities.
- Frequency diversity technique is applied in the microwave fields whenever line-of-sight links are used. In LOS links, they carry several channels in a frequency division multiplex mode (FDM).
- There can be deep fading in frequency diversity due to tropospheric propagation and resulting refractions of the signal.
- A radio licensee provides 1 : N protection switching. In 1 : N protection switching, one frequency is idle.
- An idle frequency is available on a stand-by basis in order to provide frequency diversity switching for any one of the N other carriers being used on the same link. Each frequency (carrier) carries independent traffic. The appropriate traffic is switched to the backup frequency when diversity is required.

Advantage :

- It allows several diversity branches .

Disadvantages :

1. It needs extra bandwidth.
2. It requires many receivers due to use of multiple channels.

Q. 31 Explain time diversity with Advantages andDisadvantages.

Ans. :

- In the time diversity technique, the information is transmitted repeatedly at exact time spacings that would exceed the coherence time of the mobile channel.
- This leads in the repetition of signals for several times with independent fading conditions.
- Hence it is possible to achieve the diversity branch signals, when same information is transmitted for different time slots.
- The time diversity technique is used in the spread spectrum CDMA systems where RAKE receiver is used for the reception.
- The RAKE receiver can align the replicas in time by demodulating multiple replicas of the transmitted CDMA signal. Here, each replica experiences a particular multipath delay.
- As the RAKE receiver can align the replicas in time, it can better estimate the original signal formed at the receiver.

Advantages :

1. Simple hardware is needed.
2. Multiple diversity branches can be used.

Disadvantages :

1. More frequency spectrum is required depending on the number of diversity branches.
2. In case of small diversity frequency, larger buffer memory is required.

Chapter 2 : Orthogonal Frequency Division Multiplexing

Q. 1 Explain single-carrier communication system.

Ans. :

Single-carrier communication system :

- In a single carrier communication system, a single radio frequency carrier is used to carry the information. Hence information in the form of bits is carried by only one single RF carrier.
- This system uses a single carrier for the entire baseband bandwidth of B.

- Therefore, the symbols are transmitted as symbol X(0) from $0 \le t < T$, symbol X(1) from $T \le t < 2T$, X(2) from $2T \le t < 3T$ and so on, i.e., a single symbol transmitted every T = 1 / B seconds.

Symbol time T :

- If a bandwidth B = 2W available for communication, where W is the one-sided bandwidth, or the maximum frequency, then the symbol time T for a single carrier communication system, is given by,

$$T = 1/B$$

Symbol rate :

- If the symbols can be transmitted at intervals of 1/B seconds each. Then, the symbol rate is given by,

$$\text{Symbol Rate} = \left[\frac{1}{1/B}\right] = B \quad \ldots(1)$$

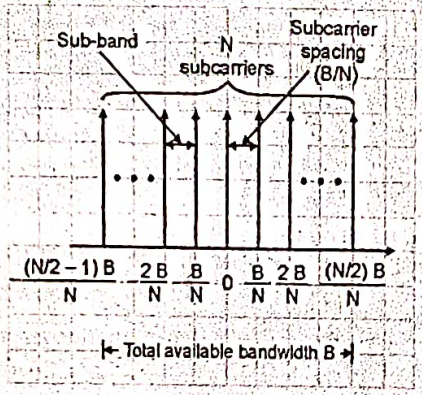
- Such a system is called as a single-carrier communication system.

Q. 2 Explain multi-carrier communication system with its implementation.

Ans. :

Multi-carrier communication system :

- Multi-carrier communication system is a method of transmitting data by splitting it into several components, and sending each of these components over separate carrier signals.
- Thus this system uses more than one carriers.
- Fig. 2.1 shows the concept of Multi-carrier communication system.



(O-1686)**Fig. 2.1 : Multi-carrier concept**

- As shown in Fig. 2.1, the total bandwidth B is divided into N sub-bands each of bandwidth B/N.
- Each sub-band is represented by a subcarrier.
- As shown in Fig. 2.1, the subcarriers are placed at frequencies (..., – B/N, 0, B/N, ...).

Example :

- If the bandwidth B = 256 kHz with N = 64 subcarriers then the bandwidth per sub-band is equal to 256 / 64 = 4 kHz.
- The frequency spacing between the subcarriers is also 4 kHz.

Implementation of multi-carrier transmission system :

- Consider the i^{th} subcarrier at the frequency $f_i = i\left(\frac{B}{N}\right)$ with $-\left(\frac{N}{2}-1\right) \le i \le \left(\frac{N}{2}\right)$.
- If X_i is the data transmitted on the i^{th} subcarrier, then the signal $s_i(t)$ corresponding to the i^{th} subcarrier is given by,

$$s_i(t) = X_i e^{j2\pi f_i t} = X_i e^{j2\pi i(B/N)t} \quad \ldots(2)$$

- Where,

  $s_i(t)$ = i^{th} subcarrier signal

  X_i = data transmitted on the i^{th} subcarrier

  f_i = i^{th} subcarrier centre frequency

  $e^{j2\pi f_i t}$ = i^{th} subcarrier

- Equation (2) shows the process of data modulation over the i^{th} subcarrier.
- There are a total N data streams and the N different data symbols X_i are modulated over the N different subcarriers with centre frequencies f_i.

Q. 3 Write a short note on multicarrier transmission.

Ans. :

MCM Transmitter :

- The block diagram of MCM (Multicarrier modulation) transmitter is as shown in Fig. 2.2.

(O-1687)**Fig. 2.2 : Multicarrier modulation transmitter**

- MCM transmitter consists of a serial to parallel converter, bank of modulators and an adder.
- Serial to parallel conversion is used to transmit N information symbols in parallel. Thus there are N numbers of data streams.

- The modulator modulates i^{th} data stream onto the i^{th} subcarrier.
- Adder will make the sum all the modulated subcarriers.
- Sum of all such subcarriers forms a composite signal which then would be transmitted on a channel.

Modulation Process :

- Consider the different modulated signals $s_i(t)$ corresponding to the N different subcarriers.
- The composite signal s(t) is formed by superposing modulated signals at the transmitter and is given by,

$$s(t) = \sum_i s_i(t) \quad ...(3)$$

- Substitute the value of s_i (t) from equation (2) we get,

$$s(t) = \sum_i X_i e^{j2\pi f_i t}$$

$$s(t) = \sum_i X_i e^{j2\pi i(B/N)t} \quad ...(4)$$

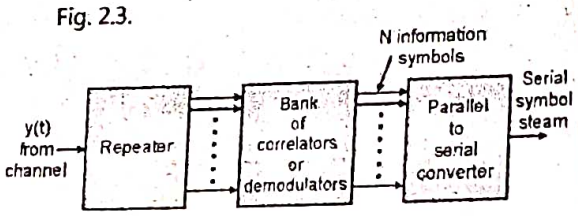
- This composite signal s(t) is then transmitted over the wireless channels.
- Thus, in the multicarrier system, N different data streams are transmitted over N subcarriers in parallel.

Q. 4 Write a short note on multicarrier reception.

Ans. :

Multicarrier reception :

- The block diagram MCM receiver is as shown in Fig. 2.3.



(O-1688)**Fig. 2.3 : Multicarrier modulation receiver**

- It consists of a repeater, bank of demodulators and parallel to serial converter. The received signal y(t) is applied to a repeater stage. At the receiver end composite signals are amplified first.
- Repeater is an antenna that simultaneously receives, amplifies, and transmits a signal.
- It is passed on to the bank of demodulators or correlators and the data is converted back to serial from parallel, forming a symbol stream.

Demodulation Process :

- At the receiver, the individual data streams are isolated from the composite signal s (t).
- The receiver receives the signal y(t) as ,

$$y(t) = s(t) = \sum_i X_i e^{j2\pi f_i t}$$

- At receiver, for simplicity of demodulation process, we assume that the noise is absent.
- It can be seen that the right-hand side of equation (4) is indeed the Fourier series representation s(t), corresponding to the fundamental frequency $f_0 = (B)N$ and the various X_i representing the Fourier coefficients.
- All the frequencies $i\left(\frac{B}{N}\right)$ are multiples of the fundamental frequency $f_0 = \left(\frac{1}{T_0}\right) = \left(\frac{B}{N}\right)$.
- To extract X_l (Fourier coefficient corresponding to the frequency $f_l = (f_0)$ follow the process similar to calculate the Fourier series as,

$$f_0 \int_0^{T_0} y(t)\,(e^{j2\pi f_l t})^*\,dt = \frac{B}{N}\int_0^{N/B} \left(\sum_i X_i e^{j2\pi i(B/N)t}\right) e^{-j2\pi l\,(B/N)}\,dt$$

$$= \frac{B}{N}\sum_i \int_0^{N/B} X_i e^{j2\pi (i-l) f_0 t}\,dt$$

$$= \underbrace{\frac{B}{N}\int_0^{\frac{N}{B}} X_l\,dt}_{i=l} + \frac{B}{N}\sum_{i\neq l}\int_0^{N/B} X_i e^{j2\pi(i-l)f_0 t}\,dt$$

$$= X_l + \frac{B}{N}\sum_{i\neq l} X_i \underbrace{\int_0^{N/B} e^{j2\pi(i-l)f_0 t}\,dt}_{=0}$$

$$= X_l \quad \text{(O-1668)}$$

- We have used $\int_0^{T_0} e^{j2\pi(i-l)f_0 t}\,dt = 0$ for $i \neq l$, because this is basically integrating a sinusoid of frequency $(i - l)f_0$, which is a multiple of the fundamental frequency f_0 over the time period T_0.
- As there are an integer number of cycles of the sinusoid of frequency $(i - l)\,f_0$, this integral is 0.
- This basically means that the different sinusoids $e^{j2\pi if_0 t}$ and $e^{j2\pi lf_0 t}$ are orthogonal.

- This property of orthogonality helps to extract the different streams X_l modulated over the different subcarriers.
- This property of orthogonality can be summarized as follows,

$$\int_0^{N/B} e^{j2\pi (i-l)(B/N)t} = \begin{cases} 0 & i \neq l \\ \frac{N}{B} & i = l \end{cases}$$

- Therefore, all the subcarriers other than the i^{th} subcarrier are orthogonal to the l^{th} subcarrier.
- A coherent demodulation is multiplying the term with $(e^{j2\pi f_l t})^*$ and integrating it.
- The coherent demodulation is the demodulation with the carrier matched to the subcarrier frequency $f_l = l\left(\frac{B}{N}\right)$.
- Thus, the data modulated on the different subcarriers X_l can be easily recovered by coherently demoudulating with each of the subcarriers corresponding to $l = -\left(\frac{N}{2}-1\right), \ldots, \left(\frac{N}{2}\right)$.
- This transmission on multiple orthogonal subcarriers and the associated data recovery at the receiver is called as Multi Carrier Modulation (MCM). The window of time associated with detection of this multicarrier signal is given by,

$$\left(\frac{N}{B}\right) = \left(\frac{1}{f_0}\right) = T_0$$

- This is basically the time period of integration.

Q. 5 What are the advantages and disadvantages of MCM system ?

Ans. :

Advantages :

- Consider a transmission bandwidth of B = 1024 kHz. This bandwidth B is much greater than the coherence bandwidth B_c which is typically around 250 kHz.
- The single-carrier system experiences frequency-selective fading and inter-symbol interference as the transmission bandwidth B >> B_c.
- Consider an OFDM system that uses N = 256 subcarriers in the same bandwidth.
- The bandwidth per subcarrier is,

$$B_s = 1024 / 256 = 4 \text{ kHz}.$$

- That means the subcarrier bandwidth of 4 kHz is significantly lower than the coherence bandwidth of 250 kHz.
- Each subcarrier in OFDM experiences flat fading, since $\left(\frac{B}{N}\right) << B_c$.
- There is no inter-symbol interference in the data transmitted on any of the subcarriers in OFDM.
- MCM eliminates the Inter-Symbol interference (ISI) through parallel transmission by using multiple narrowband subcarriers.
- This results in avoiding distortion of the received symbols.
- The advantages of MCM system as follows :
  1. Each OFDM subcarrier experiences flat fading
  2. ISI is eliminated
  3. Signal distortion is avoided.

Disadvantages :

- MCM system suffers from a significant disadvantage. Implementation of the bank of N modulators and N demodulators with closely spaced subcarrier frequencies is a challenging task.
- To overcome this problem, data transmission by Frequency Division Multiplexing using the Discrete Fourier Transform is used.
- This technique, where the MCM signal is generated by using the IFFT (Inverse FFT) operation is known as Orthogonal Frequency Division Multiplexing or OFDM.

Q. 6 Write a short note on Orthogonal Frequency Division Multiplexing (OFDM).

Ans. :

Orthogonal Frequency Division Multiplexing :

- OFDM stands for Orthogonal Frequency Division Modulation. It is a wideband wireless digital communication technique.
- OFDM is a digital modulation scheme which can be used for high speed video communication and audio communication without any inter symbol interference (ISI).
- It has a high spectral efficiency. That means it can accommodate a large number of users.

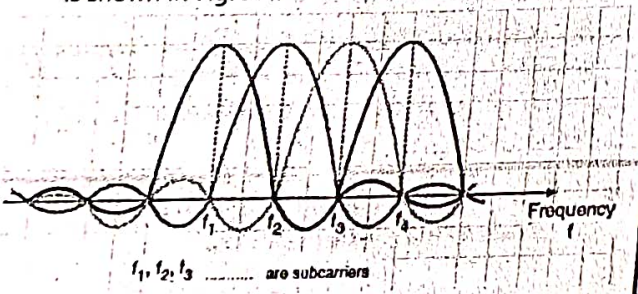
- It is a multiplexing / multiple access scheme which has advanced features suitable for the fourth generation of wireless communication systems.
- It is mainly based on the DSP techniques.

Q. 7 Define and explain orthogonality.

Ans. :

Definition of Orthogonality :

- Two signals are said to be orthogonal if they are independent of each other in a specified time interval and do not interact with each other.
- Transmit a number of orthogonal signals over a common channel without interference and detect them on the receiving end without interference.
- In FDM we have different channels (signals) occupying different frequency bands with a guard band in between to avoid any interference between the adjacent channels.
- But this makes FDM a bandwidth inefficient system.
- The bandwidth efficiency improves considerably if we use OFDM technique instead of the simple FDM.
- In the orthogonal FDM (OFDM) the subcarriers f_1, f_2, f_3 ..... etc. Are placed as close as they can be placed theoretically in the frequency domain. This is shown in Fig. 2.4.



(E-1334) **Fig. 2.4 : Orthogonal signals in frequency domain (principle of OFDM)**

- Note that the subcarriers f_1, f_2 .....etc are placed at the null points of all the other subcarriers.
- This automatically eliminates the interference among the adjacent subcarriers.
- Due to this type of placement of subcarriers, the total bandwidth of the OFDM system is much less than that of the conventional FDM system and can accommodate more number of users.

Q. 8 Define and explain OFDM-PAPR.

Ans. :

Definition of OFDM-PAPR :

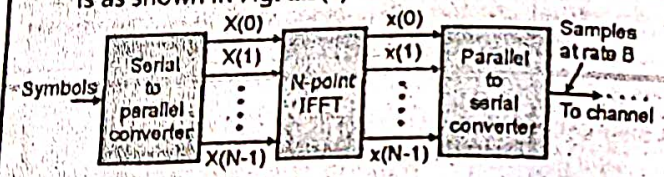
- Peak-to-peak average power ratio (PAPR) is defined as the ratio of peak power to the average power of a signal. It is measured in decibels (dB).
- It is observed that PAPR occurs, in conditions where in a multicarrier system, the different sub-carriers are out of phase with each other.
- The sub-carriers are different at every time instant with respect to each other and have different phase values.
- If all the subcarriers attain the maximum value simultaneously, then the output envelope shoots up suddenly. This causes a 'peak' to appear in the output envelope.
- Similar to the OFDM system there are a large number of independently modulated subcarriers, the peak value of the system may be very high as compared to the average value of the complete system.
- In LTE system, the value of OFDM signal PAPR is approx. 12 dB.

Q. 9 Explain OFDM with IFFT.

Ans. :

OFDM transmitter with IFFT :

- The block diagram of OFDM transmitter with IFFT is as shown in Fig. 2.5(a).



(O-1689) **Fig. 2.5(a) : OFDM transmitter with IFFT**

- The bank of modulators in MCM is replaced by IFFT block in OFDM.
- The information symbols at the input are converted from serial stream into parallel stream.
- Since we assumed that there are N subcarriers allowed for the OFDM transmission, we name them from 0 to N–1.
- The serial to parallel converter takes the serial stream of input bits and outputs N parallel streams (indexed from 0 to N-1).

- The N point IFFT modulates parallel streams in a baseband fashion.
- The output of IFFT block is then applied to the parallel to serial converter to produce the OFDM signal.
- Let s(t) is the MCM transmit signal. It is band-limited to the total bandwidth B.

  ∴ Nyquist sampling rate = B and

  Associated sampling time is $T_s = 1/B$
- Consider now the composite MCM signal $\sum_i X_i e^{j2\pi i(B/N)t}$
- The μ^{th} sample at time instant $\mu T_s = \mu / B$ is given by,

$$s(\mu T_s) = x(\mu) \sum_i X_i e^{j2\pi i (B/N)(\mu/B)}$$

$$x(\mu) = \sum_i X_i \underbrace{e^{j2\pi(i\mu/N)}}_{\text{DFT}} \quad ...(1)$$

- Equation (1) shows that the sample $x(\mu)$ is basically the Inverse Discrete Fourier Transform (IDFT) coefficient of the information symbols X(0), X(1), . . . , X (N – 1) at the μ^{th} time point.
- In order to generate the sampled MCM signal, the Inverse Fast Fourier Transform (IFFT) can be easily used.
- This method of generating the composite transmit signal through IFFT or IDFT reduces the complexity of implementing an OFDM system.
- This method with IDFT reduces complexity of the system as it eliminates the need for the bank of modulators corresponding to the different subcarrier frequencies.
- The generation of the MCM signal using the IFFT operation is called as Orthogonal Frequency Division Multiplexing (OFDM).

Q. 10 How to avoid IS In OFDMI ?

Ans. :

- If $L_c \geq (L - 1)$, then inter-symbol interference can be seen to be from x(N – 1), x(N – 2) , . . . , x(N – L + 1).
- Inter-OFDM symbol interference can be avoided with the cyclic prefix of appropriate length, i.e., $L_c \geq (L - 1)$, and inter-symbol interference is restricted to samples from the same OFDM symbol.
- The samples y(0), y(1) , . . . , y(N – 1) are given as,

$$y(0) = h(0)x(0) + h(1)x(N-1) + \ldots + h(L-1)x(N-L+1)$$

$$y(1) = h(0)x(1) + h(1)x(0) + \ldots + h(L-1)x(N-L+2)$$

$$\vdots$$

- $y(N-1) = h(0)x(N-1) + h(1)x(N-2) + \ldots + h(L-1)x(N-L)$
- From the above equations it is clear that, the output y(n) is a circular convolution between the channel filter h (n) and the input x(n).
- Hence this can be expressed as follows,
- Received samples [y(0), y(1),...,y(N – 1)]

$$= [h(0), h(1),\ldots,h(L-1),0,\ldots,0] * N [x(0),x(1),\ldots,x(N-1)]$$

- Where *N indicates the circular convolution of modulo N .
- Therefore, the output Y can be given by,

$$Y = h * Nx$$

- Taking the DFT of y(n) at the output, we get,

$$Y(k) = H(k)X(k), \; 0 \leq k \leq (N-1) \quad ...(2)$$

Where,

Y(k) = N-point DFT of y(n)

X(k) = N-point DFT of x(n)

x(n) = IDFT of X(n)

- Therefore, the DFT of the samples x(n) gives back the original transmitted symbols X(n).
- The coefficients H(k) indicates the DFT of the zero-padded channel filter,

$$h(0), h(1),\ldots,h(L-1), \underbrace{0,\ldots,0}_{(N-L)}$$

- Thus, Equation (2) represents the flat-fading channel across the k^{th} subcarrier in the OFDM system.
- Here Y(k) indicates the output symbol, while H(k) indicates the equivalent flat-fading channel coefficient.
- This is true for each subcarrier k, i.e., for $0 \leq k \leq (N - 1)$.

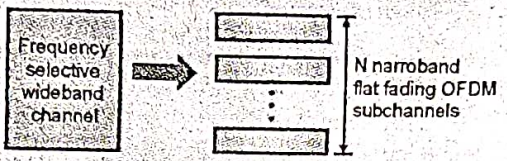
- Thus in OFDM the conversion of the frequency-selective fading channel into a group of narrowband flat-fading channels takes place.
- If a single carrier communication system is used and the symbols X(0), X(1),..., X(N – 1) are directly transmitted then the received symbol y(n) can be given by,

$$y(n) = h(0)X(n) + h(1)X(n-1) + \ldots + h(L-1)X(n-L+1)$$

- Each symbol X(n) will experience inter-symbol interference of (L – 1) past symbols.
- Therefore, using OFDM, it is possible to eliminate the inter-symbol interference due to frequency-selective nature of the channel.
- The set of parallel flat-fading channels can be summarized as,

$$Y(0) = H(0)X(0)$$
$$Y(1) = H(1)X(1)$$
$$\vdots$$
$$Y(N-1) = H(N-1)X(N-1)$$

- Fig. 2.6 shows schematic representation of conversion of the frequency-selective wideband channel into N narrowband flat-fading subchannels.



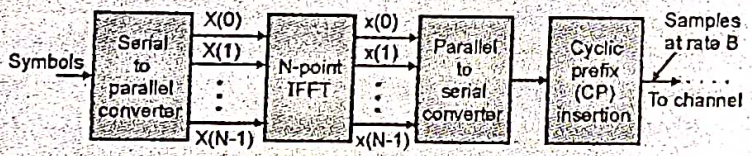
(O-1709)**Fig. 2.6 : OFDM parallel sub-channels**

Q. 11 Explain OFDM transmitter with cyclic prefix.

Ans. :

OFDM transmitter with cyclic prefix :

- Fig. 2.7 shows the OFDM transmitter with Cyclic prefix.



(O-1710)**Fig. 2.7 : OFDM transmitter with Cyclic prefix**

- The information symbols are parallelized in N different sub-streams by using serial to parallel converter. Each sub-stream will modulate a separate carrier through the N-point IFFT modulation block.
- A cyclic prefix is inserted which eliminates the inter-symbol (ISI) and inter-block interference (IBI).
- This cyclic prefix of length L_c is a circular extension of the IFFT-modulated symbol and it is obtained by copying the last L_c samples of the symbol in front of it.
- The information symbols are back-serial converted, forming an OFDM symbol that will modulate a high-frequency carrier before its transmission through the channel.

Q. 12 Explain various parameters in the design of a OFDM system.

Ans. :

- WiMAX is a well-known 4G wireless standard.
- WiMax has total number of subcarriers N = 256, with a bandwidth of 15.625 kHz per subcarrier.

$$\therefore \left(\frac{B}{N}\right) = 15.625 \text{ kHz}$$

$$\therefore B = N \times 15.625 = 256 \times 15.625$$

$$\therefore B = 4 \text{ MHz}$$

- The subcarrier bandwidth is less than the coherence bandwidth, i.e., $B_s = 15.625$ kHz << $B_c = 250$ kHz.
- So each subcarrier experiences frequency flat fading.

OFDM symbol time without CP :

- The OFDM symbol time without CP is given by,

$$\left(\frac{N}{B}\right) = \left(\frac{256}{4 \times 10^6}\right) = 64 \ \mu s$$

- The OFDM symbol time corresponding to the N = 256 IFFT samples is 64 µs.

OFDM symbol time with cyclic prefix :

- The cyclic prefix used in the WiMAX is 12.5 % of the symbol time.

∴ Duration of cyclic prefix = 12.5% × Symbol time

$$= \frac{12.5}{100} \times 64\ \mu s$$

$$= 8\ \mu s$$

∴ Total transmitted OFDM symbol duration with cyclic prefix is 64 μs + 8 μs = 72 μs.

Number of samples in the CP :

- The number of samples in the CP is given by,

$$\text{Samples in CP} = \frac{\text{CP duration}}{\text{Sample time}}$$

$$= \frac{8\ \mu s}{1/B}$$

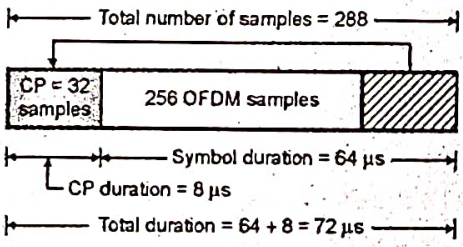
$$= 8 \times 10^{-6} \times 4 \times 10^{6}$$

$$= 32$$

∴ Length of the cyclic prefix L_c = 32 samples

∴ Total number of samples = 256 + 32 = 288

- WiMAX OFDM symbol in terms of the regular samples and cyclic prefix is as shown in Fig. 2.8.



(O-1713)**Fig. 2.8 : WiMAX OFDM symbol with cyclic prefix**

Loss in spectral efficiency :

- The loss in spectral efficiency is given by,

$$\text{Loss in spectral efficiency} = \frac{\text{Length of the cyclic prefix } L_c}{\text{Total number of samples}}$$

$$= \frac{32}{288} = 11.1\%$$

- This loss in spectral efficiency is due to the insertion of the cyclic prefix.

Q. 13 What are the advantages of OFDM ?

Ans. :

- The advantages of OFDM are as follows :

1. OFDM makes efficient use of the spectrum by allowing overlap.
2. OFDM divides the channel into narrowband flat fading sub-channels, it is more resistant to frequency selective fading as compared to single carrier systems.
3. OFDM eliminates ISI and IFI with the use of a cyclic prefix.
4. Due to the frequency selectivity of the channel, one can recover the lost symbols by using adequate channel coding and interleaving.
5. Channel equalization in OFDM becomes simpler as compared to single carrier systems that uses adaptive equalization techniques.
6. It is possible to use maximum likelihood decoding with reasonable complexity.
7. OFDM becomes efficient to implement the modulation and demodulation functions by using FFT techniques.
8. As compared to single carrier systems, OFDM is less sensitive to sample timing offsets.
9. It provides good protection against co-channel interference and impulsive parasitic noise.

Q. 14 What are the disadvantages of OFDM ?

Ans. :

- The disadvantages of OFDM are as follows :

1. OFDM requires RF power amplifiers with a high peak to average power ratio because it has a noise like amplitude with a very large dynamic range.
2. OFDM system is more sensitive to carrier frequency offset and drift due to leakage of the DFT.
3. It is sensitive to Doppler shift.
4. It needs linear transmitter circuitry, which suffers from poor power efficiency.
5. It suffers loss of efficiency caused due to cyclic prefix.

Q. 15 Explain the concept of Smart Antennas.

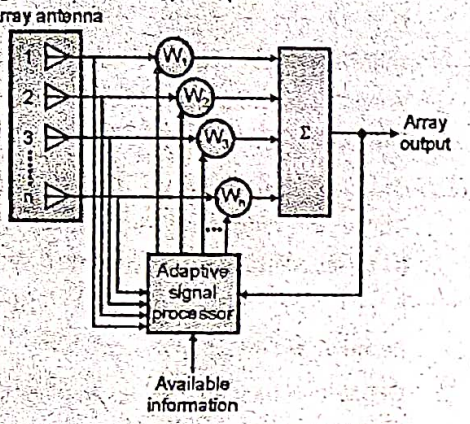
Ans. :

Definition of Smart Antennas :

- Smart antennas are arrays of antenna elements that change their antenna pattern dynamically in order to adjust to the noise, interference in the channel that affects the signal of interest.

Principle of Smart Antenna :

- Fig. 2.9 shows the principle of smart antenna.



(G-2717) Fig. 2.9 : Smart antenna system

- In smart antennas, the signals received at the different antenna elements are multiplied with their complex weights W.
- The antenna selects the summed up weights adaptively. The smart antenna is also known as adaptive array elements.
- In order to transmit and receive the data adaptively, smart antennas combine an antenna array with digital signal processing ability.
- To adjust to the noise interference in the channel, smart antennas dynamically modify their antenna pattern.
- Smart antennas combinesarray gain, diversity gain and interference suppression to improve the capacity of the wireless systems.
- Improved capacity results in higher data rate.
- In order to reduce the multipath fading problems, smart antennas use multipath wave propagation.
- Smart antennas work by using two antennas and a signal processor.
- Smart antennas can focus on individual signals by comparing the signal strengths received by both antennas.
- In mobile communication systems, the base station plays the role of the listener and the mobile equipment plays the role of signal source.
- The function of a digital signal processor equipped with an antenna array is to adjust various system parameters and to focus on the required signal while cancelling out other interferences.
- The smart antenna systems can electronically adapt to the RF environment. Multipath propagation is obtained through scattering and reflection.

Q. 16 Write a short note on functions of smart antenna.

Ans. :

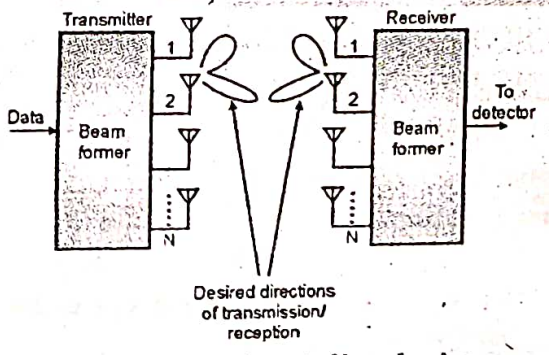
Functions of a smart antennas :

1. Estimation of Direction of arrival (DOA) :

- The smart antenna system computes the direction of arrival of the signal.
- EOA is estimated using techniques like MUSIC (Multiple Signal Classification), estimation of signal parameters through rotational invariance techniques (ESPRIT) algorithms, Matrix Pencil method or one of their derivatives. They involve finding a spatial spectrum of the antenna/sensor array, and calculating the DOA from the peaks of this spectrum.

2. Beamforming Method :

- Fig. 2.10 shows the concept of beamforming. This method is used to create the radiation pattern of the antenna array.



(G-2733) Fig. 2.10 : Concept of beamforming

- They create antenna array by adding constructively the phases of the signals in the direction of the desired targets/mobiles, and to

nullify the pattern of the targets/mobiles that are undesired/interfering targets.

Q. 17 List the types of Smart Antenna Systems. Explain Switched beam antenna.

Ans. :

Types of Smart Antenna Systems:

1. Switched beam antenna
2. Adaptive array antenna

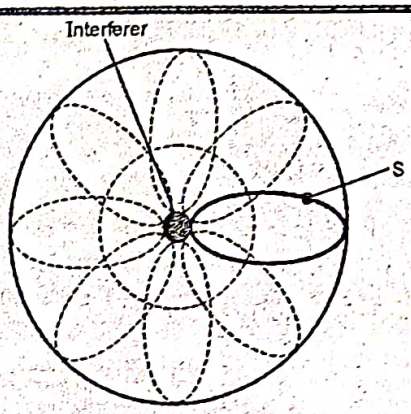
Switched beam antenna :

Definition :

- The antennas which form the multiple fixed beams with heightened sensitivity in some particular directions are known as Switched beam antennas.
- It is extension of cell sectoring as each sector is subdivided into smaller sectors.
- In this configuration of smart antenna, a finite number of fixed, predefined patterns or combining schemes (sectors) are available.

Working :

- The switched beam antenna systems detect signal strength; select from one of several predetermined, fixed beams and switch from one beam to other as the cellular phone (mobile) moves throughout the sector.
- The switched beam antennas combine the outputs of multiple antennas in such a way that they form directional beams with high spatial selectivity.
- To focus on an individual subscriber, switched beam antenna system use some predefined radiation patterns.
- After detecting signal strength, smart beam antenna system switches between thousands of predetermined patterns to match the best communication link.
- As the subscriber moves, the radiation pattern is switched and the best is selected.
- Fig. 2.11 shows the basic mechanism of a switched beam antenna system. Individual subscriber is denoted by S.



(G-2718) **Fig. 2.11 : Switched beam system**

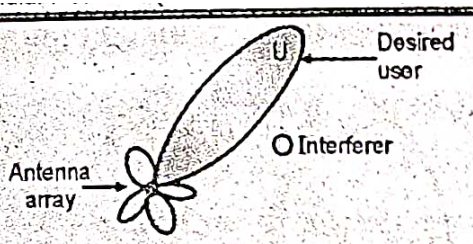
- In a splitting system, macrocells are divided into a few microcells.
- Each microcell is equipped with different types of preset radiation patterns.
- When a subscriber enters a macrocell, the microcells with the strongest signals are determined and the corresponding beam is used for the maximum output power.
- As shown in Fig. 2.11, the sector is filled with predetermined patterns.
- When the subscriber enters into a specific area, only the corresponding pattern is selected.
- The system continuously monitors the subscriber and switches from beam to beam for the best output.

Q. 18 Explain Adaptive array antenna.

Ans. :

Adaptive array antenna :

- Adaptive array antennas are the most advanced smart antenna approach as on date.
- In this system, multiple antennas are used both in the transmitting and receiving side of a communication link to adaptively optimize the transmission over the channel.
- An AAS system focus its transmit energy towards a receiver, and while receiving, it can focus towards the transmitter.
- Beamforming technique is used in AAS.
- Fig. 2.12 shows the basic principle of Adaptive array antenna system.



(G-2719) **Fig. 2.12 : Adaptive array antenna**

- Beam forming allows directional signal transmission or reception without manually steering the antennas.
- In the beam forming, several transmitters are set apart from each other.
- All transmitters transmit the same signal with different phase difference and delay.
- The interference occurred in all the transmitters can be used to guide a signal to a specific direction.
- The signal processing algorithms are used to locate and track the different types of signals, to reduce the interference and maximize the required signal reception. In an AAS, signals can be focused simultaneously on many remote devices.
- ASS controls the shape of these beams in such a way that the signal between the transmitter and receiver is always maximum.
- This system can increase link quality by combining the effects of multipath propagation and exploiting different data streams from different antennas.

Q. 19 What are the advantages and disadvantages of switched beam system and Adaptive array antenna ?

Ans. :

Advantages of SBAs :

1. Single or multiple fixed directional beams.
2. Simple algorithms are used for beam selection.
3. Significant increase in coverage and capacity.
4. Lower installation costs and less complexity.

Disadvantages of SBAs :

1. These antennas have non uniform gain with respect to angle.
2. Locking into the wrong beam due to multi path or interference.
3. Limited interference suppression.

Advantages of AAS :

1. Increased coverage
2. Increased capacity
3. Cost reduction
4. Improved link quality and reliability
5. Increased Spectral efficiency

Disadvantages of AAS :

1. Complex transceiver mechanism
2. Need of resource management
3. Physical size of the antennas

Q. 20 State the features of Smart Antennas.

Ans. :

- The important features of the smart antennas (antenna arrays) are as follows :
  1. Optimized radiation pattern.
  2. They can be used for beam forming (extremely directional antenna).
  3. They are adaptable to changes in signal power, transmission conditions and many other signal propagation effects.
  4. Smart antennas can provide the required coverage.
  5. Smart antennas reduce multipath fading and other multipath propagation effects.
  6. Smart antennas are power efficient because the inputs are combined to multiple elements in order to optimize the available processing gain in the downlink.
  7. It improves the signal to interference ratio of the received signals.
  8. With the help of smart antennas, space division multiple access adopts to the radio environment.
- The handset antennas of today's mobile phone are omnidirectional in nature.

Q. 21 What are the advantages of smart antenna systems ?

Ans. :

Advantages of smart antenna systems :

- The advantages of the smart antennas (antenna arrays) are as follows :
  1. In smart antennas, focus on the energy sent out into the cell increases base station range and coverage.

2. Lower power requirements also allows a greater battery life and smaller/lighter handset size.
3. A Smart antenna can reduce the effective delay spread of the channel, enabling higher bit rates to be supported without the use of an equalizer, improved bit error rate.
4. Smart antennas improves the capacity by precise control of signal nulls quality and mitigation of interference combine to frequency reuse reduce distance (or cluster size).
5. A smart antenna lowers amplifier costs, power consumption.
6. Smart antennas are highly reliable.

Q. 22 What are the disadvantages of smart antenna systems ?

Ans. :

Disadvantages of smart antenna systems :

– The disadvantages of the smart antennas (antenna arrays) are as follows :

1. **Cost :** The cost of such a device will be more, not only in the electronics section, but also in the power.
2. **Size :** To make this method to be efficient large base stations are required. This will increase the size.
3. **Diversity :** diversity becomes a big problem when multiple mitigation is needed. The terminals and base stations should have multiple antennas.

Q. 23 What are the applications of smart antenna systems ?

Ans. :

Applications of smart antenna systems :

1. Wi-Fi a/b/g access points and clients
2. Mobile video
3. Mobile broadband/gaming
4. Satellite/digital radio
5. GPS
6. 3G Wireless
7. WiMax
8. RFID

Q. 24 State and explain different types of multi-antenna techniques ?

Ans. :

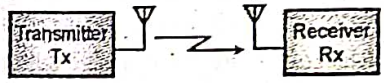
Types of multi-antenna techniques :

– Following are the types of Multi-antennas :

1. SISO (Single-input Single-output)
2. SIMO (Single-input Multiple-output)
3. MISO (Multiple-input Single-output)
4. MIMO (Multiple-input Multiple-output)

Single Input Single Output (SISO) :

– SISO stands for Single Input and Single Output. As shown in Fig. 2.13, it consists of one antenna for transmission and one for reception.



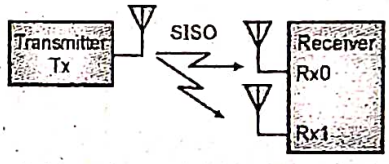
(G-2720) **Fig. 2.13 : SISO (Single Input Single Output)**

– SISO is a conventional radio system where neither the transmitter nor receiver has multiple antenna.

Single Input Multiple Output(SIMO) :

– SIMO stands for Single Input and multiple Outputs. It consists of one antenna for transmission and multiple antennas for reception.

– Here one signal is transmitted and two or more are received. A typical SIMO structure is shown in Fig. 2.14.



(G-2721) **Fig. 2.14 : SIMO (Single input multiple output)**

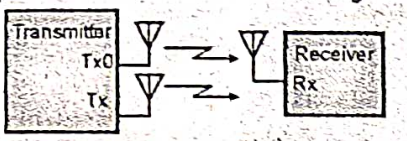
– Receive diversity is used in the SIMO antenna technique.

– While receiving a signal, the antenna can either select the strongest signal or can join all the signals received in different antennas is known as receive diversity. As compared to SISO systems SIMO systems provide more throughput with micro-diversity.

Multiple Input Single Output (MISO) :

– In the MISO (Multiple-input Single-output) antenna technique, multiple antennas are used in the transmitter while a single antenna is used in the receiver.

- This is a comparatively new technology. MISO has been a favorite as only multiple antennas need to be installed in the base station (BS).
- A typical MISO structure is shown in Fig. 2.15.

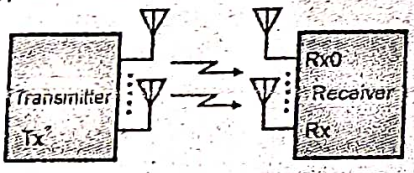


(G-2722) **Fig. 2.15 : MISO (Multiple input single output)**

- Transmit diversity is used in the MISO antenna technique.
- Transmit antenna diversity is a controlled diversity technique which provides spatial repetition of transmitted signals through different antennas.
- A method known as STC (Space Time Coding) is implemented at the transmitter with multiple antennas.
- STC allows the transmitter to transmit signals simultaneously in time and space, which means the data can be transmitted by multiple antennas at different times repeatedly.

Multiple Input Multiple Output (MIMO) :

- MIMO consists of multiple antennas in both the transmitter and the receiver.
- They have capability of combining the SIMO and MISO technologies. MIMO increase capacity by using Spatial Multiplexing (SM).
- A typical MIMO structure is shown in Fig. 2.15(a).



(G-2723)**Fig. 2.15(a) : Multiple Input Multiple Output**

Q. 25 Explain concept of MIMO w.r.t. 4G technology.

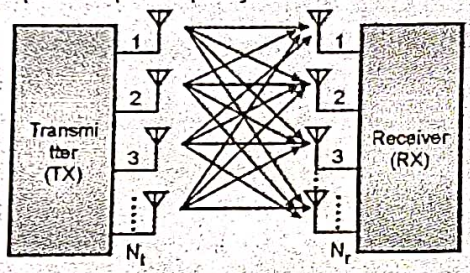
Ans. :

Principle :

- The Multiple-Input Multiple-Output (MIMO) system uses multiple antennas on both the transmitter and receiver.
- They have dual capability of combining the SIMO and MISO technologies.
- They can also increase capacity by using Spatial Multiplexing (SM).
- The MIMO method has some clear advantages over Single-input Single-output (SISO) methods.
- The fading is greatly eliminated by spatial diversity, and low power is required as compared to other techniques in MIMO.
- MIMO systems are used to obtain high speeds and throughput.

Block diagram :

- Fig. 2.16 shows the block diagram of multiple-input multiple-output system.



(G-2736) **Fig. 2.16 : Block diagram of a multiple-input multiple-output system**

- It consists of a transmitter with N_t number of transmitting antennas and a receiver with N_r number of receiving antennas as shown.
- The data stream at the transmitter (Tx) enters an encoder, and the encoded outputs are applied to N_t transmitting antennas.
- Multiple transmitting antennas transmit the signal through the wireless propagation channel, which is assumed to be quasi-static and frequency-flat.
- The meaning of the term quasi-static is that the coherence time of the channel is extremely long due to which "a large number" of bits can be transmitted within this time.

Q. 26 How do we use space-time block code (STBC) and space time trellis code (STTC) ?

Ans. :

- We need to use the Space time codes (STCs) to maximize diversity, coding gain and throughput in order to compensate for the channel fading and decrease the bit error rate.
- There are following two types of space time codes used in MIMO systems :
  1. Space time block code (STBC) and
  2. Space time trellis code (STTC)

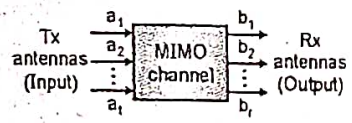
- The space time block codes (STBC) are transmitted using a block structure.
- It supports a simple decoding at the receiver end.
- With STBC the system can transmit multiple copies of the data over a number of antennas in order to improve the data transfer reliability.
- The space time trellis codes (STTEs) are the codes that transmit multiple redundant copies of convolutional or trellis code distributed over time and a number of transmit antennas.
- The receiving antenna would reconstruct the original transmitted data using the multiple redundant copies.
- The space time trellis code provides both diversity and coding gain as compared to the space time block codes.
- The STTCs have a good bit-error performance. However their encoding and decoding methods are complex.
- They require a virterbi decoder at the receiver end.

Q. 27 Write a short note on MIMO system model.

Ans. :

MIMO system model :

- Fig. 2.17 shows a MIMO wireless system which consists of t transmit antennas and r receive antennas. Such a MIMO system is also referred as an r × t system.



(O-1658) **Fig. 2.17 : MIMO system input-output schematic**

- Let $a_1, a_2 \ldots\ldots a_t$ are the t symbols transmitted from the t transmit antennas in the MIMO system, i.e. a_i.
- The a_i denotes the symbol transmitted from the i^{th} transmit antenna with $1 \le i \le t$.
- The t-dimensional vector is formed by stacking of transmit symbols.
- It is also called as the transmit vector and is given by,

$$a = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_t \end{bmatrix} \quad \text{(O-1656)}$$

- Let $b_1, b_2, \ldots b_r$ are the r received symbols across the r receive antennas, which can be stacked as the r-dimensional receive symbol vector and is given by,

$$b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_r \end{bmatrix} \quad \text{(O-1657)}$$

- Let h_{ij} is the complex coefficient representing the fading channel coefficient between the i^{th} receive antenna and the j^{th} transmit antenna.
- There are rt channel coefficients available in this wireless scenario that correspond to all possible combinations of the r receive antennas and t transmit antennas.
- The r × t channel coefficients are arranged in a matrix form as follows :

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{r1} & h_{r2} & \cdots & h_{rt} \end{bmatrix} \quad \text{(O-1659)}$$

- Here the r × t dimensional matrix H is called as the MIMO channel matrix.
- Let i is the additive noise at the receive antenna and it is denoted by n_i i.e., $n_1, n_2 \ldots, n_r$.
- The vector form representation of the net MIMO input output system model is :

$$\underbrace{\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_r \end{bmatrix}}_{b} = \underbrace{\begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{r1} & h_{r2} & \cdots & h_{rt} \end{bmatrix}}_{H} \underbrace{\begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_t \end{bmatrix}}_{a} + \underbrace{\begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_r \end{bmatrix}}_{n} \quad \text{(O-1660)} \quad \ldots(1)$$

- This can be represented using matrix notation as,

$$b = H \cdot a + n$$

- From Equation (1), the receive symbol b_1 is given as,

$$b_1 = h_{11}a_1 + h_{12}a_2 + \ldots h_{1t}a_t + n_1 \quad \ldots(2)$$

- From Equation (2) it can be seen that all the symbols $a_1, a_2, \ldots, a_t$ interfere at b_1 received at the receive antenna 1.
- Similarly, the receive symbol b_2 is given by,

$$b_2 = h_{21}a_1 + h_{22}a_2 + \ldots + h_{2t}a_t + n_2 \quad \ldots(3)$$

- This is true for all the receive antennas, that means at each receive antenna i, the receive symbol b_i is a linear sum of all the transmit symbols $a_1, a_2, \ldots, a_t$ from the t transmit antennas, observed in additive noise n_i.

Q. 28 Write a short note on advantages and applications of MIMO.

Ans. :

Advantages of MIMO :

1. Increased uplink/downlink throughput
2. High QoS (Quality of Service) with increased spectral efficiency
3. Increases the spatial diversity and multiplexing gain
4. Minimizes the fading effects on the transmitted signal traveling to receive antenna
5. Better Signal to Noise Ratio(SNR)
6. Reduction in BER (Bit Error Rate)

Applications :

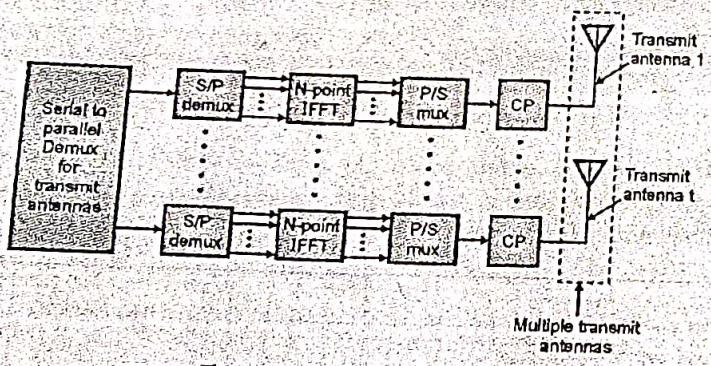
- WLAN (Wi-Fi) uses MIMO with 802.11 n standard.
- This is possible because, multiple small antennas are present in modem devices like laptops, data cards, mobiles, tablets.
- The HSPA uses MIMO in commercial networks.
- But it is difficult to install two antennas in mobile devices considering the mobile hardware limitations.
- Some mobile devices do support dual antennas that operate for MIMO. Both these antennas are cross-polarized.

Q. 29 With neat diagram explain MIMO OFDM Transmitter.

Ans. :

MIMO OFDM Transmitter

- Fig. 2.18 shows the processing at the transmitter of the MIMO-OFDM system.



(O-1714)**Fig. 2.18 : MIMO OFDM transmitter**

- MIMO OFDM transmitter consists of Serial to parallel demux block for transmit antennas, N-point IFFT, parallel to serial mux and Cyclic Prefix(CP). On each transmit antenna again S/P demux operation is performed.
- Each information symbol is passed through a serial to parallel (S/P) converter and becomes parallel data. On the parallel data, the IFFT operation is performed. Time domain symbols are parallel to serial (P/S) converted and then a cyclic prefix (CP) is added.
- CP is added to eliminate ISI and ICI (inter-carrier interference). Finally, the amplified modulated signals are transmitted.

Q. 30 State advantages and disadvantages of MIMO-OFDM.

Ans. :

Advantages of MIMO-OFDM :

- The advantages of MIMO-OFDM are as follows :
  1. MIMO-OFDM enables support for more antennas and larger bandwidth.
  2. MIMO-OFDM increases the data rates up to several hundreds of M bits/sec. and achieves spectral efficiencies of several tens of bits/Hz/s.
  3. It increases spectral efficiency of the system.

4. It improves reliability of link.
5. It has low sensitivity to time synchronization error.
6. It has extra resistance to fading.
7. It has high bandwidth spectral efficiency.
8. The complexity for FFT and IFFT becomes low.

Disadvantages of MIMO-OFDM :

- The disadvantages of MIMO-OFDM are as follows :
  1. MIMO-OFDM needs multiple antennas.
  2. An implementation cost is high.
  3. Accuracy of synchronization must be very high.
  4. High power consumption.

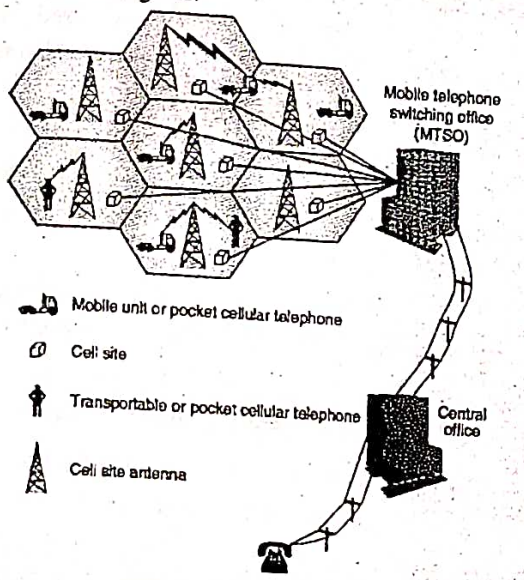
Chapter 3 : Introduction to Mobile Communication

Q. 1 Explain the concept of cellular telephone system.

Ans. :

Block diagram :

- The block diagram of the cellular network is as shown in Fig. 3.1.



(G-1025) **Fig. 3.1 : The cellular network**

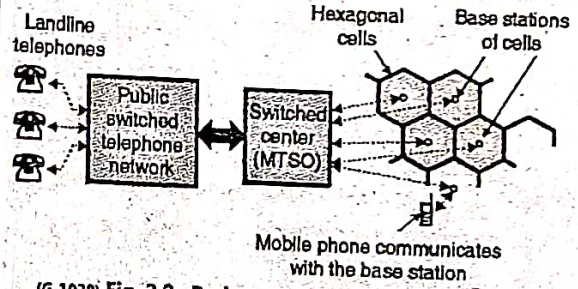
- It is basically a multiuser wireless telephone system.
- Cellular phone is wireless communication system just like cordless phone.
- In cell phone, distance is not restricted to within home but one can travel in the city or even outside the city without interruption in communication.
- The demand for cellular mobile phone is increasing at alarming level and is likely that wired communication will be replaced by wireless technology.
- In the cellular system city is divided into small areas called 'cells'.
- Each cell is around 10 square kilometre (depends upon power of base station).

Q. 2 Draw general block diagram of mobile phone system and explain its operation.

Ans. :

Block diagram :

- The structure of the mobile phone network along with the public switched telephone networks is shown in Fig. 3.2.



(G-1028) **Fig. 3.2 : Basic structure of mobile telephone network**

- Cellular telephone system is a wireless telephone system. It is a multiuser system.

Operation :

- The mobile telephone system has hexagonal shaped cells as shown in Fig. 3.2. Each cell has a base station situated at the center.
- The task of the base stations is to act as an interface between the mobile phone and the cellular radio system.
- The base stations of all the cells are connected to the switched center MSC or MTSO. Observe that this interface is a bi-directional one.

- That means the exchange of information between the switched center and the base stations is a two way. As shown in Fig. 3.2, the communication area of the mobile communication is divided into hexagonal cells.
- Therefore, the system is named as the cellular radio system. The switching center acts as the interface between the Public Switched Telephone Network (PSTN).
- In addition to that it performs the supervision and control operations in the mobile communication system. Due to this kind of a system layout, the communication can take place between two mobile subscribers or between a mobile subscriber and a landline telephone as well.
- If a mobile subscriber travels from one cell area to the other then it automatically gets connected to base station of that cell. Thus the service provided to a mobile subscriber is continuous without any break.

Q. 3 State the advantages of cellular concept.

Ans. :

Advantages of cellular concept :

1. Only a fixed number of channels (frequency slots) are required to be used. This is because the same frequencies can be used for multiple cells due to the principle of frequency re-use.
2. Large area can be covered.
3. Low power transmitters can be used as the cell area is small.
4. Every piece of subscriber equipment (e.g. mobile handset) within a country or continent can be manufactured with the same set of channels so any mobile can be used anywhere.
5. Higher capacity.
6. Local interference only.
7. Robustness to failure at single component.

Q. 4 Define the following :

1. **Base station**
2. **Control channel**
3. **Forward channel**
4. **Reverse channel**
5. **Mobile station.**

Ans. :

1. **Base station :**
- It is defined as a fixed (non-moving) station in a mobile radio system, which communicates with the mobile stations.

2. **Control channel :**
- It is defined as the radio channel used for transmitting the control signals such as call set up, call request, call initiation as well as the control information.

3. **Forward channel :**
- It is defined as the radio channel used for transmitting the information from the base station to the mobile i.e. in the forward direction.

4. **Reverse channel :**
- It is defined as the radio channel used for transmitting the information from a mobile to base station i.e. in the reverse direction.

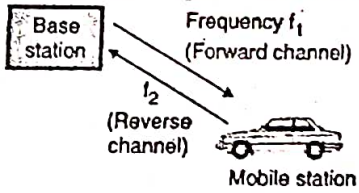
5. **Mobile station :**
- It is defined as a station in the cellular radio service which is used when in motion at an unspecified location.
- Mobile stations can be portable hand held personal units or they can be the ones installed in vehicles.

Q. 5 Explain FDD and TDD.

Ans. :

FDD and TDD :

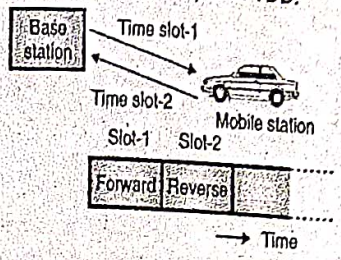
- In the full duplex systems simultaneous communication takes place between the base station and subscriber.
- This can be achieved by providing two simultaneous but separate channels operating at different frequency ranges as shown in Fig. 3.3.



(G-1557) **Fig. 3.3 : Concept of FDD**

- This is called as Frequency Division Duplexing (FDD).

- Another technique used in full duplex systems is called as Time Division Duplexing (TDD) in which adjacent time slots on the same radio channel are allotted for the forward and reverse channels.
- Fig. 3.4 shows the principle of TDD.



(G-1558) **Fig. 3.4 : Concept of TDD**

Q. 6 Write a note on frequency reuse and its advantages. April 17, April 18, March 19

Ans. :

Frequency reuse :

- In frequency reuse concept the radio channels use the same frequency to cover different areas that are physically separate from each other.
- In frequency reuse it is necessary to see that the co-channel interference is not objectionable.
- Frequency reuse is an important concept because in this a single transmitter of higher power need not be used to cover the entire area.
- Instead many transmitter of small output power operating at the same frequency can be used.
- This technique also reduces the minimum height of the transmitting antenna, because now each antenna has to cover a small area.
- Frequency reuse is very important concept of the cellular mobile radio system.
- The users located in different geographical areas i.e. different cells can use the same frequency simultaneously.
- The advantage of frequency reuse is that it drastically increases the spectrum efficiency but the disadvantage is that if the system is not designed properly then co-channel interference may take place.

Advantages of Frequency Reuse :

1. A single transmitter of high power need not be used to cover the entire area.
2. Many transmitter of small power working at the same frequency can be used.
3. This technique reduces the minimum height of the antenna.
4. The users located in different geographical areas i.e. different cells can use the same frequency simultaneously.
5. It drastically increases the spectrum efficiency.

Q. 7 A spectrum of 30 MHz is allocated to a wireless FDD cellular system which uses two 25 kHz simplex channels to provide full duplex voice and control channel, compute the number of channels available per cell if a system uses :

1. **4 cell reuse**
2. **7 cell reuse**
3. **12 cell reuse**

Assume 1 MHz of spectrum is allocated to control channel. Give distribution of voice and control channels. April 17

Ans. :

Given : Total bandwidth = 30 MHz,

Channel bandwidth = 25 kHz × 2 simplex channels

= 50 kHz/duplex channel

$$\therefore \text{Total available channels} = \frac{30 \times 10^6}{50 \times 10^3}$$

= 600 channels

1. Four-cell reuse :

- Total number of channels available per cell

$$= \frac{600}{4} = 150 \text{ channels} \quad \textbf{...Ans.}$$

2. Seven cell reuse :

- Total number and channels available per cell

$$= \frac{600}{7} \approx 86 \text{ channels} \quad \textbf{...Ans.}$$

3. 12 cell reuse :

- Total number of channels available per cell

$$= \frac{600}{8} = 75 \text{ channels} \quad \textbf{...Ans.}$$

- A 1 MHz spectrum for control channel implies that there are $\frac{1000 \times 10^3}{50 \times 10^3}$ = 20 control channels out of the 600 channels available.
- The 600 channels must be evenly distributed to each cell within the cluster. Practically only the 580 voice channels will be allocated as control channels are allocated as 1 per cell.
  1. For four-cell reuse we can have five control channels and 145 voice channels per cell.
  2. For seven-cell reuse, we can have cells with two control channels and 84 voice channels.
  3. For 12 cell reuse, we can have one control channel and 74 voice channels.

Q. 8 Explain different channel assignment strategies. Dec. 16, May 17

Ans. :

Different channel assignment strategies :

1. Fixed channel assignment
2. Dynamic channel assignment and
3. Hybrid channel assignment strategies.

Fixed Channel Assignment (FCA) :

- In the fixed channel assignment strategy, a fixed predetermined set of voice channels is assigned to each cell.
- A mobile phone number within the cell can be called by making use of the unused channels in that particular cell.
- However if no channels in that cell is free, then the call is blocked and the subscriber does not get service.
- Different modifications have been done in the fixed channel assignment strategy.
- One of them is channel borrowing.

Dynamic Channel Assignment (DCA) :

- In the dynamic channel assignment strategy, no predetermined voice channels are permanently allocated to any cell.
- Instead, whenever a call request is made in a cell, the base station of that cell, requests the MSC for an extra channel.
- The MSC then allocates a channel to the requesting cell after following an algorithm.
- This algorithm considers the following aspects :
  1. Possibility of blocking in future within the cell.
  2. The frequency used by the requesting cell.
  3. The reuse distance of the channel.
  4. Other cost functions.
- Depending on these factors, the MSC only allocates a frequency which is not being used presently in the cell or any other cell which is too close, for avoiding the co-channel interference.
- For successful operation of dynamic channel assignment strategies, the MSC has to collect real time data on the following parameters of all channel continuously :
  1. Channel occupancy.
  2. Traffic distribution.
  3. Radio signal strength indications CBSSI).

Hybrid Channel Assignment :

- Hybrid channel assignment strategy is the combination of fixed and dynamic channel assignment strategies.
- Here they assign a fixed number of channels to each cell site on a long-term basis.
- When all of them are busy and a call is initiated, the BS will raise a request for dynamic channel.
- The ratio of number of fixed channels and dynamic channels is an important number and its value depends on the traffic conditions.
- This ratio may vary in its value according to the estimated values of instantaneous load distributions.
- The hybrid channel assignment schemes show a better performance for the traffic loads up to 50 %.
- But fixed channel assignment (FCA) gives better results for the traffic loads beyond 50 %.

Q. 9 What is handoff ? Why is it necessary in mobile cellular system ? Explain mobile assisted handoff.

May 16, April 17, May 17, March 19, March 20

Ans. :

Definition of handoff :

- The call in progress will continue even when the mobile station moves from one cell to the other.

- This process of continuing the call in progress without terminating it is called as "hand-off".
- It is also called as handover.

Need of hand-offs :

- Assume that there is a call going on between two parties over a voice channel.
- When the mobile unit moves out of coverage area of a particular cell site, the reception becomes weak. Then the present cell site will request a handoff. The system will switch the call to a new cell site without interrupting the call. This procedure is called as the hand off procedure or handover procedure.
- The user can continue talking without even noticing that the handoff procedure has taken place.
- The advantage of handoff procedure is increase in the effectiveness of the mobile system.

MAHO : Mobile Assisted Hand-off :

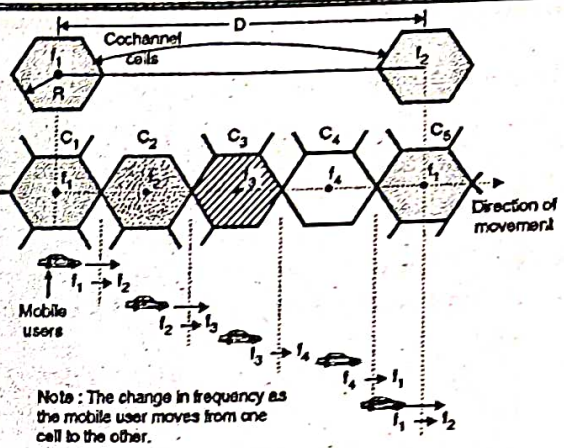
- In the second-generation (2G) systems, the hand off decisions is assisted by the mobile stations. The mobile assisted hand offs are known as MAHO.
- In MAHO, every mobile station measures the power it receives from all the base stations around it and continuously reports these measured power levels to the serving base station.
- If the power received from the base station of the neighbouring cell begins to go beyond the power received from the current base station by a certain margin then the hand off will be initiated.
- The advantage of MAHO is that this method reduces the time required to handover the call between the base stations.
- MAHO is particularly suitable for the microcellular environment where the hand off procedure needs to be followed very frequently.

Q. 10 Draw neat figure to illustrate handoff and explain. March 19

Ans. :

Hand off procedure :

- Refer Fig. 3.5 to understand the handoff procedure clearly.



(G-1033) **Fig. 3.5 : Hand off procedure**

- Fig. 3.5 shows two co-channel cells separated by a distance D and using the frequency f_1.
- Other cells such as C_1, C_2, C_3, C_4, C_5 etc. exist in-between the two co-channel using frequency f_1.
- The cells C_1, C_2, C_3 and C_4 use different frequencies f_1, f_2, f_3, f_4, etc. as shown in Fig. 3.5.
- Suppose a mobile unit initiates a call in cell C_1 and then moves to cell C_2.
- Then as it starts going away from C_1, the call is dropped and reinitiated in the frequency channel from f_1 to f_2 when the mobile unit (such as car) moves form C_1 to C_2.
- Similarly when the mobile unit moves from cell C_2 to C_3 the frequency is changed automatically from f_2 to f_3 as shown in Fig. 3.5.
- The process of changing the frequency is done automatically by the system and the user does not even notice it.

Q. 11 Explain SHO ? March 20

Ans. :

Soft hand off :

- The hand off is known as soft handoff if the MS starts communication with a new base station without stopping the communication with the older base station.
- In a soft hand off the operating frequencies of the old and new base stations are identical.
- Soft hand off enhances the signal by providing different-site selection diversity.
- In simple words the soft hand-off is based on the Make before Break strategy.

- This technique is used to lower the rates of call drops,
- Soft hand-off is used in CDMA systems.

Q. 12 Explain : 1. Intra cell handover 2. Inter cell handover. Dec. 16

Ans. :

Inter cell Handoff :

- During an ongoing call, if a mobile station moves from one cell to another cell, then the corresponding handover is known as inter cell hand-off. Thus the inter cell hand-off switches a call in progress from one cell to the other cell.

Intra cell hand-off :

- The Intra cell handover is the handover within one sector or between different sectors of the same cell.
- It does not require network connections to be altered.
- The intra cell handover switches a call in progress from one channel to the other channel of the same cell.

Q. 13 Explain :

1. Forced handoff. 2. Queued handoff.

Ans. :

Forced handoff :

- A forced handoff is defined as the hand off which would normally occur but is not allowed to happen by force or a handoff that should not occur but is forced to take place.

Queued handoff :

- In the queued handoff process, the MTSO arranges the handoff requests in a queue instead of rejecting them, if it finds that new cell sites are too busy to makes the handoff possible.
- These handoff requests are then acted upon in a sequential manner. Queueing of handoffs is more effective than the two threshold handoff.
- Also, a queueing scheme is effective only when the handoff requests arrive at the MTSO in the form of batches or bundles.

Q. 14 Write a note on : Interference and system capacity. April 17

Ans. :

Definition of Interference :

- In electronic communications, especially in telecommunications, an interference is defined as that which modifies a signal in a disruptive manner, as the signal travels along a channel between its source and receiver.
- The term is often used to refer to the addition of unwanted signals to a useful signal.
- Interference is said to have occured when unwanted signals disrupt wireless communication, including the use of your television, radio, mobile phone etc.

Effects of Interference :

- Interference may prevent reception altogether, may cause only a temporary loss of a signal, or may affect the quality of the audio or video produced by your equipment.
- The performance of a cellular radio system gets degraded due to the interference.
- So it is an important limiting factor.

System capacity :

- The total Number of duplex channels in a cellular system is defined as capacity of a cellular system. It is given by,

$$C = MGN = MF$$

Where M = Number of times the cluster is replicated in a fixed service area

G = Number of channels per cell

N = Number of cells in a cellular system

F = Total number of channel in a system.

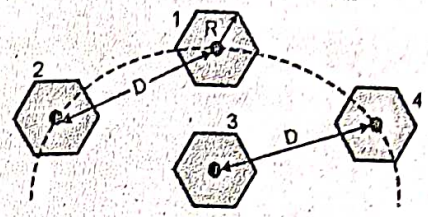
Q. 15 With neat diagram, describe co-channel and adjacent channel interference in GSM. May 19

Ans. :

Co-channel Interference :

- A number of cells operating at the same set of frequencies are called as the co-channel cells.
- And the interference taking place between the signals originating from these cells is called as the co-channel interference
- Fig. 3.6 shows the co-channel interference diagrammatically.

We can reduce the co channel interference by increasing the separation (D) between the adjacent co - cells



1 to 4 : Cochannel cells

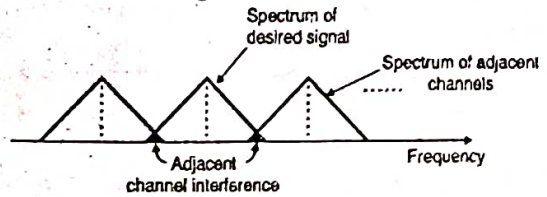
(G-2561(a)) **Fig. 3.6 : Co-channel interference**

How to reduce co-channel interference ?

- Note that we cannot reduce the co-channel interference by simply increasing the transmitter power for each cell.
- In fact increasing the transmitter power will increase the co-channel interference.
- The co-channel interference can be reduced by separating the co-channel cells physically by a minimum distance.
- Assume that all the cells are of the same size and all the base stations are transmitting equal amount of power.
- Also let the cell radius be (R) and the distance between centers of the co-channel cells that are closest to each other be equal to (D), as shown in Fig. 3.6.
- The co-channel interference reduction ratio is denoted by D/R.
- The co-channel interference ratio is independent of the transmitted power, but it will be dependent on the values of R and D.
- If we increase the ratio (D/R) then the co-channel interference will reduce.

Adjacent Channel Interference :

- The interference that results from signals which are close (adjacent) in frequency domain to the desired signal frequency is called as adjacent channel interference.
- The principle of adjacent channel interference is illustrated in Fig. 3.7.



(G-1565) **Fig. 3.7 : Adjacent channel interference**

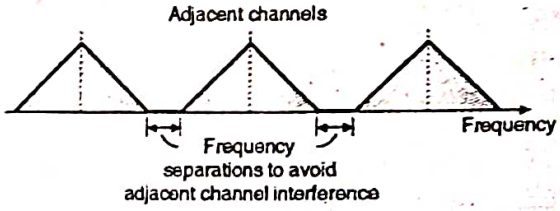
- Fig. 3.8 shows that due to imperfect receiver filters, the frequencies from adjacent channels interfere with the passband of the desired signal to create the adjacent channel interference.

Near-far effect :

- The adjacent channel interference will be serious if an adjacent channel user is transmitting from a very close distance to the subscribers receiver.
- This is called as the near-far effect in which a nearby strong transmitter captures the subscriber's receiver.

Reducing the interference :

- The adjacent channel interference can be reduced by :
  1. Careful filtering.
  2. Careful channel assignment (carefully assigning the channel frequencies).
- There should be adequate frequency separation between the spectrums of the adjacent channels in a cell as shown in Fig. 3.8.



(D-1501) **Fig. 3.8 : Frequency separation to avoid adjacent channel interference**

- If the frequency reuse factor is large or if the cluster size (N) is small, the adjacent channels at the base station will be too close to each other in the frequency domain.
- This will increase the adjacent channel interference.
- Tight base station filters when the same cell is being shared by the close-in and distant users.
- The practical base station receivers use high Q cavity filters in order to minimize the adjacent channel interference.

Q. 16 For given path loss component n = 4 and frequency reuse factor of N = 7. Calculate S/I ratio in cellular system. April 16

Ans. :

Given : n = 4, N = 7

Step 1 : Find Q :

$$Q = \frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 7} = 4.582$$

Step 2 : Find S/I :

- We know that,

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(D/R)^n}{i_0}$$

- Assuming the number of interfering co-channel cells i_0 to be equal to 6, we get,

$$\frac{S}{I} = \frac{1}{6} \times (4.582)^4 = 73.46$$

$$\frac{S}{I} = 10 \log (73.46)$$

$$= 10 \times 1.8660 = 18.66 \text{ dB} \quad \text{..Ans.}$$

Q. 17 Calculate Signal to Interference ratio in dB for a system having frequency reuse factor of 4 if path loss component is 3, assume suitable data if any ? March 20

Ans. :

Given : n = 3, N = 4

Step 1 : Find Q :

$$Q = \frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 4} = 3.464$$

Step 2 : Find S/I :

- We know that,

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(D/R)^n}{i_0}$$

- Assuming the number of interfering co-channel cells i_0 to be equal to 6, we get,

$$\frac{S}{I} = \frac{1}{6} \times (3.464)^3 = 6.93$$

$$\frac{S}{I} = 10 \log (6.93) = 8.4 \text{ dB} \quad \text{..Ans.}$$

Q. 18 Write a note on : Channel planning for wireless systems.

Ans. :

Channel planning for wireless systems :

- The process of assigning the appropriate radio channels to each base station in a cellular system is very important.
- These should be an appropriate frequency reuse ratio (or cluster size) and an adequate separation between the adjacent co-channel cells.
- The wireless engineers will have to deal with some practical problems such as difficulties associated with the radio propagation and imperfect coverage regions of each cell.
- Generally the available mobile radio spectrum is divided into control channels (used for initiating, requesting or paging a call), and voice channels which carry the data messages.
- Out of the entire spectrum only 5% is allotted to control channels and the remaining 95% is allotted to the voice channels.
- Any suitable frequency reuse scheme can be chosen.
- The frequency reuse strategy applied to the control channels is generally different than that applied to the voice channels.
- Sectoring is used for improving the signal to interference ratio which can result in smaller cluster size.
- For the CDMA schemes the cluster size N = 1 and the frequency planning is far less difficult as compared to that in the TDMA systems.
- CDMA schemes need hard hand offs similar to TDMA and FDMA schemes.

Q. 19 With a neat diagram explain the term : Cell splitting.

April 16, Dec. 17, April 18, March 19

Ans. :

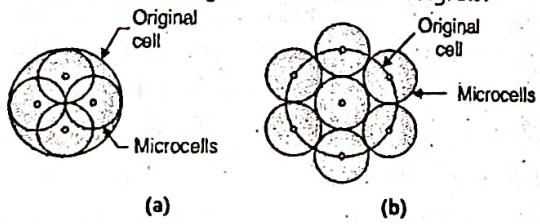
Definition of Cell splitting :

- Cell splitting is the technique of dividing a larger cell into smaller cells to increase capacity in congested areas.
- Separate antennas are placed in smaller cells which transmit low power compared to larger cells.

Concept :

- In order to improve the spectrum efficiency of a cellular mobile systems, we can take the following two steps :
  1. Implement some frequency reuse technique.
  2. Use the cell splitting technique.

- Every cell is supposed to handle a particular value of maximum traffic.
- But sometimes the demand (traffic) is higher than this maximum permissible traffic which can be handled by a cell.
- Under such circumstances, a technique called cell splitting is used for handling the increased traffic within that cell.
- In cell splitting, the cell boundaries are changed in such a way that the local area which was considered as one single cell will now contain a number of smaller calls.
- These new cells which are smaller than the original cells are called as microcells.
- Thus in cell splitting the original cell is split into smaller cells.
- Generally the radius of a new cell is one half of the radius of the original cell as shown in Fig. 3.9.



(G-1032) **Fig. 3.9 Cell splitting**

Q. 20 With a neat diagram explain the term : Cell sectoring. April 16, March 19

Ans. :

Definition of Cell sectoring :

- Sectoring is another method of increasing the number of channels per unit area.
- But the technique is different than that used for cell splitting.
- Sectoring is a technique in which an omni directional antenna at the base station is replaced by several directional antennas.
- In sectoring, the cell radius R is kept constant and the D/R ratio is decreased.

Concept :

- The Sectoring technique is used for increasing the signal to interference ratio (SIR) so as to reduce the cluster size N.
- In the sectoring approach, the SIR improves due to the use of directional antennas, and the system capacity increases as the number of cells are reduced in a cluster and the frequency reuse is increased.
- However all this can be achieved only if we reduce the interference, by keeping the transmitter power unchanged.
- The co-channel interference is reduced by replacing the omni-directional antenna at the base station by several directional antennas.
- Each directional antenna is allowed to radiate within a specific sector, so that that the transmitters in adjacent cells will not interfere with each other.
- The amount of reduction in the co-channel interference depends on the amount of sectoring.

Types of sectoring :

- There are two types of sectoring as shown in Fig. 3.10(a) and (b) namely, 120° sectoring and 60° sectoring.

(a) 120° sectoring **(b) 60° sectoring**

(G-1566) **Fig. 3.10 : Principle of sectoring**

- In the 120° sectoring, a cell is divided into three sectors, with each sector occupying 120° whereas in 60° sectoring a cell is split into six sectors with each sector occupying 60°.
- While carrying out the sectoring, the channels used in a cell are divided into sectored groups (3 or 6) and used only within a particular sector (1, 2, 3 or 1, 2, ..., 6) as shown in Fig. 3.10(a) and (b).

Q. 21 Write a note on : Repeaters.

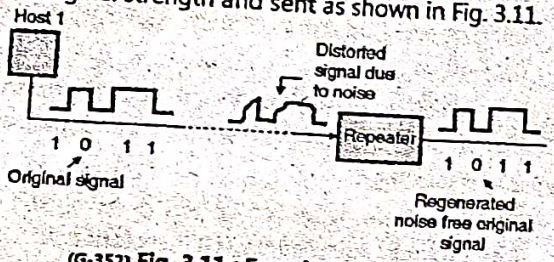
Ans. :

Definition of Repeaters :

- A repeater is a connecting device. All transmission media weaken the electromagnetic waves that travel through them.
- Attenuation of signals limits the distance any medium can carry data.
- Devices that amplify signals to ensure data transmission are called repeaters.

Function of a Repeater :

- A repeater receives a signal and before it gets attenuated or corrupted, regenerates the original signal. Thus we can use a repeater to extend the range of communication.
- Repeater is not an amplifier because amplifiers simply amplify the entire incoming signal along with noise. Signal – regenerating repeaters create an exact duplicate of incoming data by identifying it amidst the noise, reconstructing it and retransmitting only the desired information.
- The original signal is duplicated, boosted to its original strength and sent as shown in Fig. 3.11.



(G-352) Fig. 3.11 : Function of a repeater

Wireless Repeaters :

- Fig. 3.12 illustrates the concept of a wireless repeater.

(G-2397) Fig. 3.12 : Concept of wireless repeater

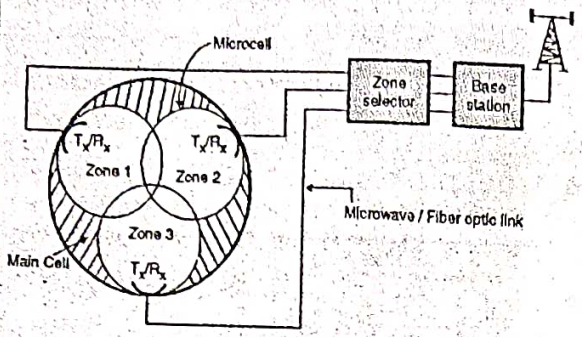
- It simply regenerates the network signal and extends the range of the wireless LAN. It does not use wires but receives the radio signals from an AP, end users, or other repeaters, regenerates the signal and retransmits it.
- We can overcome the signal impairment caused by RF attenuation, with the help of repeaters.

Q. 22 What is microcell zone concept ? How is it used to improve capacity ? **May 17**

Ans. :

Microcell Zone Concept :

- We know that the number of handoffs increase in the sectoring technique.
- This puts an additional load on the switching and control link elements of the mobile system.
- A solution to this problem was presented on the basis of the microcell concept for seven cell reuse as shown in Fig. 3.13.



(G-1568) Fig. 3.13 : The microcell concept

- As shown in Fig. 3.14, all the three or more zone sites represented as T_x/R_x are connected to the same base station and they share the same radio equipment among themselves.
- The transmission media such as coaxial cable, fiber optics cable or a microwave link, can be used for connecting the zones to the base station.
- In this way each cell consists of a base station and multiple zones
- A mobile station traveling within a cell (see Fig. 3.14) is attended by the zone that has the strongest signal of all.
- The antennas in various zones are placed at the outer edges of the cell as shown in Fig. 3.14, and it is possible to assign any base station channel to any zone within the cell.
- This is a better approach than sectoring.
- Now as a mobile station moves from one zone to the other within a cell, it uses the same channel. Therefore hand-offs will be totally avoided.
- Thus the micro zone concept allows the use of a given channel only in a particular zone in which the mobile unit is travelling.
- In this way, the base station actually radiates its power in a localized manner which will reduce interference.

Q. 23 Explain the following cell sizes with its application :

1. Microcell
2. Pico cell
3. Macrocell
4. Femtocell

March 20.

Ans. :

Table 3.1 : Types of cells, their sizes and applications

Sr. No.	Type of cell	Size	Applications
1.	Macro cells	Several km	Cover large metropolitan areas, vehicular drivers
2.	Micro cells	Several hundred metres	In urban areas to support PCS, for pedestrians, offices, residential buildings etc.
3.	Pico cells	Few tens of metres	To support WLANs for indoor use.
4.	Femto cells	Few metres	To interconnect cell phoned, laptops and other personal wireless devices

Chapter 4 : Wireless System Planning

Q. 1 What is the path loss ? Explain the factors affecting the path loss.

Ans. :

Path loss :

- Path loss is the signal power loss as a function of distance. Therefore, the received signal strength varies with variation in distance between transmitter and receiver. Various path loss models can be used to estimate the variation of received signal strength (RSS).

Factors affecting the path loss :

- Various factors affecting the path loss are as follows :
  1. Distance
  2. Frequency
  3. Line of sight (LOS) or NLOS transmission
  4. Antenna heights
  5. Type of terrain 6. Weather conditions

Q. 2 What is link budget ?

Ans. :

- Link budget of a cellular link is an equation which contains the transmitted power, antenna gains, received power and all the losses as follows :

$$P_r(dBW) = P_t(dBW) + \sum dB\ Gains - \sum dB\ Losses$$

Q. 3 Define the terms trunk, trunking and traffic.

Ans. :

Trunk :

- Trunk is defined as the term used for describing any entity that carries one call.

Trunking :

- Trunking is defined as the arrangement of trunks and switches within a communication system.

Traffic :

- Traffic is defined as the average number of calls in progress.

Q. 4 Define and explain : Erlang and CCS

May 12, May 13

Ans. :

Erlang and CCS :

- The international unit of traffic is the Erlangs. It is named after the Danish Mathematician, A. K. Erlang, who places the basis to traffic theory in the work he did for the copenhagen telephone company starting 1908.
- A server is said to have 1 erlang of traffic if it is engaged for the entire period of observation.
- More simply, one erlang represents one circuit occupied for one hour. Traffic is also expressed in Cent Call Seconds (CCS). CCS is a call time product.
- This is used to compute the amount of traffic which is expressed in units of 100 seconds.

– Sometimes Call Seconds (CS) and Call Minutes (CM) are also used as a parameter of traffic intensity. The relation between erlang and CCS is given by,

1 Erlang = 36 CCS = 3600 CS = 60 CM ...(1)

Q. 5 Define and explain : Busy hour call rate.

Dec 12, May 13

Ans. :

Busy hour call rate :

– The busy hour calling rate or BHCR is the average number of calls per subscriber during the busy hour.

$$BHCR = \frac{\text{Average busy hour calls}}{\text{Number of subscribers}} \quad ...(2)$$

– As an example for an exchange serving 1000 subscribers, if the average number of busy hour calls is 3500, then the BHCR is given by,

$$BHCR = \frac{3500}{1000} = 3.5$$

Q. 6 Define and explain : holding time.

May 12, Dec 12

Ans. :

Holding time :

– The holding time of a call is the time from the instant at which the first selector is seized to set up a call to the instant when all selectors are released. In simple terms, holding time is the duration of a call.

Traffic carried :

– The traffic carried by a group of trunks is defined as :

$$A = \frac{HC}{T}$$

Where, A = Traffic in erlang
H = Average holding time
C = Average number of calls
T = time

Q. 7 Define and explain : call completion rate.

May 12, May 13

Ans. :

Call completion rate :

– The call completion rate (CCR) is the ratio of number of successful calls to the total number of attempted calls.

$$CCR = \frac{\text{No. of successful calls}}{\text{Number of call attempts}} \quad ...(3)$$

Q. 8 A group of 20 servers carry a traffic of 10 E. If average duration of calls is 3 minutes, calculate the number of calls put through by a single server and a group as a whole in 1 hr period.

April 18

Ans. :

Given : A = 10 E,
T = 3 minutes
Number of servers = 20

To find : Total number of calls put through by the group

Step 1 : Traffic per server :

– The traffic per server is given by,

$$\text{Traffic per server} = \frac{A}{\text{No. of server}}$$

$$= \frac{10}{20} = 0.5 \text{ E}$$

– One erlang represents one circuit occupied for one hour. Therefore, 0.5 erlang shows that one server is busy for 30 minutes in one hour.

Step 2 : Number of calls put through :

– Number of calls put through by a server is given by,

$$\text{No. of calls/ server} = \frac{\text{Server busy time}}{T}$$

$$= \frac{30}{3} = 10 \text{ calls}$$

– Total number of calls put through by the group is ,

Calls by the group = 10 x no. of server
= 10 × 20
= 200 calls ...Ans.

Q. 9 Over a 20 minutes observation interval 40 subscribers initiates a call. Total duration of calls is 4800 sec. Calculate load offered to network by the subscribers and average subscriber traffic ?

April 18

Ans. :

Given : Number of subscribers = 40

To find : Load offered to network, average subscriber traffic

Step 1 : Mean call arrival rate C :

$$\text{Mean call arrival rate } C = \frac{\text{Number of subscribers}}{\text{Observation interval}}$$

$$= \frac{40}{20} = 2 \text{ calls/min}$$

Step 2 : Mean holding time t_h :

$$\text{Mean holding time} = \frac{\text{Total duration of calls}}{\text{Number of subscribers}}$$

$$= \frac{4800/60}{40} = 2 \text{ minutes / calls}$$

Step 3 : Offered traffic :

$$\text{Offered traffic} = A \times C = 2 \times 2 = 4E$$ ...Ans.

Step 4 : Average subscriber traffic :

$$\text{Average subscriber traffic} = \frac{A}{N} = \frac{4}{40} = 0.1\ E$$ ...Ans.

Q. 10 Calculate the busy hour calling rate for exchange that serves 1000 subscribers if average BHCA is 5000 and CCR is 60 %.

March 20

Ans. :

Given : Average BHCA = 5000, CCR = 60%

Step 1 : Find average no. of busy hour calls :

$$\text{Average no. of busy hour calls} = \text{BHCA} \times \text{CCR}$$

$$= 5000 \times 0.6$$

$$= 3000$$

Step 2 : Find busy hour calling rate :

$$\text{Busy hour calling rate} = \frac{\text{Avg busy hour calls}}{\text{Total no of subscribers}}$$

$$= \frac{3000}{1000} = 3$$ ...Ans.

Q. 11 Define and explain : Grade of service.

May 12, Dec 12, May 13, May 18

Ans. :

Grade of service :

- This is the parameter of congestion which is specified as the probability of a call being blocked or call being delayed beyond certain amount of time.
- That means, some calls may be rejected and retried when the lines are used by other subscribers. The grade of service is defined as the proportion of unsuccessful calls as compared to the total number of calls.
- GOS is defined as the ratio of lost traffic because of busy hours to the offered traffic in busy hour.

$$GOS = \frac{\text{Lost busy hour calls}}{\text{Offered busy hour calls}}$$

$$GOS = \frac{A - A_0}{A}$$

Where, A_0 = Carried traffic

A = Offered traffic

$A - A_0$ = Lost traffic.

Q. 12 Define : Blocking probability **Dec. 12, May 18**

Ans. :

Blocking probability :

- The blocking probability as the probability that all servers in a system are busy.
- When all servers are busy, the system cannot carry any further traffic.
- The basic difference between GOS and blocking probability is that GOS is measured from subscriber point of view while the blocking probability is a measured from the network or switching point of view.

$$B = \frac{\text{Number of calls lost}}{\text{Number of calls offered}}$$

$$B = \frac{\text{Traffic lost}}{\text{Offered traffic}}$$

Q. 13 During busy hours 1000 calls were offered to a group of trunks and 5 calls were lost. The average call duration was 2 minutes.

1. **Find traffic offered**
2. **Traffic carried**
3. **Traffic lost**
4. **Grade of service**
5. **Total duration of periods of congestion.**

April 16

Ans. :

Given : H = 2 minutes, C = 1000 calls, Lost calls = 5

1. Traffic offered :

$$A = \frac{CH}{T} = \frac{1000 \times 2}{60} = 33.33$$

$$\therefore A = 33.33 \text{ Erlangs}$$ ...Ans.

2. Traffic carried :

$$A_0 = \frac{CH}{T}$$

But C = Total calls – lost calls

= 1000 – 5 = 995

And T = 1 h = 60 min.

$$\therefore A_0 = \frac{995 \times 2}{60}$$

= 33.166 Erlangs ...Ans.

3. **Traffic lost :**

C = 5 lost calls

$$A_c = \frac{CH}{T} = \frac{5 \times 2}{60} = 0.166 \text{ E} \quad \text{...Ans.}$$

4. **Grade of service :**

$$GOS = \frac{\text{Traffic lost}}{\text{Traffic offered}}$$

$$= \frac{0.166 \text{ E}}{33.33 \text{ E}} = 0.005 \quad \text{...Ans.}$$

5. **Total duration of periods of congestion :**

Duration = GOS × 3600

= 0.005 × 3600

= 18 seconds ...Ans.

Q. 14 During busy hour, 1200 calls were offered to a group of trunks and six were lost. The average call duration was 3 minutes. Find :

1. **Traffic offered**
2. **Traffic carried**
3. **Traffic lost**
4. **Grade of service**
5. **Total duration of periods of congestion.**

May 17, May 18

Ans. :

– *Similar to Q. 13.*

A = 60 E, A_0 = 59.7 E, Traffic lost = 0.3 E,

GOS = 0.005, Duration = 18 seconds.

Q. 15 During busy hours, 1500 calls were offered to a group of trunks and six calls were lost. The average call duration was 5 minutes. Find traffic offered, traffic carried, grade of services and total duration of period of congestions. **March 19**

Ans. :

– *Similar to Q. 13.*

A = 125 E, A_0 = 124.5 E, Traffic lost = 0.5 E,

GOS = 0.004, Duration = 14.4 seconds.

Q. 16 Explain the assumptions in :

1. **Pure chance traffic**
2. **Statistical equilibrium** **May 17**

Ans. :

1. Pure chance traffic :

– Pure chance traffic means that call arrival and call terminations are independent random actions.

– As the call arrival is random action, if is independent of previous calls.

– Consequently traffic generally is referred to as memory less traffic.

– This assumption of calls arriving randomly and terminated randomly lead to the following results.

1. The number of calls arriving in a given time has a Poisson's distribution.

Therefore, $P(x) = \frac{\mu^x}{x!} e^{-\mu}$ ...(1)

Where, P (x) = Probability of number of call arrivals in time T

μ = Mean number of call arrivals

x = Number of call arrivals in time T.

2. The time interval T between the independent random event of call arrivals have negative exponential distribution.

$$P(T \geq t) = e^{-t/\overline{T}}$$

Where $\overline{T}$ = Mean interval between call arrivals

3. The call durations (T) exhibit a negative exponential distribution.

$$P(T \geq t) = e^{-t/H}$$

– Where, H is the holding time or mean call duration.

2. Statistical Equilibrium :

– The meaning of statistical equilibrium is that the generation of traffic is a stationary random process.

– It means the probabilities do not change for the duration under consideration. As a result, mean number of calls is constant.

- This condition is normally true during busy hour's traffic. Hence in a way, during busy hours, statistical equilibrium is obtained.

Q. 17 Explain the concept of Markov chain.

Ans. :

Concept of Markov chain :

- The number of calls in progress in a group of N trunks will vary randomly between 0 and N.
- Thus the number of calls in progress has (N+1) states. The variation in its value will depend on the probability of change from a state to the state above or below it. This process is referred to as Markov chain.

Fig. 4.1 shows a simple Markov chain with N trunks.

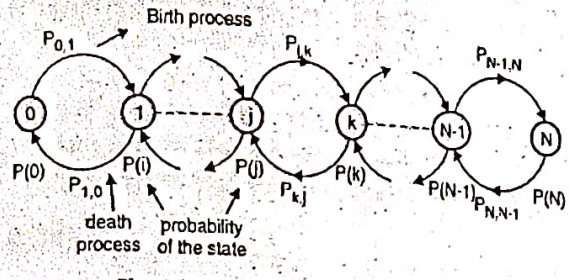


Fig. 4.1 : Markov chain with N trunks

- In this diagram, P(0), P(1) ....., P(N) are the state probabilities. P(j) represents the probability of state j. P(k) represents the probability of next higher state of state j. $P_{k,j}$, $P_{j,k}$ etc represent the transitional probabilities.
- If there are x calls in progress, then the probability of call arriving is given by the following expression :

$$P(x) = \frac{A^x}{x!} P(0) \qquad ...(4.3.2)$$

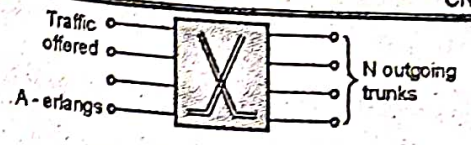
- Where A represents the average number of calls arriving during the average holding time H. That means C = A.

Q. 18 Derive the first Erlang Distribution for Lost call systems. **Dec. 12, April 16**

Ans. :

First Erlang Distribution for Lost call systems :

- Refer Fig. 4.2 to understand the lost call system.
- The assumption of pure chance traffic, implies that call arrival and call termination are independent random events.



(G-3002) **Fig. 4.2 : Lost call system**

- The meaning of statistical equilibrium is that probabilities do not change.
- The meaning of full availability is that every arriving call can be connected to any outgoing trunk which is free.
- And finally, the lost call assumption means that if any attempted call encounters congestion, then the system immediately clears it.
- Here we assume that the traffic offered is the sum of all successful and unsuccessful calls. Let there be "x" calls in progress, then we can write,

$$P(x) = \frac{A^x}{x!} P(0) \quad ... 0 \le x \le N \qquad ... (1)$$

Now, $\sum_{x=0}^{N} P(x) = 1$

$$1 = \sum_{x=0}^{N} \frac{A^x}{x!} P(0)$$

$$P(0) = \frac{1}{\sum_{k=0}^{N} \frac{A^x}{x!}} \qquad ...(2)$$

- Substituting P(0) from Equation (2) to Equation (1), we get,

$$P(x) = \frac{\frac{A^x}{x!}}{\sum_{k=0}^{N} \frac{A^k}{k!}}$$

- Here x is actually number of occupied trunks.
- Hence x can be replaced by N for simplicity and P(N) = P(x) = Probability of congestion i.e. probability of lost call which is nothing but Grade of service.

$$\therefore B = E_{1,N}(A) = \frac{\frac{A^N}{N!}}{\sum_{k=0}^{N} \frac{A^k}{k!}} \qquad ...(3)$$

- This is Erlang's Lost call formula

- For assumption of full availability of N trunks, grade of service can be determined directly or by iterative application of simple recurrence relation.
- By putting N = N – 1. in Equation (3), we get,

$$B = E_{1,N-1}(A) = \frac{\frac{A^{N-1}}{(N-1)!}}{\sum_{k=0}^{N-1}\frac{A^k}{k!}}$$

$$\sum_{k=0}^{N-1}\frac{A^k}{k!} = \frac{\frac{A^{N-1}}{(N-1)!}}{E_{1,N-1}(A)} \quad \text{...(4)}$$

- Now, consider the term,

$$\sum_{k=0}^{N}\frac{A^k}{k!} = \frac{A^0}{0!} + \frac{A^1}{1!} + \frac{A^2}{2!} + \frac{A^3}{3!} + \text{.....} + \frac{A^{N-1}}{(N-1)!} + \frac{A^N}{N!}$$

- From Equation (4),

$$\sum_{k=0}^{N}\frac{A^k}{k!} = \frac{\frac{A^{N-1}}{(N-1)!}}{E_{1,N-1}(A)} + \frac{A^N}{N!}$$

- Substituting in Equation (3) we get,

$$E_{1,N}(A) = \frac{\frac{A^N}{N!}}{\frac{A^{N-1}(N-1)!}{E_{1,N-1}(A)} + \frac{A^N}{N!}}$$

- Dividing numerator and denominator by $\frac{A^N}{N!}$ and simplifying the equation we get,

$$E_{1,N}(A) = \frac{A\,E_{1,N-1}(A)}{N + A\,E_{1,N-1}(A)}$$

- As this is an iterative formula, $E_{1,N}(A)$ needs, to be calculated for all values of 'N'.

Q. 19 On an average one call arrives every 5 seconds. During a period of 10 seconds, what is the probability that :

1. No call arrivals.

2. More than one call arrives. April 16

Ans. :

Given : μ = 1 call every 5 seconds

$\therefore \mu$ = 2 every 10 seconds

- Let x be the number of call arrivals in time T.
- It has Poisson distribution

$$P(x) = \frac{\mu^x}{x!}e^{-\mu}$$

1. Probability of no call arrivals :

No call arrival, $\mu = 2, x = 0$

$$\therefore P(0) = \frac{2^0}{0!}e^{-2} = 0.135 \quad \text{...Ans.}$$

2. Probability of more than one call arrivals :

$$P(>1) = 1 - P(0) - P(1)$$

$$P(1) = \frac{\mu^x}{x!}e^{-\mu} = \frac{2^1}{1!}e^{-2} = 0.270$$

$$\therefore P(>1) = 1 - 0.135 - 0.270$$

$$= 0.595 \quad \text{...Ans.}$$

Q. 20 A group of 5 trunks is offered 2 Erlangs of traffic. Find :

1. Grade of service.

2. Probability that only one trunk is busy.

3. Probability that only one trunk is free.

4. Probability that at least one trunk is free

April 17

Ans. :

Given :

1. N = 5 2. A = 2E

1. Grade of service :

$$B = E_{1,N}(A) = \frac{\frac{A^N}{N!}}{\sum_{k=0}^{N}\frac{A^k}{k!}} = \frac{\frac{2^5}{5!}}{\sum_{k=0}^{5}\frac{2^k}{k!}}$$

$$\therefore B = \frac{32/120}{\frac{2^0}{0!}+\frac{2^1}{1!}+\frac{2^2}{2!}+\frac{2^3}{3!}+\frac{2^4}{4!}+\frac{2^5}{5!}}$$

$$\therefore B = \frac{32/120}{1+\frac{2}{1}+\frac{4}{2}+\frac{8}{6}+\frac{16}{24}+\frac{32}{120}}$$

$$\therefore B = \frac{0.2667}{7.2667} = 0.037 \quad \text{...Ans.}$$

2. Probability that only trunk is busy :

$$P(x) = \frac{\frac{A_x}{x!}}{\sum_{k=0}^{N}\frac{A^k}{k!}}$$

$$\therefore P(1) = \frac{\frac{2^1}{1!}}{\sum_{k=0}^{5} \frac{A^k}{k!}}$$

$$= \frac{2}{7.2667} \quad \left[\text{since } \sum_{k=0}^{N} \frac{2^k}{k!} = 7.2667\right]$$

$$\therefore P(1) = 0.275 \quad \text{...Ans.}$$

3. **The probability that only one trunk is free :**

- That means we need to obtain the probability that 4 trunks are occupied.

$$\therefore P(4) = \frac{\frac{2^4}{4!}}{\sum_{k=0}^{5} \frac{A^k}{k!}} = \frac{\frac{16}{24}}{7.2667}$$

$$\therefore P(4) = 0.09174 \quad \text{...Ans.}$$

4. **The probability that at least one trunk is free :**

- That means we need to obtain the probability that $x < 5$.

$$\therefore P(x < 5) = 1 - P(5)$$

but $P(5) = B$ i.e. all trunks are occupied

$$\therefore P(x < 5) = 1 - B = 1 - 0.037$$

$$\therefore P(x < 5) = 0.963. \quad \text{...Ans.}$$

Q. 21 Group of 18 trunks provide grade of services of 0.01 when offered 15 E of traffic.

1. **How much is grade of service improved if one trunk is added to the group ?**
2. **How much grade of service deteriorate if one trunk is out of service ?** Dec. 19

Ans. :

Given : $N = 18$, $A = 15$,

Grade of service $(B) = 0.01$

Grade of service if one trunk is added to the group :

$$N = 18 + 1(1 \text{ added trunk}) = 19$$

$$B(K) = \frac{\frac{Ak}{k!}}{\sum_{k=0}^{\infty} \frac{Ak}{k!}}$$

$$\therefore B(K) = \frac{15^{19}/19!}{\sum_{k=0}^{19} 15^{19}/19!}$$

$$\therefore B(K) = \frac{182238.151196}{\sum_{k=0}^{19} 15^{19}/19!}$$

$$\therefore B(K) = \frac{182238.151196}{\frac{1 + 15^1}{1!} + \frac{15^2}{2!} \ldots\ldots + \frac{15^{19}}{19!}}$$

$$\therefore B(K) = \frac{182238.151196}{2861105.3415}$$

$$= 0.06369 \quad \text{...Ans.}$$

Grade of service when one trunk is out of service :

$$B(k) = 1 - 0.01 = 0.99 \quad \text{...Ans.}$$

Q. 22 Explain GoS and Blocking Probability in Lost Call System.

Ans. :

GoS and Blocking Probability in Lost Call System :

- The grade of service (B) in a lost-call system as follows :

$$B = \frac{\text{Number of lost calls}}{\text{Number of offered calls}}$$

$$\therefore B = \frac{\text{Lost traffic}}{\text{Offered traffic}}$$

- We can use two formulae namely Erlang-B and Erlang-C to calculate the blocking probability.
- We can select the appropriate formula based on the method of handling of customers when all resources are busy.
- Erlang-B formula is used for lost-call systems when calls are lost due to all resources being busy.
- Erlang-C is used for queueing systems when calls are queued due to all resources being busy.
- The Erlang - B formula is as follows :

$$P_B = \frac{\frac{1}{N!}A^N}{\sum_{i=0}^{N} \frac{A^i}{i!}}$$

- The Erlang-C formula is as follows :

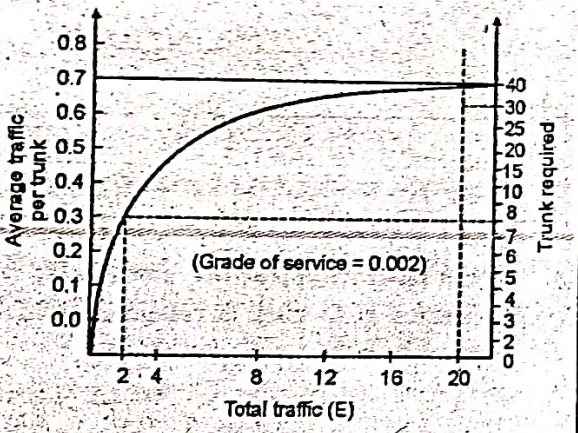
$$P_C = \frac{\frac{A^N}{N!}\frac{N}{N-1}}{\sum_{i=0}^{N}\frac{A^i}{i!} + \frac{A^N}{N!}\frac{N}{N-A}}$$

Q. 23 Write short note on : Traffic performance.

April 17

Ans. :

- The traffic performance is measured in terms of the value of grade of service.
- In order to achieve the preferred GOS, we need to increase the number of trunks N with increase in the offered traffic 'A'.
- However, with increase in the number of trunks, the probability of trunk occupancy becomes important.
- It has been observed that for a given GOS, a large group of trunks can have a higher occupancy than that of a smaller group of trunks.
- This shows that the efficiency of larger groups is higher than that of the smaller groups of trunks.
- Refer Fig. 4.3 to understand the concept of traffic performance.



(G-3003) **Fig. 4.3 : Traffic performance**

- Fig. 4.3 has been drawn for a GOS = 0.002. It shows that in order to achieve this GOS at a traffic of 2E, we need to use 7 trunks. The occupancy of these trunks is 2/7 = 0.285 E.
- Now if we increase the traffic to 20 E then, the number of trunks required in a group will increase to 32.
- The occupancy of these trunks is 20/31 = 0.65. Thus higher group of trunks have a higher efficiency.

Q. 24 Write short note on : Loss system in Tandem.

April 17

Ans. :

Loss system in Tandem :

- A system consists of several links in tandem. Consider a system with two links having grade of service as B_1 and B_2 respectively for offered traffic 'A' Erlangs.
- Now obtain the expression for the grade of service of a system with several links in tandem.

  Traffic offered to second link = $A[1 - B_1]$
- And the traffic actually reaching destination is,

$$= A[1 - B_1][1 - B_2]$$

$$= A[1 - B_2 - B_1 + B_1 B_2]$$

- The overall GOS of the entire connection is given by,

$$B = B_1 + B_2 - B_1 B_2$$

- If $B_1, B_2 << 1$, then $B_1 B_2$ is negligible and overall GOS of the entire connection is given by,

$$B = B_1 + B_2$$

- This is the approximate expression for GOS of a connection with two trunks. Therefore, the expression for GOS of a connection with N trunks in tandem is given by,

$$B = \sum_{k=1}^{N} B_k$$

Q. 25 Explain with neat diagram queuing system.

March 19

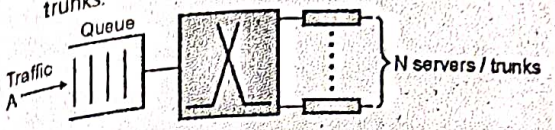
Ans. :

Definition of queuing system :

- The system which keeps call requests waiting in queue because of unavailability of trunks is known as a queuing system.
- A queue system consists of storage space services such as blocks of memory in a message switching mode or it may consist of only list of sources waiting for service.

Block diagram :

- Fig. 4.4 shows the block diagram of a queuing system with offered traffic A and N number of trunks.



(G-3004) **Fig. 4.4 : A queueing system**

Q. 26 Derive second Erlang distribution formula of a queuing system.

May 16, April 17, May 18, Dec. 17

Ans. :

Second Erlang distribution :

- The probability of encountering delay is based on the following assumptions :
  1. Pure - chance traffic
  2. Statistical equilibrium
  3. Full availability
  4. Calls encountering congestion will enter a queue and are stored there until a server becomes free.
- Out of these assumptions, the first three are common to those for a lost call system.
- The queueing system with all these assumptions is known as M/ M/ N queueing system.
- Under static equilibrium condition the offered traffic is less than or equal to the number of trunks i.e. $A \leq N$ and the queue is not needed.
- However if the traffic offered is higher than number of trunks i.e. $A \geq N$, then the queue comes into existence and its length increases with increase in traffic.
- Let x be the total number of calls in the system of N trunks.
- Consider the following two operating conditions :
  1. Condition-1 : $x \leq N$ and
  2. Condition-2 : $x > N$

Condition 1 : $x \leq N$

- Here, the total number of calls (x) is less than number of trunks.
- Therefore, there will be no delays in serving the calls and there is no queue. This system behaves as the lost call system without any congestion.
- For this operating condition,

$$P(x) = \frac{A^x}{x!} P(0)$$

Condition 2 : $x \geq N$

- Here, the number of calls (x) is much higher than the number of trunks (N).
- Therefore, there will be delays in serving the calls and the queues will come into existence.
- The incoming calls will encounter delays because all the servers will be busy.
- For this operating condition,

$$P(x) = \frac{A^x}{N^{x-N} \cdot N!} P(0)$$

OR

$$P(x) = \frac{N^N}{N!} \times \left(\frac{A}{N}\right)^x P(0)$$

- The state probability at trunk 0 is given by :

$$P(0) = \left[\frac{N \cdot A^N}{N!(N-A)} + \sum_{x=0}^{N-1} \frac{A^x}{x!}\right]^{-1}$$

- This is second Erlang distribution.

Q. 27 State and explain Erlang's delay formula.

May 13

Ans. :

Erlang's delay formula :

- The delay occurs if the incoming calls x are much higher than the available trunks N i.e. $x \geq N$.
- The probability that there are at least z calls in the system where $z \geq N$ is given by,

$$P(x \geq z) = \sum_{x=z}^{\infty} P(x)$$

- From equation of P(x) for $x \geq N$ we get,

$$P(x \geq z) = \sum_{x=z}^{\infty} \frac{N^N}{N!} \left(\frac{A}{N}\right)^x P(0)$$

$$= \frac{N^N}{N!} P(0) \sum_{x=z}^{\infty} \left(\frac{A}{N}\right)^x$$

$$\therefore P(x \geq z) = \frac{N^N}{N!} P(0) \left(\frac{A}{N}\right)^z \sum_{k=0}^{\infty} \left(\frac{A}{N}\right)^k$$

Where, $k = x - N$

$$P(x \geq z) = \frac{N^N}{N!} \left(\frac{A}{N}\right)^z P(0) \left[1 - \frac{A}{N}\right]^{-1}$$

$$P(x \geq z) = \frac{N^N}{N!} \left(\frac{A}{N}\right)^z P(0) \left[\frac{N-A}{N}\right]^{-1}$$

$$P(x \geq z) = \frac{N^N}{N!} \left(\frac{A}{N}\right)^z P(0) \left[\frac{N}{N-A}\right]$$

- Let, the probability of delay be P_D

  and $P_D = P(x \geq N)$

  $$\therefore P_D = \left[\frac{A^N}{N!}\right] \left[\frac{N}{N-A}\right] P(0)$$

- Substituting P(0) from earlier equation we get,

  $$P_D = E_{2,N}(A)$$

- This is Erlang's delay formula.

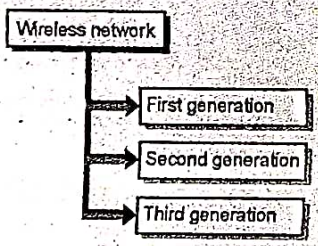
Chapter 5 : Wireless and Mobile Technologies and Protocols and their Performance Evaluation

Q. 1 Explain evolution of wireless communication in detail.

Ans. :

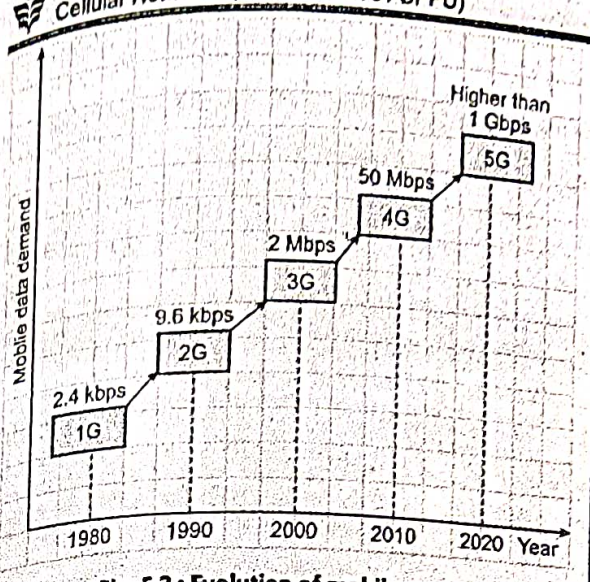
Evolution of wireless communication :

- The cellular systems are classified into different evolutionary generations from first generation (1G) to fifth generation (5G).
- The first generation wireless networks are based on analog technology and they are used only for analog voice services.
- The second generation wireless systems (2G) employ digital modulation and advanced call processing capabilities.
- Typical examples include Global System for Mobile (GSM), cordless telephone (CT2) etc.
- The third generation wireless systems (3G) are developed to provide universal access throughout the world.
- They have used broadband ISDN to provide access to information networks like internet, communications using Voice Over Internet Protocol (VoIP), voice-activated calls etc.
- The fourth generation wireless systems (4G) are currently under deployment but continue to evolve. The next generation cellular networks have been designed to support high speed data communications traffic in addition to the voice calls.
- The new technologies and standards are being implemented so that the wireless networks can replace the fiber optic or copper cables.
- The wireless networks are used as replacement for wires within offices, buildings, homes with the use of Wireless Local Area Networks (WLANs).
- The Bluetooth modem standard can connect several devices with invisible wireless connections within a person's personal workspace.
- It was conceived as a wireless alternative to RS232 cables.
- WLANs and Bluetooth use low power levels. They don't need a license for spectrum use.
- They are used for adhoc wireless communication of voice and data anywhere in the world.
- The cellular systems are classified into three different evolution of generations.
- Fig 5.1 shows classification of wireless network generations.



(G-2543) **Fig. 5.1 : Classification of evolution of generations**

- Fig. 5.2 shows an evolution path from 1G to 5G.
- It is a graph of year of the corresponding maximum data rate.



(GT-14) **Fig. 5.2 : Evolution of mobile generations**

- The first generation could support a maximum data rate of only 24 kbps whereas the fifth generation is expected to support a data rate of above 1 Gbps.

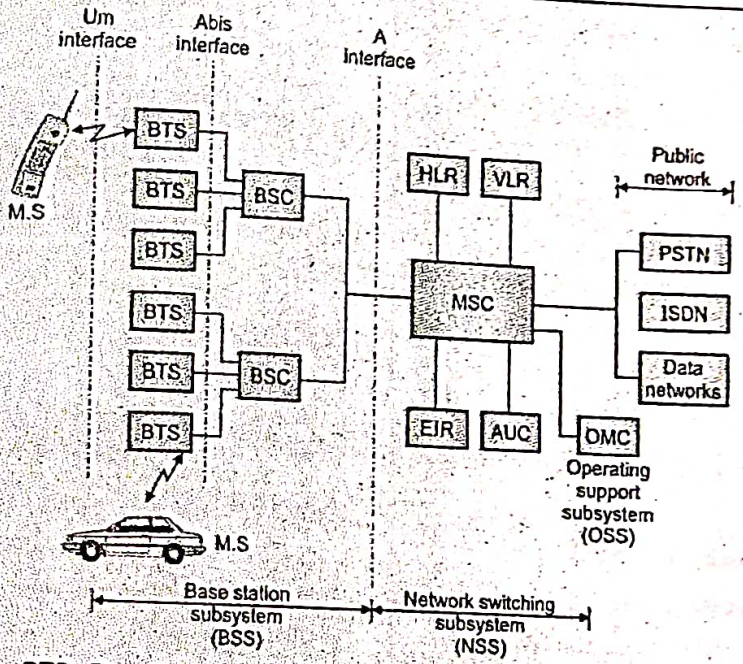
Q. 2 Draw neat diagram of GSM architecture and explain the function of each block in it.

Dec. 16, May 17, Dec. 17, May 18, May 19, Dec. 19

Ans. :

Block diagram :

- The detail architecture of a GSM system is shown in Fig. 5.3.
- The BTS and BSC both are part of the Base Station Subsystem (BSS).



BTS : Base Transceiver Station — **BSC : Base Station Controller**

HLR : Home Location Register — **VLR : Visitor Location Register**

MSC : Mobile Switching Centre — **EIR : Equipment Identity Register**

AUC : Authentication Center — **OMC : Operation Maintenance Center**

(GT-8) **Fig. 5.3 : GSM system architecture**

- Each BSC has hundreds of BTSs. (Bus Transceiver Stations) connected to it.
- These BTSs are controlled by the corresponding BSCs. The BTSs are connected to BSCs either physically or via microwave links or dedicated leased lines.
- The interface between BTS to BSC is called as Abis interface.
- This interface is expected to carry the voice data (traffic) and maintenance data.
- The BSCs are physically connected to MSC (Mobile Switching Center) via dedicated / leased lines or

microwave link. This interface is known as the A interface.

- The NSS contains three different databases, called Home Location Register (HLR), Visitor Location Register (VLR) and Authentication Center (AUC).
- The HLR is a database containing the subscriber information and location information of each user, who is staying in the same city as MSC.
- Each subscriber is assigned a unique International Mobile Subscriber Identity (IMSI) and this number will identify each user.
- VLR database is used to temporarily store the IMSI and customer information for each roaming subscriber.
- AUC is the strongly protected database which takes care of authentication and handles the encryption keys for all the subscribers in HLR and VLR.
- The OSS supports one or more Operation Maintenance Centers (OMC).
- The OMC is used for monitoring and maintaining the performance of each MS, BS, BSC and MSC used in a GSM system.

Operating support subsystem (OSS) :

- The OSS takes care of the following areas of operation :
  1. Network operation and maintenance.
  2. Charging and billing.
  3. Management of mobile equipment.

Q. 3 Explain the function of following with respect to GSM architecture :

1. BSC 2. MSC May 18, Dec. 19

Ans. :

Functions of BSS :

- Functions performed by BSS are as follows :
  1. Coding of speech channels,
  2. To allocate the available radio channels to mobile stations on request,
  3. To transmit the paging signals,
  4. To transmit and receive both control and data signals over the air interface.

Functions of MSC :

- Functions performed by MSC are as follows :
  1. To perform all the necessary switching functions required by MSs located in MSC area.
  2. To communicate with other MSCs present in the GSM network.
  3. To communicate with the other networks like PSTN etc.
  4. To track the location of the subscriber to carry out the handover process whenever necessary.
  5. To perform all the necessary interworking functions.
  6. To perform the call routing and echo control functions.

Q. 4 State and explain data services in GSM.

May 16, 4 Marks, May 17, Dec. 17

Ans. :

Data services in GSM :

- The GSM services can be classified into three types of services :
  1. Teleservices
  2. Data services / Bearer services
  3. Supplementary services

Teleservices :

- These services allows subscriber to use terminal equipment functions for communication with other subscribers.
- The teleservices support emergency calling, FAX services, Videotex and Teletex services though they are not integral part of the GSM standard.
- In other words, the standard mobile telephony and the mobile originated or base originated traffic comes under the teleservices.
- The tele-services are as follows :
  1. Digital telephony 2. Emergency calling
  3. SMS 4. EMS
  5. MMS 6. Group 3 FAX

Data Services / Bearer services :

- These services allow subscriber to transmit appropriate signals across user network interfaces.
- Data services are the GSM services corresponding to the communication between computers and packet switched traffic.
- It supports packet switched protocols and data rates from 300 bps to 9.6 kbps.
- New developments are going on to increase the data rate further.
- Data can be transmitted in two modes :
  1. **Transparent mode :** GSM network provides standard channel coding method for user data.
  2. **Non-transparent mode :** GSM network provides special coding methods based on particular data interface.

Bearer Services :

- Bearer services are basically the data services which correspond to the communication between a computer and packet switched traffic.
- Bearer services are defined as all those services that enable the transmission of data between interfaces and networks.
- In the classical GSM model, the bearer services are connection oriented and use circuit or packet switching.
- Bearer services are of two types :
  1. Transparent bearer services
  2. Non-transparent bearer services

Supplementary Services :

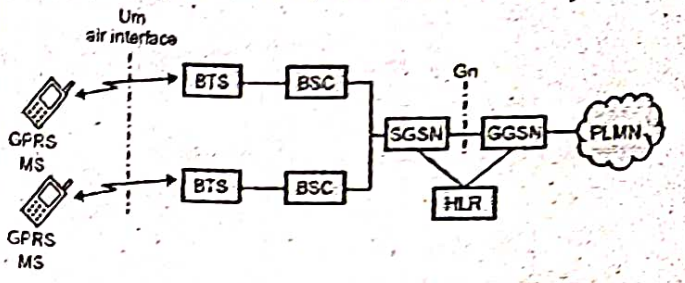
- These services are digital in nature and they are offered as supplements with the basic teleservices.
- The supplementary services provide various enhancements for the standard telephony services.
- Some of the typical supplementary services are as follows :
  1. Conference Call
  2. Call Waiting
  3. Call Hold
  4. Call Forwarding
  5. Call Barring
  6. Caller Identification
  7. Suggestion of Charge
  8. Closed User Groups

Q. 5 Draw and explain the architecture of GPRS.

Ans. :

Architecture of GPRS system :

- Fig. 5.4 shows the architecture of the GPRS system.



(GT-48) **Fig. 5.4 : Architecture of GPRS system**

- In GPRS two new network elements are introduced, which are known as GSN (GPRS support nodes).
- Fig. 5.4 shows GPRS architecture, which is formed with all GSNs, which are integrated into the standard GSM architecture, alongwith some interfaces.

GPRS support nodes :

- There are two types of support node in GPRS :
  1. SGSN (Serving GPRS support node)
  2. GGSN (Gateway GPRS support node)

1. Serving GPRS Support Node (SGSN) :

- As shown in Fig. 5.4, the BSCs are connected to SGSN which acts as the service access point to the GPRS network, for the GPRS user.
- SGSN is analogous to MSC in the GSM networks. We may view it as a packet switched MSC.
- Within the service area of SGSN, it delivers packets to MS (mobile stations).
- SGSNs send queries to home location registers (HLRs) for obtaining the profile data of GPRS subscribers.
- In their service area, SGSNs detect new GPRS MS and process the registration of new mobile subscribers and keep records of their locations inside a given area.
- In this way the SGSNs perform the mobility management functions such as attaching / detaching a mobile subscriber and its location management.

Functions of SGSNs :

- The main functions of SGSN are as follows :
  1. Routing of data to and from mobile station.
  2. To handle authentication.
  3. To carry out data compression and ciphering.
  4. Tracking of location and mobility administration.
  5. Stores the location and profile of users.
  6. Mobility management.

2. Gateway GPRS Support Node (GGSN) :

- The GGSNs are connected to the external packet switching data networks, like the X.25 or the Internet as shown in Fig. 5.4.
- For all these networks the GGSNs acts simply as a router. When the data addressed to a specific mobile user is received by a GGSN, it first checks if the called address is active.
- If it is active, then the GGSN forwards the data packets to SGSN.
- However if the called address is found inactive, then GGSN simply discards the received packets.
- The GGSNs route the mobile originated data packets to the desired network.
- They also track the mobile user in association with the SGSNs.

3. GPRS Interfaces :

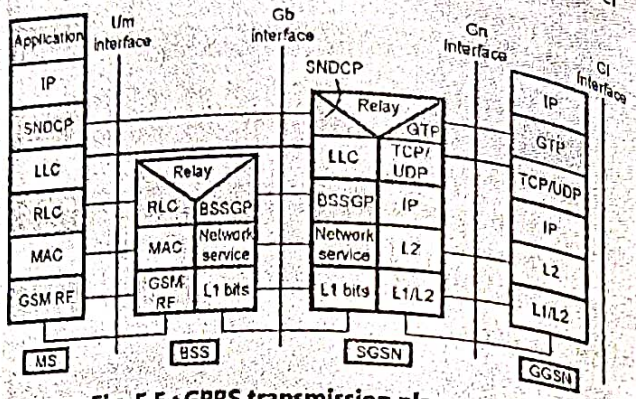
- The GPRS architecture includes signaling interfaces with various protocols, which controls and support the transmission of packets across the networks and to the mobile stations.
- Following are the GPRS interfaces :
  1. Air Interface (Um) : It connects MS and BTS (Base transceiver station).
  2. A-bis Interface : It connects BTS and BSC (Base station controller).
  3. Gb Interface : It connects BSC with SGSN.
  4. Gn Interface : It connects SGSN and GGSN.
  5. Gi Interface : It connects GGSN with external PDN (Packet Data Network).
  6. Gr Interface : It connects SGSN and HLR. Exchange the user information between SGSN and HLR.
  7. Gc Interface : It connects GGSN and HLR. Exchange the location information between GGSN and HLR.

Q. 6 Draw and explain the GPRS protocol stack.

Ans. :

GPRS protocol stack :

- Fig. 5.5 shows GPRS protocol stack for the user data transmission.



(G-2427) **Fig. 5.5 : GPRS transmission plane protocol stack**

- Um (air interface) is located between MS and BSS, the Gb interface is located between BSS and SGSN and Gn interface is located between SGSN and GGSN.
- SNDCP (Subnetwork dependant convergence protocol) encapsulates the IP packets in GPRS specific packet format which is used between SGSN and MS.
- LLC layer provides a reliable logical link to the data units from the higher layers, which depends on the underlying radio interface protocols.
- LLC provides either acknowledged or unacknowledged data transmission.
- GTP (GPRS tunneling protocol) tunnels user data between the two GSNS in the GPRS backbone network.
- BSSGP (base station subsystem GPRS protocol) layer conveys routing and QoS related information between the BSS and SGSN. RLC (Radio Link Control) protocol provides reliable radio link for the data transfer between MS and BSS.
- MAC layer controls the multiplexing of signaling and data messages from various GPRS users.

- GSM RF (Radio Frequency) layer controls the physical channel management, modulation / demodulation, transmission, power control and channel coding / decoding.

Q. 7 Write the characteristics of GPRS.

Ans. :

Characteristics of GPRS :

1. GPRS uses packet switched network.
2. It uses GSM architecture and GPRS support nodes.
3. It enables voice and data flow through the network.
4. It has dynamic time slot allocation.
5. It is faster than GSM and code division multiple access (CDMA).

Q. 8 State advantages, disadvantages and applications of GPRS.

Ans. :

Advantages :

- Following are the advantages of GPRS :

1. **Speed :** GPRS technology offers higher data rate than GSM. GPRS provides speed limit upto 171 kbps and offers throughput upto 40 kbps.
2. **Packet switched :** GPRS is packet switched system circuit and parallely packet switching can be used.
3. **Always on :** GPRS provides "Always on" capability.
4. **Spectral efficiency :** Because of shared use of radio channels, GPRS provides a better traffic management and it has service access to a greater number of users.
5. **Packet transmission :** For long data packet transmission GPRS works more efficiently.

Disadvantages :

- Following are the disadvantages of GPRS :

1. As GPRS uses the GSM band for data transfer, when a connection is active, calls and other network related functions cannot be used.
2. Depending on the individual service provider GPRS is usually to be paid per Mbytes or kbytes. But this has been modified in various places where there is no more charge of per usage of GPRS downloads instead GPRS downloads are rather unlimited with a flat fee to be paid every month.
3. It does not provide store and forward service therefore if the MS is not available the data gets lost.

Applications of GPRS :

- Following are the applications of GPRS :

1. Sending and receiving e-mail, Short Message Service (SMS), Multimedia Message (MMS), fax etc.
2. Internet access and video conference.
3. Provides location based services.
4. Provides the connection with PC's and other devices.
5. Non-real time Internet applications.
6. Retrieval of e-mails, faxes.
7. Asymmetric web browsing (more downloading and less uploading).

Q. 9 Compare : GSM and GPRS.

Ans. :

Comparison of GSM and GPRS :

Table 5.1 Comparison of GSM and GPRS

Sr. No.	Parameter	GSM	GPRS
1.	Abbreviation	Global system for mobile communication	General packet radio service
2.	Based system	TDMA	GSM
3.	Users per channel	8	8
4.	Type of connection	Circuit switched technology	Packet switched technology
5.	Frame duration	4.6 ms	4.6 ms
6.	Carrier size	200 kHz TDMA	200 kHz

Q. 10 Compare EDGE and GPRS systems.

Ans. :

Table 5.2 : Comparison of EDGE 2.5G and GPRS

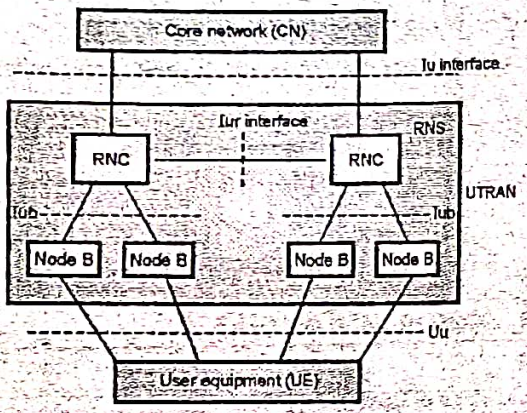
Sr. No.	Parameter	EDGE 2.5 G	GPRS
1.	Data rate	547.2 kbps	171.2 kbps
2.	Channel bandwidth	200 kHz	200 kHz
3.	Modulation technique	GMSK and 8 PSK	GMSK and 8 PSK
4.	Number of voice channels	8	8

Q. 11 With neat diagram explain UTRA-Network (UTRAN) Architecture.

Ans. :

UTRA-Network (UTRAN) Architecture :

- The basic architecture of UTRAN is as shown in Fig. 5.6.



(G-2464) **Fig. 5.6 : UTRAN architecture**

Components of UTRAN :

- The two components of UTRAN are :
  1. RNS (Radio Network Subsystem)
  2. Node B
- UTRAN architecture consists of many RNS (Radio Network Subsystem) controlled by RNC (Radio Network Controller) and includes many node B components as well.
- In UMTS, RNC and node B are similar to BSC and BTS respectively in GSM. Antennas which makes a radio cell are controlled by node B. UE (mobile device) is connected to one or more antennas.
- Through the interface Iu the core network is connected to RNC and RNC is connected to Node B through Iub interface Iur is the interface through which two RNCs are connected to each other.

Radio Network Controller (RNC) :

- The functions of RNC are as follows :

1. **Call admission control :**
- Within each cell the RNC computes the traffic and decides whether to accept or not the additional transmissions.
2. **Encryption / decryption :**
- Before the transmission over the wireless link the RNC encrypts all information which comes from the fixed network and vice versa.
3. **Congestion control :**
- Many stations share the radio resources available during packet oriented data transmission.
- In a cyclic fashion the RNC allocates bandwidth to every station by considering the QoS requirements.
4. **Radio resource control :**
- RNC controls radio resources of the cells which are connected through a node B.
5. **Protocol conversion, ATM switching and multiplexing :**
- ATM is the base of connection between RNCs, Node B and CN. The RNC needs to switch the connections to multiplex different data streams.
6. **Setup and release of radio bearer :**
- The function of RNC is to setup, maintain and release a logical data connection to a user equipment (UE).
7. **Allocation of code :**
- The RNC selects the CDMA codes used by a UE.
8. **Management :**
- The RNS provides interfaces to the tasks such as information regarding the current load, error states, current traffic required for the network operators.
9. **Power control :**
- A relatively loose power control is performed by the RNC. It controls transmission power is based on the interference values from other RNCs or other cells.

10. RNS location and handover control :

- Whether another cell is better suited for a certain connection or not is decided by RNC depending on the strength of signal received by UEs or node B. If handover is decided by RNC it informs the new cell an UE.
- If a UE moves Out of the range of one RNC then, a new RNC has to be selected which takes responsibility of the UE. This is known as relocation.

Node B :

- Node B is connected to one / more antennas which creates one / more cells. The cell may use either FDD or TDD or both.
- The main function of Node B is inner loop power control to moderate the near far effects. Connection qualities and signal strengths are measured by Node B, to exercise the power control
- Node B can support soft handover which occurs between different antennas of the same node B. Node B logically equivalent to the GSM base station.

User equipment (UE) :

- As shown in Fig. 5.7 UE is the counterpart of several nodes of architecture.
- As the counterpart of a node B, UE performs following functions :
  1. Signal quality measurements.
  2. Inner loop power control.
  3. Rate matching.
  4. Spreading and modulation.
- A the counterpart of RNC, UE performs following functions :
  1. Cooperation during handover.
  2. Cell selection.
  3. Encryption / decryption.
  4. Participation in the radio resource allocation process.
- As the counterpart of core network, UE performs following functions :
  1. It implements mobility management function.
  2. Bearer negotiation.
  3. Requests certain services from the network.

Q. 12 State important features of W-CDMA.

Ans. :

Important features of W-CDMA :

Table 5.3 : UMTS Specifications

Specification	Value
Channel Bandwidth	5 MHz
Multiple access scheme	CDMA
Data Rate	384 kbps to 2 Mbps
Duplex Mode	FDD and TDD
Downlink RF Channel Structure	Direct Spread (DS)
Chip Rate	3.84 Mcps
Frame Length	10 mS
Spreading Modulation	Balanced QPSK (downlink), Dual-channel QPSK (uplink) Complex spreading circuit
Data Modulation	QPSK (downlink), BPSK (uplink)
Coherent detection	User dedicated time multiplexed pilot (downlink and uplink) Common pilot in downlink
Channel Multiplexing in Downlink	Data and control channel are multiplexed

Q. 13 Write a note on HSUPA.

Ans. :

- HSUPA stands for High Speed Uplink Packet access. It was introduced in Release 6 in 2004.
- The main objective of HSUPA is to improve spectral efficiency of uplink and to reduce the latency. HSUPA has peak data rates of 5.8 Mbps in the uplink.
- SUPA technology is compatible with HSDPA and it is applied to the uplink transmission directions.

- Several similar technologies are applied in both HSDPA and HSUPA.
- There are some basic differences in HSDPA and HSUPA due to the different conditions of links.
- HSUPA provides a considerable growth in the upload speed but does not provide the same capacity as HSDPA.

Q. 14 Write a note on HSPA.

Ans. :

HSPA :

- High Speed Packet Access (HSPA) is known as 3.5G technology (Release 7).
- The High Speed Packet Access (HSPA) was introduced in order to improve the performance and to provide a higher speed. HSPA joined the HSDPA and HSUPA. HSPA allow the new service to provide a better performance for the user.

Advantages :

- The main advantages of HSPA are :
  1. Use of shared channel transmission
  2. Use of link adaptation
  3. Use of higher order modulation
  4. Fast scheduling
  5. Use of Hybrid ARQ
  6. Shorter transmission time interval (TTI)

1. Use of shared channel transmission :

- Due to shared channel transmission the resource sharing takes place which allows us to achieve high levels of efficiency.

2. Use of link adaptation :

- With the use of link adaptation the channel usage is maximized.

3. Use of higher order modulation :

- 16 QAM modulation scheme is used in the downlink which allows data to be transmitted at higher rates.

4. Fast scheduling :

- If the system makes use of fast scheduling with modulation and adaptive coding, it can react to the varying radio channel and interference conditions and receives bursty data traffic.

5. Use of Hybrid ARQ :

- Hybrid ARQ technique reduces retransmission round trip times and improves the robustness of the system by allowing soft combining of retransmissions.

6. Shorter transmission time interval (TTI) :

- The round trip time is decreased by using a shorter TTI.
- Use of shorter TTI enables improvements in adapting to fast channel variations and it reduces latency.

Q. 15 State the specifications of 4G LTE.

Ans. :

specifications of 4G LTE

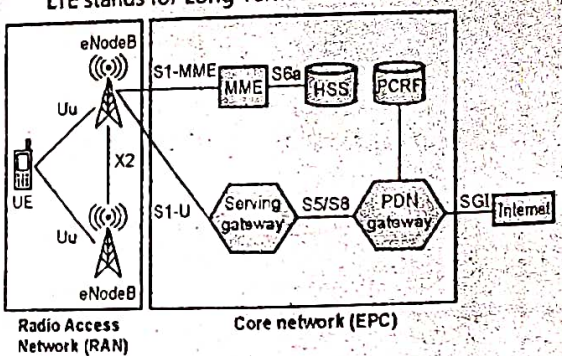
1. Peak data rates : Downlink - 1 Gbps ; uplink - 300 Mbps.
2. Spectrum efficiency : 3 times greater than LTE.
3. Speed 10 times faster than the 3G network.
4. Peak spectrum efficiency : Downlink - 30 bps / Hz; uplink - 15 bps / Hz.
5. 4G LTE is flexible and reliable.
6. It is easy to standardize and affordable.

Q. 16 Explain with diagram, the working operation of LTE network structure. **Dec. 19**

Ans. :

LTE-Advanced architecture :

- Fig. 5.7 shows the network structure of LTE, where LTE stands for Long Term Evolution.



MME : Mobile Management Entity PDN : Packet Data Network
HSS : Home Subscriber Server UE : User Equipment
PCRF : Policy and Charging Rules Function

(G-2590(a)) **Fig. 5.7 : LTE-Advanced architecture**

- LTE network architecture is simple which contains single type of access point i.e eNode B or Base station. One or more cells are supplied by eNode B or BS.
- As shown in Fig. 5.7, the LTE-A network consists of :
  1. Radio Access Network (RAN) / EUTRAN
  2. Core network (EPC)
  3. Radio interface

1. Radio Access Network (RAN) :

- The radio access network is also known as EUTRAN or Evolved Universal Mobile Telecommunications System.
- The Radio Access Network consists of an LTE mobile terminal, radio interface and eNodeB.
- **LTE Mobile Terminals :** LTE mobile terminals are the mobile phones and other devices which support the LTE.
- **Radio Interface :** Radio interface are the radio links that connect the LTE mobile terminals and eNodeB.
- **eNodeB :** E-UTRAN Node B or eNodeBs are located all over the network of the mobile operator and they connect the LTE mobile terminal to the core network via radio interface S1.

Functions of eNodeB :

- The functions of eNodeB are as given below :
  1. Scheduling / Radio resource allocation.
  2. Retransmission control.
  3. Physical layer functions.
  4. Air interface communication.

2. Core network (EPC) :

- The Enhanced Packet Core (EPC) developed for the 4G is also known as System architecture evolution (SAE) which is based on the packet switched transmission. The LTE Core Network is the brain of 4G system.
- Core network consists of :
  a. Mobility management Entity (MME)
  b. Serving gateway (S-GW)
  c. Packet data network(PDN) gateway (P-GW)
  d. Home subscriber server (HSS)
  e. Policy and Charging Rules Function (PCRF)

Functions of core network :

- Functions of the core network are as follows :
  1. Charging and subscriber management.
  2. Mobility management.
  3. Provision of quality of service.
  4. Policy control of user data flows.
  5. Connection to other external networks.

3. Radio Interface :

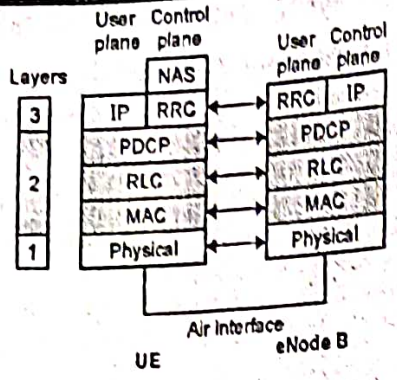
- Refer Fig. 5.7 to understand different radio interfaces in LTE.
- **Interface x2 :** This is an interface, which connects different base stations. The important information required for the coordination of transmission in neighboring cells can be exchanged through this interface.
- **Interface S1 :** RAN is connected to the core network through interface S1.
- **Interface Uu :** This is an interface, which connects UE (user equipment) and eNodeB.
- This is an interface for the user plane between an E-UTRAN and S-GW. It provides GTP tunnel per carrier.
- **Interface S1-MME :** This is an interface for the control plane between an E-UTRAN and MME.
- **Interface S6a :** This is an interface for the control plane between an HSS and MME. It exchanges user subscription and authentication information.
- **Interface S5/S8 :** This is an interface defined for the control and user planes between an S-GW and P-GW.
- **Interface SGI :** This is an interface defined for the control and user planes between an P-GW and Internet.

Q. 17 Draw the LTE Radio Protocol Architecture.

Ans. :

LTE Radio Protocol Architecture :

- Fig. 5.8 shows the structure of LTE protocol.



(GT-17) **Fig. 5.8 : LTE protocol structure**

Q. 18 Enlist the Key technologies of LTE - Advanced. Explain any two.

Ans. :

Key technologies / Features of LTE-A :

- The following are some of the key technologies considered for the LTE advanced :
  1. Carrier aggregation
  2. Enhanced MIMO techniques
  3. Wireless relays
  4. Coordinated multipoint transmission and reception

Carrier Aggregation :

- The carrier aggregation ensures the wider bandwidths.
- The major goal of LTE-advanced is to fully utilize the maximum bandwidth of 100 MHz, which is extremely large bandwidth.
- To deal with this problem, a scheme known as a carrier aggregation has been proposed.
- A technique where multiple carriers of maximum bandwidth of 20 MHz would be aggregated for the same user equipment(UE) is known as Carrier aggregation (CA).
- LTE-A allows a mobile to transmit and receive upto five component carries (CCs) simultaneously, each of which has a maximum bandwidth of 20 MHz.
- CA supports aggregation of both continuous and non-continuous carriers.
- Continuous carrier aggregation is used for super-high bandwidth.
- Non-continuous carrier aggregation has a much wider range of applications than continuous carrier aggregation.

Enhanced MIMO :

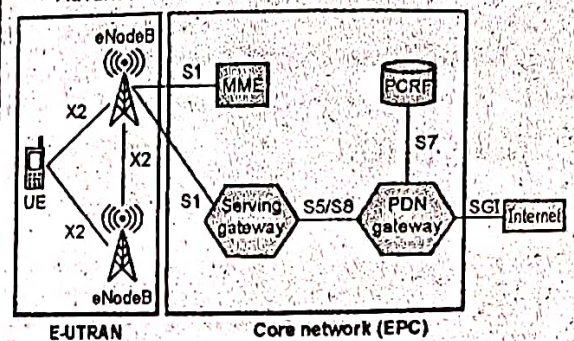
- In LTE-A, enhanced MIMO technique ensures higher efficiency enabled by improved uplink multiple access and multiple antenna transmission.
- Out of the several technologies made by release 10, we consider the advanced antenna techniques.
- In the advanced antenna techniques, multiple transmit and receive antennas and mutli-cell MIMO techniques are used to offer an enhanced downlink MIMO and uplink MIMO that improves the downlink and the uplink data rates, respectively.
- Enhanced MIMO is an important aspect of LTE advanced technique. It allows the system to meet the IMT advanced rate requirements.
- Enhanced MIMO expands the MIMO capabilities of LTE release 8.
- Enhanced MIMO supports eight downlink antennas, allowing the possibility in the downlink of 8 × 8 spatial multiplexing and four uplink antennas allowing the possibility of up to 4 × 4 transmission in the uplink, when jointed with four eNB receivers.

Q. 19 Draw LTE-A Radio Network Architecture.

Ans. :

LTE advanced architecture :

- Fig. 5.9 shows the network structure of LTE-Advanced.



MME : Mobile Management Entity
UE : User Equipment
PDN : Packet Data Network
PCRF : Policy and Charging Rules Function

(G-2590(b)) **Fig. 5.9 : LTE advanced architecture**

Q. 20 Compare between 3GPP / LTE and advanced LTE.

Ans. :

Comparison of LTE and LTE-A :

Table 5.4 : Comparison of LTE and LTE-A

Sr. No.	Parameter	LTE	LTE-Advanced
1.	3GPP releases	Release 8/9	Release 10
2.	Modulation	QPSK, 16QAM, 64QAM	64QAM, 64QAM
3.	Duplex Method	TDD and FDD	TDD and FDD
4.	Channel bandwidth	1.4, 1.6, 3, 5, 10, 15, 20 MHz	Upto 100 MHz for downlink and 40 MHz for uplink with carrier aggregation
5.	Spectral efficiency	Moderate	3 times higher than that of LTE
6.	Peak data rates	Downlink : 300 Mbps Uplink : 75 Mbps	Downlink : 1 Gbps Uplink : 500 Mbps
7.	Mobility	< 350 kmph	≤ 350 kmph, ≤ 500 @ frequency band
8.	Access methodology	OFDMA / SC – FDMA	OFDMA / SC – FDMA
9.	Latency roll out time	~ 10 ms	< 5 ms

Q. 21 List out various challenges and requirements for 5G service. **Dec. 19**

Ans. :

Challenges for 5G Networks :

- Following are the challenges for 5G networks while establishing 5G wireless networks :
  1. 5G networks should be capable of providing large connectivity and huge capacity.
  2. It should support a huge range of services, applications and users related to different areas of life.
  3. The key challenge in establishing the 5G network is its flexibility and efficiency in using the available capacity in the spectrum for the deployment of various networking scenarios.
  4. 5G should be able to deliver a connection with a suitable QoS as mobile networks have been covering all aspects of our daily communications.
  5. 5G networks should be highly reliable and secure.
  6. In order to achieve the above goals, the designed technology for establishing the 5G network must consider the capability to support visual communications with ultra-high-quality and attractive multimedia interactions.

Requirements for 5G Networks :

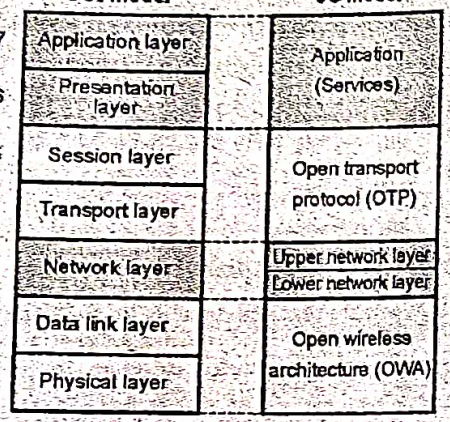
- Following are the requirements for 5G networks :
  1. 5G networks need extreme flexibility to support various applications and services.
  2. In 5G networks it is necessary to consider end-to-end application quality.
  3. 5G should be able to support at least 1 Gb/s or more data rate in order to meet the requirements for providing ultra-HD video and virtual reality applications.
  4. 5G networks should increase their capacity by a factor of nearly 1000 in traffic load and peak data rate of 5–10 Gbps.
  5. It should increase the spectral efficiency of 10 bps/Hz, and latency of 1 ms for the user plane and 50 ms for the control plane.
  6. 5G network should consider Millimeter waveform (mmWAV) and unlicensed bands for spectrum usage.

Q. 22 With the help of Layers, explain 5G concept in wireless technology. **May 19, Dec. 19**

Ans. :

5G concept in wireless technology :

- The 5G concept in wireless technology corresponds to the open system interconnected (OSI) layers.
- Fig. 5.10 shows the correspondence of ISO-OSI reference model and the 5G model. 5G model consist of four basic layers :



(GT-25) Fig. 5.10 : 5G protocol Stack

1. Open Wireless Architecture (OWA)
2. Network Layer
3. Open Transport protocol (OTP)
4. Application layer

1. Open Wireless Architecture (OWA) :

- It is lowest layer of 5G model. It corresponds to the physical and data link layer of the OSI model.

2. Network Layer :

- As shown in Fig. 5.10, network layer of 5G is subdivided into two layers namely upper network layer and lower network layer.
- The network layer of 5G corresponds to the network layer of OSI model and it is based on IP.
- Due to problems in IPv4 and IPv6, all mobile networks will use mobile IP standard in 5G.
- Each mobile terminal in 5G will be a foreign agent (FA), maintaining care of address (CoA) mapping between its fixed IPv6 address and the CoA address for the current wireless network.
- A mobile terminal can be attached to several mobile or wireless networks at the same time.

3. Open Transport Protocol (OTP) :

- It corresponds to the transport (layer 4) and session (layer 5) layers of the OSI model.
- In all transmission control protocol (TCP) versions, it is considered that the packet loss takes place due to network congestion.
- But in wireless technology, losses can occur due to a higher bit error ratio in the radio interface.
- Hence, TCP adjustments and alterations are anticipated for the mobile and wireless networks that retransmit the damaged TCP segments over the wireless link only.
- It will be suitable to have a transport layer for 5G mobile terminals, which can be downloaded and installed.
- Such mobiles will have the ability to download the desired version specifying wireless technology installed at the Base station. This is known as open transport protocol (OTP).

4. Application (Services) Layer :

- The application layer is the topmost layer of 5G and it corresponds to the application layer of the OSI model.
- Application layer provides intelligent QoS management over a variety of networks.
- It provides the quality testing service and store the measurement information in the database at the mobile terminal.
- In the 5G mobile phone, the QoS parameters such as delay, jitter, losses, bandwidth, and reliability, etc will be stored in a database.
- Application layer selects the best wireless connection for the given service.

Q. 23 List out various applications of 5G.

Ans. :

Various applications of 5G :

- 5G technology can be used in the following applications :
  1. Entertainment and multimedia
  2. Internet of Things – Connecting everything
  3. Smart Home
  4. Logistics and shipping
  5. Smart cities
  6. Smart farming
  7. Healthcare and mission critical applications
  8. Drone operation

Q. 24 Write a short note on properties of OFDM.

Ans. :

Properties of OFDM :

- Some of the important properties of OFDM are as follows :
  1. OFDM can eliminate the intersymbol interference (ISI) without increasing the bandwidth.
  2. It does not require very complex signal processing.
  3. OFDM is very sensitive to frequency offsets and timing jitter and it needs to use some additional mechanisms to address these issues.

Q. 25 State the features of OPNET.

Ans. :

Features of OPNET :

- The following are the main features of OPNET :
  1. OPNET has powerful means and it helps in model building, simulation running and analysis of the simulation outputs.
  2. It supports a hierarchical configuration of modeling.
  3. A set of library modules in OPNET supports communication protocols and network-related topologies.
  4. The model can be easily compiled and run because OPNET has an excellent troubleshooting tool.

Q. 26 Write a short note on OMNeT++.

Ans. :

OMNeT++ :

- OMNeT++ simulation tool is an open-source discrete-event simulation software.
- It is used for simulating computer communication networks, including wireless networks.
- In OMNeT++, The programming characteristics follow a modular style.

Features :

1. OMNeT++ offers a standard library which explains some standard modules that can be used during the modeling process of the system.
2. In OMNeT++, the key modules for troubleshooting, tracing and animation are efficient.
3. Tracing and simple debugging is the key feature of the OMNeT++ package. It is used for tracing the behavior of the system.

Different classes of the OMNeT++ library :

- The library of OMNeT++ contains the following :
  1. Message classes
  2. Container classes
  3. Routing classes
  4. Random number generator classes
  5. Statistical classes
- The classes are used to gather data when the simulation is on the run.
- Message classes provides message packets for various types of networks.
- Container classes provide various storing services such as queues and stacks and uphold the general actions on these classes.
- Routing classes offers the base for using a range of routing methods for movement of the message packets in the network.

Q. 27 What are the different methods used in OMNeT++. State its advantages and disadvantages.

Ans. :

Methods used in OMNeT++ :

- Three methods used in OMNeT++ are : automatic animation, module output windows and object inspectors.
- While designing, some text data is generated as a checkpoint for troubleshooting.
- This type of text data used for debugging is shown in the module output window.
- The status of the object at any point of time is shown by using object monitors / inspectors.
- In order to build the network simulators, OMNET++ is an extensible, modular, component-based C++ simulation library and framework.
- OMNET++ can be used in various problem domains including wireless communication and networks due to its generic architecture.

Advantages :

1. It supports parallel distributed simulation.
2. It is used for queuing network simulations
3. It Provides rich class of libraries for implementation of various modules
4. Graphical tools are available for the analysis of simulated output.
5. It provides both event based and process based programming style.

Disadvantages :

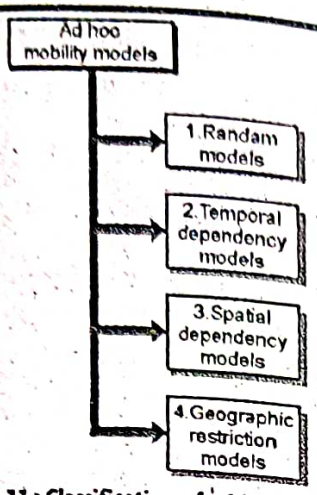
1. Poor documentation.
2. Limited protocol support.
3. Analysis of performance measures is poor.
4. Poor run time performance.

Q. 28 Give the classification of ad hoc mobility models.

Ans. :

Classification of ad hoc mobility models :

- Fig. 5.11 shows the classification of ad hoc mobility models.



(O-1037) Fig. 5.11 : Classification of ad hoc mobility models

Q. 29 What are the limitations of the random waypoint model.

Ans. :

Limitations of the random waypoint model :

- The advantages of Random Waypoint Model and its variants are simplicity of implementation and wide acceptance.
- However, they may fail to adequately capture certain mobility characteristics such as temporal dependency, spatial dependency and geographic restriction.
- Therefore these models have some limitations in the following scenarios :

1. Temporal dependency of velocity :

- In certain scenario the velocity of MN cannot be absolutely random.

2. Spatial dependency of velocity :

- In certain scenarios, such as battlefield communication the movement pattern of a MN cannot be absolutely random, rather it will be correlated with some other nodes.
- Geographic Restrictions of Movement : In the Random Waypoint Model, it is assumed that the mobile nodes can move freely within the simulation field without any restrictions. However, in many realistic applications in urban areas, the movement of a mobile node will be bounded by obstacles, buildings, streets etc.

Q. 30 Write a short note on Gauss-Markov mobility model.

Ans. :

Gauss-Markov mobility model :

- The Gauss-Markov mobility model is a type of temporal dependency models.
- This models does not assume the node velocities to be random in nature. Instead it assumes that the velocities of single node at different time slots are "correlated".
- Such correlation could be because of the constraint on the mobility of a node due to the physical laws of acceleration, velocity and rate of change of direction. Hence, the current velocity of a mobile node may depend on its previous velocity.
- This mobility characteristic is defined as the temporal dependency of velocity. However the memory less nature of the Random Waypoint Model is not suitable to capture this temporal dependency behavior.
- Therefore various mobility models considering temporal dependency are proposed and Gauss- Markov mobility model is one of the most important of this kind.
- The Gauss-Markov Mobility Model is a widely utilized model. In this model, the velocity of the mobile node is assumed to be correlated over time and it is modeled as a Gauss-Markov stochastic process.
- In a two-dimensional simulation field, represent the Gauss-Markov stochastic process by the following equation :

$$V_t = \alpha V_{t-1} + (1 - \alpha)\sqrt{1 - \alpha^2}\, W_{t-1} \quad ...(1)$$

- In this expression α is the memory level parameter which determines the degree of dependency.
- In other words the value of α determines the degree of randomness of this model.
- Depending on the value of α the following three mobility behaviors are possible :

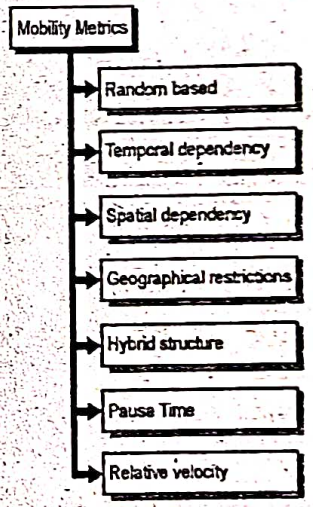
1. A memory less Gauss-Markov model when $\alpha = 0$. Here the velocity of a MN is completely random.
2. The Gauss-Markov Model has strong memory (i.e., $\alpha = 1$). Here the velocity of the mobile node at time slot t is exactly the same as its previous velocity. In the nomenclature of vehicular traffic theory, this model is called the "Fluid Flow Model".
3. The Gauss-Markov Model has some memory (i.e., $0 < \alpha < 1$). Here the velocity in the current time slot is somewhat dependent on both its velocity at time $t - 1$ and the Gaussian random variable W_t. With increase in α, the current velocity is more mainly dependent on its previous velocity. Otherwise, it will be mainly dependent on the Gaussian random variable.

Q. 31 Give the classification of mobility metrics.

Ans. :

Classification of mobility metrics :

- Fig. 5.12 shows the classification of Mobility metrics.



(G-2997)**Fig. 5.12 : Classification of Mobility metrics**

Q. 32 Compare 1 G to 5 G mobile generation. May 19

Ans. :

- Table 5.5 shows the comparison of Various Mobile System Generations.

Table 5.5 : Comparison of Various Mobile System Generations

Sr. No.	Feature	Generation				
		1G	2G	3G	4G	5G
1.	Generation	First	Second	Third	Fourth	Fifth
2.	Year of introduction	1970	1990	2001	2010	2020
3.	Technology	Analog cellular	Digital cellular	Broadband, IP, FDD, TDD	IP-broadband Wi-Fi, MIMO	IPv6
4.	Standard	AMPS	CDMA, TDMA, GSM	CDMA, UMTS, W-CDMA	Wi-Max and LTE	Yet to be finalized
5.	Switching	Circuit	Circuit / Packet	Circuit/Packet	Packet	packet
6.	Frequency band	824-894 MHz	850-1900 MHz	1.6-2.5 GHz	2-8 GHz	15 GHz
7.	Data speed	2.4 kbps	9.6 kbps	2 Mbps	50 Mbps	Higher than 1Gbps
8.	Multiplexing	FDMA	CDMA, TDMA	CDMA	MC-CDMA OFDM	MC-CDMA, LAS-CDMA, OFDM
9.	Core network	PSTN	PSTN	Packet Network	Internet	Internet
10.	Services	Only voice or only message	Digital voice, Data, SMS	High speed data, Voice, Video	Dynamic Information Access.	Interactive multimedia, Voice over IP

Chapter 6 : Performance Analysis Issues

Q. 1 Define network coding.

Ans. :

- Network coding is defined as a networking technique in which transmitted data is encoded and decoded to increase network throughput, reduce delays and make the network more robust.

Q. 2 What are the functions of network coding ?

Ans. :

Functions of network coding :

- Network coding techniques increase immunity of the transmitted signal to radio channel noise frequency fading and multipath spread.
- These techniques also reduce bit errors and frame errors. It is possible to reduce number of requests for retransmission by using specific error detection and correction codes.
- Network coding includes a method of detecting and correcting the errors and ensures safe transfer of information from its source to its destination.
- Error coding is used in many applications for fault tolerant computing.
- In the error control coding a mathematical rule is used to encode the source data bits into longer code words for transmission.
- These "code words" are then decoded at the destination to obtain the original information.
- The extra bits in the code word are known as parity bits or check bits which provide redundancy according to the coding scheme used.
- These extra bits allow the destination to check and correct the errors introduced by the communication medium.
- This reduces the need for data retransmission.

Q. 3 State various applications and challenges of network coding.

Ans. :

Applications :

- Network coding is perceived to be useful in the networks where the same data needs to be transmitted to a number of destination nodes.

- Some of such networks are as follows :
  1. Wireless mesh networks,
  2. Messaging networks,
  3. Storage networks,
  4. Multicast streaming networks,
  5. File-sharing peer-to-peer networks

Challenges :

- The regular topology change occurring in peer-to-peer networks can pose challenges to the network coding technique because it makes the network synchronization more complicated.
- Another challenge posed by the peer-to-peer networks is that the peers may need a large amount of processing time while trying to decode data.

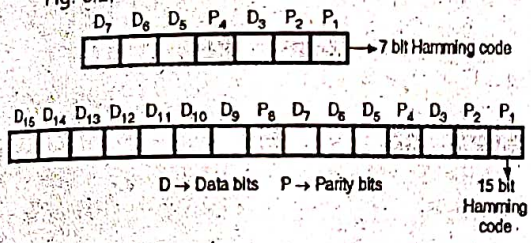
Q. 4 Explain the procedure of encoding in Hamming codes.

Ans. :

- Hamming code is a linear block code. It is an error correcting code.

Hamming code structure :

- Hamming code is basically a linear block code named after its inventor.
- It is an error correcting code. The parity bits are inserted in between the data bits as shown in Fig. 6.1.

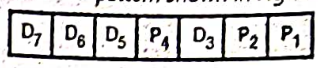


(G-1946) Fig. 6.1 : Hamming code words

- The 7-bit Hamming code is used commonly, but the concept can be extended to any number of bits.
- Note that the parity bits are inserted at each 2^n bit where n = 0, 1, 2, 3 ..... . Thus P_1 is at $2^0 = 1$, i.e. at first bit, P_2 is at $2^2 = 2$ P_4 is as 2^2 and P_8 is at 2^3 as shown in Fig. 6.1.

7-Bit Hamming Code :

1. A scientist named R.W. Hamming developed a coding system which was easy to implement. Assuming that four data bits are to be transmitted, he suggested a code word pattern shown in Fig. 6.2.



(G-1947) Fig. 6.2 : Code word pattern for Hamming code

2. The D bits in Fig. 6.2 are data bits, whereas P bits are parity bits. The parity bits P_1, P_2, P_4 are adjusted in a particular way as explained below.

Minimum number of parity bits :

- Table 6.1(a) gives a listing of minimum number of parity bits needed for various ranges of "m" information bits.

Table 6.1(a) : Number of parity bits to be used

Number of Information bits	Number of parity bits
2 to 4	3
5 to 11	4
12 to 26	5
27 to 57	6
58 to 120	7

Deciding the values of parity bits :

- Table 6.1(b) indicates which bit positions are associated with each parity bit in order to establish required parity (even or odd) over the selected bits positions.

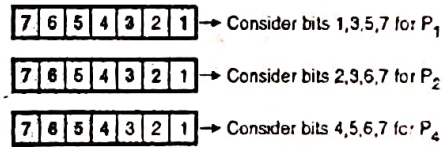
Table 6.1(b)

Parity Bit	Bits to be checked
P_1	1,3,5,7,9,11,13,15,.....
P_2	2,3,6,7,10,11,14,15, ...
P_4	4,5,6,7,12,13,14,15, ...
P_8	8,9,10,11,12,13,14,15, ...

Selection of parity bits :

Selection of P_1 :

- P_1 is adjusted to 0 or 1 so as to establish even parity over bits 1, 3, 5 and 7 i.e. P_1, D_3, D_5 and D_7



(G-2291)

Selection of P_2 :

- P_2 is adjusted to 0 or 1 so as to set even parity over bits 2, 3, 6 and 7 (P_2, D_3, D_6 and D_7).

Selection of P_4 :

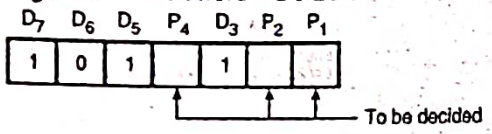
- P_4 is adjusted to 0 or 1 so as to set even parity over bits 4, 5, 6 and 7 (P_4, D_5, D_6 and D_7).
- The selection of parity bits will be clear after solving the following example.

Q. 5 A bit word 1 0 1 1 is to be transmitted. Construct the even parity seven-bit Hamming code for this data.

Ans. :

Step 1 : The code word format :

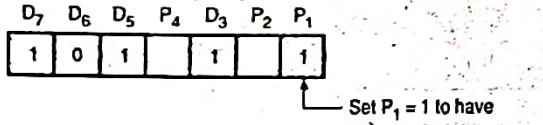
- The seven bit Hamming code format is shown in Fig. 6.3. Given bit word = 1 0 1 1



(G-1948) **Fig. 6.3**

Step 2 : Decide P_1 :

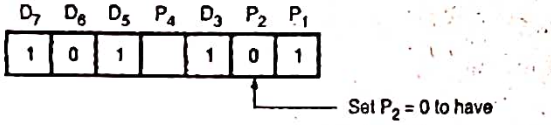
- P_1 sets the parity of bits P_1, D_3, D_5 and D_7. As D_7, D_5, D_3 = 1 1 1 we have to set P_1 = 1 in order to have the even parity.



(G-1949)

Step 3 : Decide P_2 :

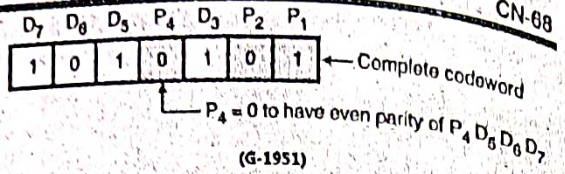
P_2 is set to have the even parity of P_2 D_3 D_6 and D_7. But D_3 D_6 D_7 = 1 0 1 hence set P_2 = 0.



(G-1950)

Step 4 : Decide P_4 :

P_4 is set to have the even parity of P_4 D_5 D_6 and D_7. But D_5 D_6 D_7 = 1 0 1, hence set P_4 = 0.



(G-1951)

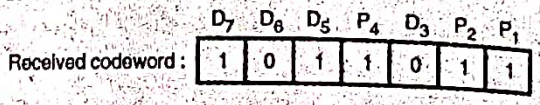
Q. 6 Explain the procedure of decoding in Hamming codes.

Ans. :

- The Hamming coded data is now transmitted. At the receiver it is decoded to get the data back.
- The bits (1, 3, 5,7) , (2, 3, 6,7) and (4, 5, 6,7) are checked for even parity.
- If all the 4-bit groups mentioned above possess the even parity then the received code word is correct i.e. it does not contain errors.
- But if the parity is not even (i.e. it is odd) then error exists. Such an error can be located by forming a three bit number out of the three parity checks. This process becomes clear by solving the example given below.

Q. 7 If the 7-bit Hamming code word received by a receiver is 1 0 1 1 0 1 1. Assuming the even parity state whether the received code word is correct or wrong. If wrong, locate the bit in error.

Ans. :



(G-1957)

Step 1 : Analyze bits 4, 5, 6 and 7 :

P_4 D_5 D_6 D_7 = 1 1 0 1 → Odd parity.

∴ Error exists here.

∴ Put P_4 = 1 in the 4's position of the error word.

Step 2 : Analyze bits 2, 3, 6 and 7 :

∴ P_2 D_3 D_6 D_7 = 1 0 0 1 → Even parity so no error.

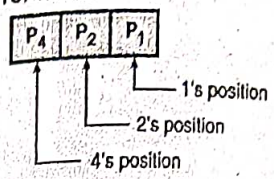
Hence put P_2 = 0 in the 2's position of the error word.

Step 3 : Check the bits 1, 3, 5, 7 :

∴ P_1 D_3 D_5 D_7 = 1 0 1 1 → Odd parity so error exists.

Hence put P_1 = 1 in the 1's position of the error word.

Step 4 : Write the error word :

Error word E = 

(G-1958)

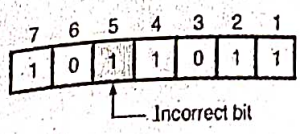
- Substituting the values of P_4 , P_2 and P_1 obtained in steps 1, 2 and 3 we get

$E =$ | 1 | 0 | 1 |

$E = (5)_{10}$

(G-1959)

- Hence bit 5 of the transmitted code word is in error.



(G-1960)

Step 5 : Correct the error :

- Invert the incorrect bit to obtain the correct code word as follows :

Correct code word = [1 0 0 1 0 1 1]

Q. 8 Write a note on : significance of information theory.

Ans. :

Significance of Information Theory :

- Information theory is the scientific study of the quantification, storage, and communication of digital information.
- This field was established by Harry Nyquist and Ralph Hartley, in the 1920s, and Claude Shannon in the 1940s.
- The field of information theory makes use of probability theory, statistics, computer science, statistical mechanics, information engineering, and electrical engineering.
- An important measure in information theory is entropy.
- Entropy quantifies the amount of uncertainty involved in the value of a random variable or the outcome of a random process.
- mutual information, channel capacity, error exponents, and relative entropy are some other important measures in information theory.
- Some of the key sub-fields of information theory are source coding, algorithmic complexity theory, algorithmic information theory and information-theoretic security.

Q. 9 Explain applications of information theory.

Ans. :

1. Data Compression :

- Use Shannon's concept of entropy to determine the maximum theoretical compression for a given message alphabet.
- Compression is possible if the entropy is less than the average length of an encoding.
- With the help of information theory obtain the relative frequency of every English alphabet in the English text.
- Based on this the entropy is calculated which equal to 4.08 bits per character.
- Normally 8 bits per character are used in any common code to represent a character.
- Thus, Shannon's theory shows that there exists an encoding that is roughly twice as efficient as the normal one.
- Later Lempel and Ziv suggested a technique of dynamic compression.
- The dynamic compression has been adapted to optimize the encoding based on particular text.
- Many computer programs use compression techniques based on these ideas.
- In practice, most text files are compressed by about 50 percent.
- They use approximately 4 bits per character which is the number suggested by the entropy calculation.

2. Error Detecting and Correcting Codes :

- Another important application of information theory is in error detecting and correcting codes.
- Shannon's work in the area of discrete, noisy communication indicated towards the possibility of constructing error-correcting codes.

- Error-correcting codes add extra check bits to the data to help correct errors and thus operate in the opposite direction from compression.
- On the other hand, the error -detecting codes only indicate that an error has occurred but do not automatically correct the error.
- Such an error is corrected by an automatic request to retransmit the message.
- The error-correcting codes need more extra bits than error-detecting codes.
- Therefore, in some cases it is more efficient to use an error-detecting code simply to indicate what has to be retransmitted.
- Selection of error-correcting or error-detecting codes depends on factors like, nature of the errors that are likely to occur under the circumstances in which the message is being sent.
- Transmissions with the space vehicles generally use error-correcting codes because retransmissions are difficult due to long distances and low available power.
- Instead it is necessary to employ utmost skill and art to build communication systems that operate at the limits imposed by Shannon's results.

3. Cryptography :

- One more important application of information theory is in the field of cryptography.
- Cryptology is the science of secure communication. It consists of both cryptanalysis and cryptography.
- Cryptanalysis is the study of how encrypted information is revealed (or decrypted) when the secret "key" is unknown.
- Whereas, cryptography is the study of how information is concealed and encrypted.
- Shannon's analysis of communication codes led him to apply the mathematical tools of information theory to cryptography in "Communication Theory of Secrecy Systems" (1949).
- He noted from his analysis of simple transposition ciphers that they do not affect the entropy of the source.
- Cryptographic systems make use of special information called a key to encrypt and decrypt messages.
- Some systems use different keys for the encoding and decoding, while some other systems use same key for both processes.
- Shannon made a general observation : "the amount of uncertainty introduce into the solution cannot be greater than the key uncertainty."
- This means, that random keys should be selected to make the encryption more secure.
- While Shannon's work did not lead to new practical encryption schemes, he provided a framework to understand the essential features of any such system.

Q. 10 Explain use of power control to suppress interferences in cellular networks.

Ans. :

Use of power control :

- Signals from mobile stations operating in a coverage area of a BS cause interference to other MSs operating in the same.
- Such interference can be reduced by monitoring and controlling the power transmitted by the mobile stations. This is known as the power control. Power control also helps to increase the battery life of MSs.
- Thus it is necessary for the wireless network to monitor the radio resources, signal strength, and other associated information about communication between an MSs and BSs to control power and reduce interference.
- Power control is defined as the algorithms, protocols and techniques used in cellular networks to control the power transmitted by MSs and BS in order to reduce various interferences.
- This not only reduces interference but also enhances the battery life of MSs.
- Transmit power control Increases the Signal to Interference Ratio (SIR) thereby improving the quality of communication.
- It also improves the system capacity.

Q. 11 Explain the concept of open loop power control and state its disadvantages.

Ans. :

Open loop power control :

- The open loop power control is generally employed on the uplink or reverse link i.e. the link from MS to BS.
- The open-loop power control does not consider any feedback from the BS to control power at MS.
- Thus, open loop power control is entirely dependent on the mobile unit.
- The open-loop control is simple to achieve but it is not as accurate as close-loop control.
- The open-loop power control also can react quickly to any fluctuations in signal strength.
- The powers transmitted by the MS and BS change dynamically due to many factors such as velocity of mobile, fading, and distance between MS and BS. For exercising power control the MS measures the received signal strength (RSS), quality of the reference channel from BS and BER frames.
- The MS will reduce its transmit power if the RSS or BER are above certain thresholds. The MS would increase its transmitted if RSS or BER are below certain thresholds.

Disadvantages of open loop power control :

- Some of the major disadvantages of open loop power control are :
  1. The power control decision depends on the measurement RSS and signal on the reference channel of the downlink
  2. Due to the delay between BS and MS, the power control is implemented after a significant delay
  3. The uplink and downlink channels are usually not correlated. This may introduce errors in power control.
  4. In TDMA systems, the MS receives and transmits on different time slots. Therefore, a time lag is introduced in implementing the open loop power control.

Q. 12 Explain the concept of closed loop power control and state its advantages.

Ans. :

Closed loop power control :

- In the closed-loop power control technique the signal in reverse channel is adjusted based on metric of performance.
- The BS makes the decision about power adjustment of MS and communicates it to MS on control channel.
- Closed loop power control implements a feedback mechanism between the BS and MS to eliminate the disadvantage of open loop power control.
- In closed loop power control, the BS measures the quality of received signal from MS and instructs the MS of the actions to be taken via control signaling on the downlink channel.
- It is also possible to use the closed loop power control to adjust the transmitted power of the BS.

Advantages of closed loop power control :

1. The delay in implementation of power control is minimal
2. The errors introduced in the power control are extremely low
3. It improves the quality of power control and reduces interference

Q. 13 Discuss various power saving mechanisms.

Ans. :

Power saving mechanisms :

- In addition to the interference suppression, the power control can be exercised to reduce the power consumption of MSs and enhance their battery life.
- Power saving mechanisms achieves this goal by making a MS operate in suspended or semi-suspended mode of operation.
- The transmission mode consumes the highest amount of power while reception mode consumes the second highest power.
- The standby mode consumes the least amount of power.
- The wireless network can be designed to ensure that the mobile stations spend most of the time either in standby or sleep mode in order to save power.

- Another technique of saving power is to employ discontinuous transmission is mostly employed in cellular telephone networks.
- Use sleep mode for saving battery power of MS when it is inactive.

Q. 14 State different MAC protocol issues.

Ans. :

Different MAC protocol issues :

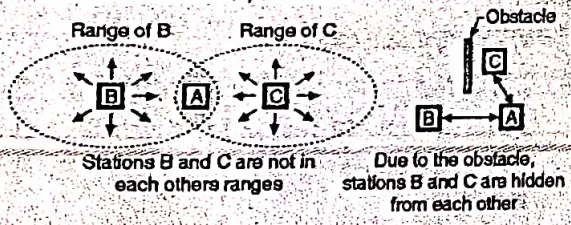
1. Hidden terminal problem
2. Reliability
3. Collision avoidance
4. Congestion avoidance
5. Congestion control
6. Energy efficiency.

Q. 15 Explain the hidden station problem.

Ans. :

Hidden station problem :

- The hidden station problem occurs when a station may not be aware that some other station is transmitting because of either range problem or some obstacle.
- In this situation collision may occur but may not be detected. The hidden station problem is illustrated in Fig. 6.4. Refer Fig. 6.4(a) which shows three wireless stations A, B and C.



(G-2098) Fig. 6.4 : Hidden station problem

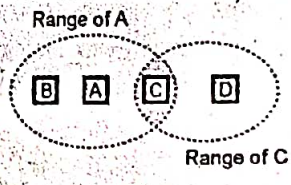
- The transmission ranges of stations-B and C have been shown by the two ovals on left and right respectively which shows that station-C is not in the range of B and B is not in the range of C.
- However station-A is in the range of both B and C. So A can hear signals transmitted by B and C. Refer Fig. 6.4(a) where station-B is transmitting to station A.
- Now if station-C checks the medium to see if anyone is transmitting, it will not hear station B because it is out of range.
- So station-C will come to a wrong conclusion that no one is transmitting and so it can start transmitting to station A.
- If station-C starts transmitting, it will create a collision at station-A and will wipe out the frames from station-B.
- This problem in which a station is not able to detect an already transmitting other station which is too far away is called as the hidden station problem.
- In this example it is said that stations-B and C are hidden from each other with respect to station-A.
- Now consider Fig. 6.4(b) which shows the hidden station problem occurring due to an obstacle.
- Due to hidden station problem, the possibility of collision increases and the capacity network will reduce.

Q. 16 Explain the exposed station problem.

Ans. :

Exposed station problem :

- The exposed station problem is a similar problem.
- In this problem, a station refrains from using the common medium even when no other station is using it (i.e. the channel is actually free).
- In order to understand this concept clearly, refer Fig. 6.5 where A is the sending station and B is the destination.
- A is sending data to B. Station C wants to send its data to station D and it is possible to do so without interfering in the communication between A and B.
- As shown in Fig. 6.5, station C is in the range of station A. In other words C is exposed to A.



(O-918) Fig. 6.5 : Exposed station problem

- Therefore C listens to what A is transmitting and decides to refrain itself from sending its message to D. This causes wastage of channel capacity.

Q. 17 Describe the operation of RTS-CTS messages.

Ans. :

Operation of RTS-CTS messages :

- IEEE 802.11 MAC addresses the hidden station problem by adding two additional frames, the RTS (request to send) and CTS (clear to send).
- Here, the source sends a RTS and the destination replies with a CTS.
- The other nodes that overhear the RTS and CTS messages will suspend their transmissions for a certain time period indicated in the RTS/CTS frames.
- The source station retransmits the RTS frame if the RTS/CTS handshake fails.
- The system treats this as a collision and retransmission occurs as per rules.
- For avoiding faulty consecutive retransmissions, the retry counters and timers are employed to limit the lifetime of a frame.

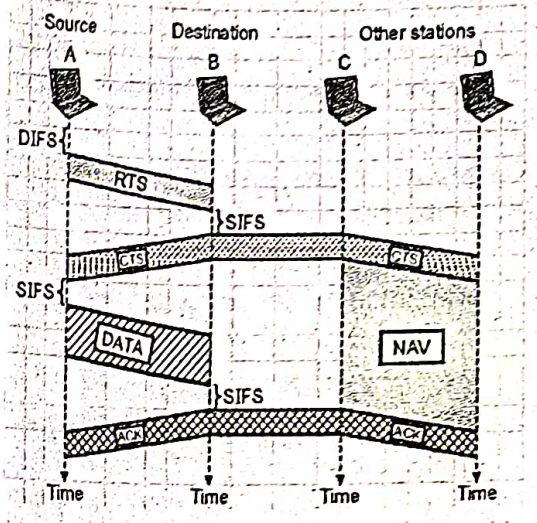
Q. 18 Write a note on DCF.

Ans. :

- The access method used by DCF is CSMA/CA.

Frame exchange time line :

- The exchange of control and data frames with time has been shown Fig. 6.6.
- We assume that there are four wireless stations A, B, C and D present in a wireless LAN. A is a source and B is the destination.
- Therefore C and D are referred to as other stations.
- The sequence of control and data exchange is as follows :
  1. The source station A senses the medium for its idleness before sending a frame. It does the media sensing by checking the energy level at the carrier frequency.
     (a) A persistence strategy is used with back of until the channel is found to be idle.
     (b) Once the channel is found to be idle, the source station A waits for a specific amount of time called as the Distributed Interframe Space (DIFS).
- After this waiting time the station A sends a control frame called as Request to Send (RTS) as shown in Fig. 6.6.



(G-2100) **Fig. 6.6 : CSMA/CA and NAV**

  2. After receiving the RTS, the destination station B waits for a specific amount of time called the Short Interframe Space (SIFS) and then sends a control frame Clear to Send (CTS) back to the source station A. The CTS frame is an indication that the destination station is ready for receiving the data.
  3. The source station receives the CTS frame, waits for a duration of SIFS and then sends the data to the destination station.
  4. The destination station receives the data, waits for a duration of SIFS and sends the acknowledgement (ACK) frame to indicate that it has received the data frame.
- Note that in the CSMA/CA protocol, the acknowledgement (ACK) is needed because otherwise the source station does not have any means to know that the data has been received by the destination station.
- In CSMA/CD the ACK is not needed because the lack of collision itself is treated as an acknowledgement of data being received successfully.

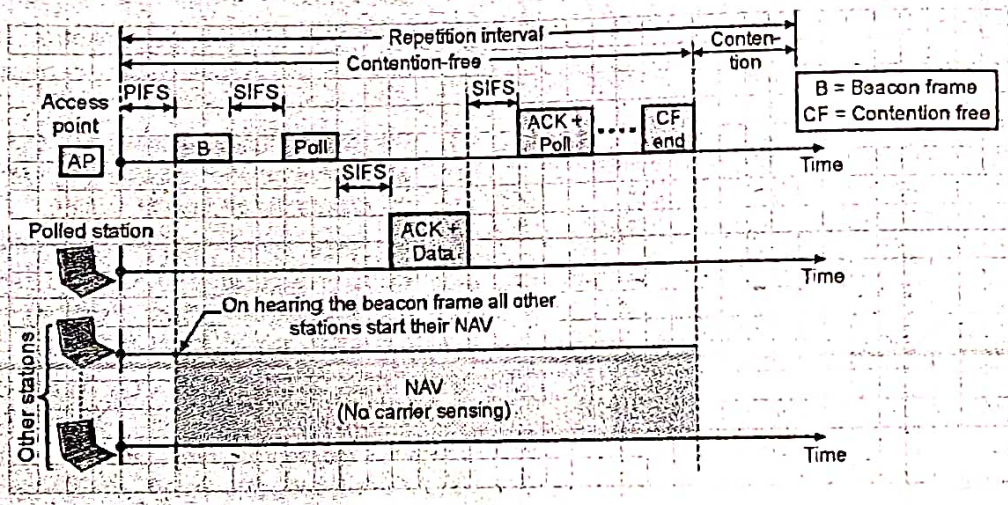
Q. 19 Write a note on PDF.

Ans. :

- An optional access method which can be implemented in the infrastructure network

(a wireless LAN with AP) but not in the ad-hoc network (WLAN without and AP) is called as the Point Co-ordination Function (PDF).

- Note that the PCF is implemented on top of the DCF and used mostly for those applications that are time sensitive.
- The access method used by PCF is the centralized, contention free polling access method.
- The polling for stations that can be polled is performed by the A.P. These stations when polled in a sequential manner will send their data to AP on one by one basis.
- One more interframe space called PIFS has been defined to give priority to PCF over DCF. This inteframe space PIFS (PCF IFS) is shorter than DIFS.
- The meaning of this arrangement is that if at the same time, a station wants to use DCF and an AP wants to use PCF, then the priority will be given to the AP.
- But the effect of this higher priority of PCF over DCF, is that the stations using DCF may never get the access to the common medium.
- But this should be avoided. Hence a repetition interval has been designed in order to cover the PCF (contention-free) as well as DCF (contention-based) traffic.
- The repetition interval always starts with a special type of frame called beacon frame as shown in Fig. 6.7.
- The repetition frame is repeated continuously. As shown in Fig. 6.7, on hearing the beacon frame, the stations start their NAV for the duration of the contention free period of repetition interval.
- An example of repetition interval has been shown in Fig. 6.7.



(G-2101) **Fig. 6.7 : Example of repetition interval**

- The PC (Point controller) can perform the following operations or any combination of them, during the repetition interval.
- 802.11 uses the concept of piggybacking. The PC (point controller) sends a CF end (contention - free end) frame at the end of the contention free period, so that the contention based (DCF traffic) stations can use the common medium.

Note