Chapter 1 : Introduction to Wireless Communication Systems 1-1 to 1-38

Syllabus : Evolution of mobile communications, Mobile Radio System around the world, Types of Wireless communication System, Comparison of Common wireless system, Trend in Cellular radio and personal communication. Second generation Cellular Networks, Third Generation (3G) Wireless Networks, Wireless Local Loop(WLL), Wireless Local Area network (WLAN), Bluetooth and Personal Area Networks.

Chapter 2 : The Cellular Concept 2-1 to 2-42

Syllabus : The Cellular Concept : System Design Fundamentals : Cellular system, Hexagonal geometry cell and concept of frequency reuse, Channel Assignment Strategies, Distance to frequency reuse ratio, Channel and co-channel interference reduction factor, S/I ratio consideration and calculation for Minimum

Co-channel and adjacent interference, Handoff Strategies, Umbrella Cell Concept, Trunking and Grade of Service, Improving Coverage and Capacity in Cellular System-Cell splitting, Cell sectorization, Repeaters, Micro cell zone concept, Channel antenna system design considerations.

Chapter 1

Introduction to Wireless Communication Systems

Syllabus

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Chapter Contents

1.1 Introduction :

- In 1897 the wireless communication system came into existence and then after it evolved remarkably.
- Throughout the world new wireless systems have been developed by people and companies.
- During the past ten years the mobile radio communication industry has grown up.
- The reason behind the development of wireless systems is great improvement in the digital and RF fabrication technology, large scale circuit integration etc. which results in making portable radio equipment reliable, smaller and cheaper.
- Now a days it becomes very easy to use affordable radio communication networks due to the digital switching techniques.

1.1.1 Wireless Communication :

Definition :

- 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.
- 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.
- Wireless communication is the fastest growing part of electronic communication.
- Wireless communication began with Hertz first experiment on radio in 1887.
- Then Marconi communicated across the English channel in 1899 and across the Atlantic ocean in 1901.
- The early radio transmitter were too bulky to be installed in vehicles.
- The first mobile radio system for police department was one way with only receiver in the police car.
- World war II provided a major breakthrough in the development of mobile and portable radio systems including the two way systems called as Walkie-talkies.
- In the post war era the branch of mobile communication grew at the fastest rate.
- In the wireless communication systems, the signal energy propagates in the form of electromagnetic waves over the wireless media or wireless channels.
- The examples of wireless media are radio waves, microwave and infrared light.
- The wireless media does not use a conductor or wire as a communication channel. Instead it uses the air or vacuum as medium to carry the information from transmitter to receiver.
- The transmitter first converts the data signal into electromagnetic waves and transmits them using a suitable antenna.
- The receiver receives the electromagnetic waves using a receiving antenna and converts them into data signal again.

1.1.2 Need of Wireless Communication :

- The communication systems can be classified into two broad categories as :
  1. Wired or guided communication systems.
  2. Wireless or unguided communication systems.
- The wired communication systems such as conventional telephone system use some kind of wired media such as coaxial cable or optical fiber cable to inter connect its end users.
- The **wireless systems** do not use wires as the transmission media.
- Instead air acts as the communication medium and communication takes place using electromagnetic (EM) waves.
- Examples of wireless communication systems are : Satellite communication, mobile phones, wireless LAN and WAN, etc.

- 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 we can avoid wiring and improve reliability.

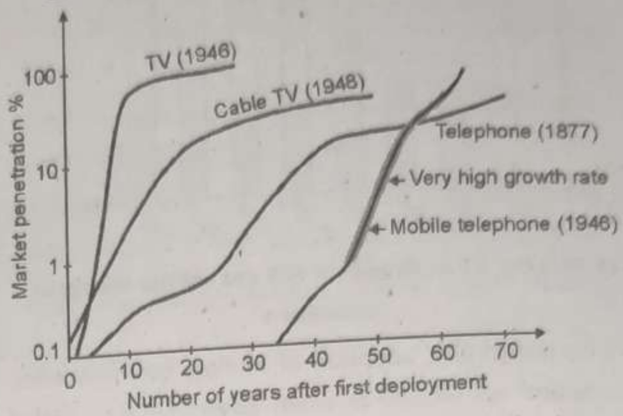
1.2 Evolution of Mobile Communications :

GTU : S-16

University Questions

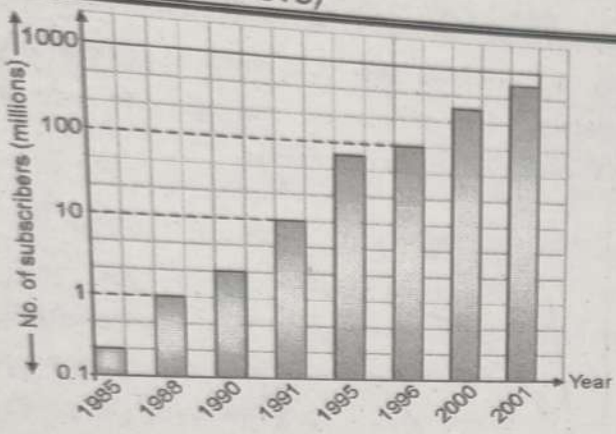
Q. 1 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

- The wireless communication field is growing very rapidly due to the development in the technologies.
- In past the growth of mobile communication was slow because it is dependent on the technological improvements which was poor in past days.
- The Bell Laboratories developed the concept of cellular mobile communication in 1960 s and 1970 s.
- Now the technologies of 1970s have matured resulting the exponential growth of mobile communication.
- The future growth of consumer-based mobile and portable communication systems are connected to the regulatory decisions and allocation of radio frequency spectrum.
- Fig. 1.2.1 shows the comparison of how mobile telephony has penetrated our daily life with other 20th century popular inventions.



(G-2541) **Fig. 1.2.1 : Growth of mobile telephony**

- Fig. 1.2.1 is a graph of number of years after the first commercial deployment versus percentage of market penetration.
- From Fig. 1.2.1 it is clear that the first 35 years of mobile telephony has less market penetration due to involved technological challenges and high cost.
- Consumers accepted wireless communications in the past decade at rates comparable to the video cassette recorder and television.
- In 1935 Edwin Armstrong demonstrated the frequency modulation (FM) and all over the world. FM was adopted as Modulation Technique.
- In the years to come it is expected by consumer that increasingly they use wireless service as their sole telephony access method.
- It is observed that, since the mid 1990s, the wireless communication networks has explosive growth in communication industry.
- Fig. 1.2.2 shows growth of PCS and cellular telephone subscribers throughout the world.
- As shown in Fig. 1.2.2 in 2001 the worldwide cellular and personal communication subscriber crossed 600 million users and by 2006 the number of individual subscribers is projected to reach 2 billion i.e. almost 30% of the world's population ?



(G-2542) Fig. 1.2.2 : Growth of PCS and cellular telephone subscribers

- In mid 1990's, adoption of wireless communication speed up worldwide when governments provided increased competition and licenses for new radio spectrum for PCS (Personal Communication System) throughout the world in the frequency band of 1800-2000 MHz.

1.3 Mobile Radiotelephony in the U.S. :

- In the U.S. the first public mobile telephone service was introduced in the year 1946.
- This service was made available in 25 cities of the U.S.
- The mobile system in each city used a single transmitter with a large output power and a large tower for covering a distance of up to 50 km.
- In the late 1940s, a push -to-talk telephone system was being used.
- It was an EM based half duplex system, with a bandwidth of 120kHz.
- Such a high bandwidth was required to transmit a voice grade signal of 3 kHz bandwidth.
- In 1950s, the FCC decided to double the number of mobile phone channels, keeping the spectrum allocation of 120 kHz unchanged.
- Thus each channel occupied spectrum of 60kHz only.
- By the 1960s, the bandwidth of each EM voice channel was reduced to 30 kHz from 60 KHz.
- Thus from 1946 to 1960, the EM voice channel bandwidth reduced by only a factor of four, due to technological advances.
- In 1950s and 1960s, the telephone companies introduced **automatic channel trunking** and implemented it under the name IMTS (Improved Mobile Telephone Service).
- But IMTS got saturated in the main markets very soon.
- In 1970s, the major telephone companies had only twelve channels and could provide service to only 570 customers in a market of 1 million potential subscribers.
- On top of that, this service was of very poor quality due to call drops and call blocking.

1.3.1 Cellular Radiotelephony :

- During the 1950s and 1960s many telephone companies including AT&T Bell laboratories developed the theory and technique of **cellular radiotelephony.**
- It was a concept of breaking (dividing) a large coverage zone (market) in smaller cells.
- Each small cell could **reuse** a portion of all tech spectrum.
- This would increase the spectrum Usage and spectrum efficiency but increase the infrastructure requirement.
- This concept made the use of the same spectrum Possible in the cells that are physically apart by large distances.
- The same spectrum is reused only when there is a sufficient distance between the cells to avoid any interference.
- In cellular telephony, the same channels (frequency bands can be reused within the same service area or market.
- The concept of **cellular mobile system** was first proposed by AT ST to FCC in 1968, but the technology was not implemented until late 1970s.

1.3.2 AMPS :

Specifications

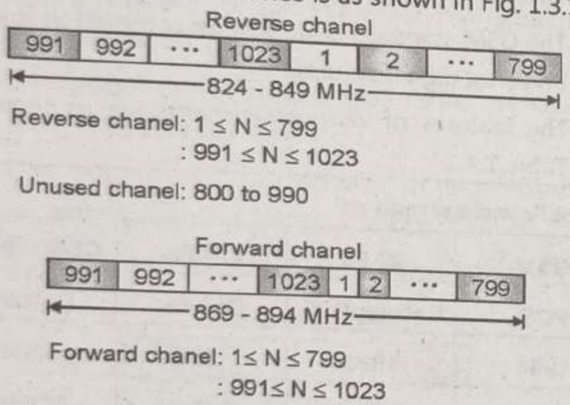
- In 1983, the FCC finally allocated the spectrum to the **Advanced Mobile Phone System (AMPS)**, with the following specifications :

1. No. of duplex channels : 666
2. Spectrum width : 40 MHz
3. Band : 800 MHz band.
4. One way B.W. of each channel : 30 kHz.
5. Total two way B.W. of each channel : 60 kHz.

- FCC instructed to have only two system providers in each market and the radio channels were split equally between the two carriers.
- Thus AMPS is the first U.S. cellular system. An additional 166 channels with 10 MHz additional spectrum was granted by FCC, to the U.S. service providers to cater for the rapid increase in the demand.

1.3.3 Spectrum Allocated to the U.S. Cellular Radio Service :

- The spectrum that is currently allocated for the cellular telephone service is as shown in Fig. 1.3.1.



(G-2620) Fig. 1.3.1 : Frequency spectrum allocation for the U.S. cellular radio service

- Any cellular radio system operates in an interference limited environment.
- It makes use of the **frequency reuse** technique and FDMA (Frequency Division Multiple Access) for maximizing the system capacity.

1.3.4 Digital Cellular Telephony :

- The system hardware for first US digital cellular (USDC) system was installed in the year 1991 in a few major U.S. cities.
- Due to the USDC standard, it was possible for the operators to replace some analog channels by digital channels digital channel can support three users in the same bandwidth of 30 kHz allotted to an analog channel.
- Thus USDC could improve the capacity of AMPS by factor of 3.
- With increase in the number of digital handset users, FCC gradually phased out AMPS.
- The three fold improvement in system capacity offered by USDC was possible due to the use of the digital modulation called $\frac{\pi}{4}$ DQPSK, speech coding and TDMA.
- Very soon, this capacity was increased six folds i.e. six users in 30 kHz bandwidth due to advancement in DSP and speech coding technologies.

1.3.5 CDMA Based Systems :

- The interim standard IS-95 was developed by Qualcomm, Inc and standardized by TIA for a cellular system based on CDMA (Code Division Multiple Access).
- The IS-95 system was designed to allow a variable number of users in a channel of B.W. 1.25 MHz, using the direct sequence spread spectrum technique.
- Because of the spread spectrum technique, the CDMA systems can operate at much higher interference levels as compared to AMPS which is based on FM/FDMA.
- CDMA systems can work satisfactorily at much smaller values of S/N ratios.
- Therefore it is possible to use the same set of frequencies in every cell.
- Therefore the system capacity of CDMA systems is high.
- A new specialized mobile radio service (SMR) was developed in early 1990s to compete with the cellular radio carriers in the U.S.
- Motorola and Nextel formed an extended SMR (E-SMR) network to provide services and capacity similar to cellular.
- The E-SMR network used the 800 MHz band.

- SMR used Motorola's integrated radio system (MIRS) to integrate the following services on the same network.
  1. Voice related services.
  2. Cellular phone service
  3. Messaging
  4. Data transmission.
- Later on (in 1995), the MIRS was replaced with **iDen** (Integrated Digital Enhanced Network).
- In 1995, the U.S. government auctioned the spectrum in the 1800/1900 MHz band for the Personal Communication Service (PCS) licenses.

1.4 Mobile Radio Systems Around the World :

- A number of mobile radio standards have been developed for wireless systems throughout the world till date and many more will be developed in the years to come.
- Some of the important ones are :

  1. AMPS 2. NAMPS 3. IS-95
  4. GSM 5. UMTS 6. CDMA 2000
- All these mobile standards are developed in North America.
- In 1979 a Japanese company named Nippon Telephone and Telegraph Company (NTT) implemented the world's first cellular telephone system.
- The European Total Access Cellular System (ETACS) was deployed in 1985.
- The American system AMPs was almost identical to ETACS.
- The earlier European systems were not compatible to one another because of different frequencies used and different communication protocols being used by them.
- These systems are being replaced by the GSM (Global System for Mobile) system now.
- This system was developed in 1990 for the entire Europe in a new 900 MHz band.
- The GSM standard is worldwide accepted as the first universal digital system.
- The features of various standards are as shown in Table 1.4.1.

Table 1.4.1 : Features of various mobile radio standards

Sr. No.	Feature / Standard	AMPS	NAMPS	GSM	IS-95	UMTS	CDMA 2000
1.	Type	Cellular	Cellular	PCS	Cellular/PCS	Cellular	Cellular
2.	Introduced in the year	1983	1992	1994	1993	1999	1999
3.	Multiple Access Method	FDMA	FDMA	TDMA	CDMA	CDMA	CDMA
4.	Type of Modulation	FM	FM	GMSK	QPSK/BPSK	QPSK	QPSK/BPSK
5.	Frequency band used	824-894 MHz	824-894 MHz	1.85-1.99 GHz	824-894 MHz 1.82 GHz	850-900 MHz 1.8-2.1 GHz	450-850 MHz 1.7-2.1 GHz
6.	Channel bandwidth	10 kHz	10 kHz	200 kHz	1.25 MHz	5 MHz	1.25 MHz

- Some of the key words used in Table 1.4.1 are as follows :

  PCS = Personal Communication Services

  FDMA = Frequency Division Multiple Access

  TDMA = Time Division Multiple Access

  CDMA = Code Division Multiple Access

  BPSK = Binary Phase Shift Keying

  QPSK = Quadrature PSK

1.4.1 AMPS :

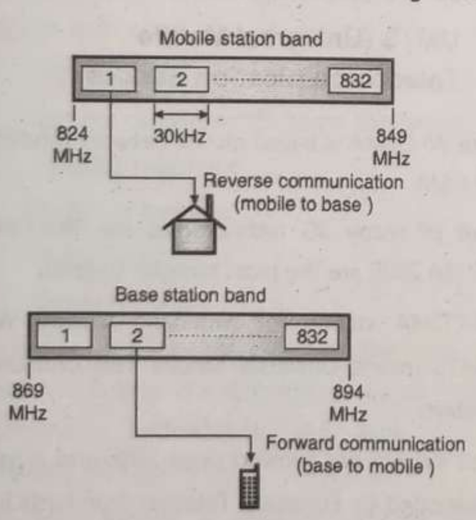
- Long form of AMPS is Advanced Mobile Phone System.
- It is one of the leading analog cellular system in North America.
- It makes use of FDMA (Frequency Division Multiple Access) to separate channels in a link.

Frequency bands :

- AMPS uses the ISM 800-MHz band for its operation.
- It uses two separate channels for forward i.e. base station to mobile station and for reverse i.e. from mobile station to base station communication.
- The frequency bands allotted for the forward and reverse communication are as follows :
- Reverse Communication : 824 MHz to 849 MHz.
- Forward Communication : 869 MHz to 894 MHz.
- Each band has been divided into 832 channels. But two providers are allowed to share an area.
- That each provider is allowed to use 416 channels in each cell.
- Out of 416, 21 channels are used for control and the remaining 395 channels for information.

Transmission :

- AMPS makes use of FSK and FM systems for modulation.
- FM stands for frequency modulation while FSK is frequency shift keying.
- FM is used for the modulation of voice signals whereas FSK is used for the control channels.
- Cellular bands for AMPS are shown in Fig. 1.4.1.



(G-1416)**Fig. 1.4.1 : Cellular bands for AMPS**

Specification of AMPS :

- Some of the important specifications/features of AMPS system is as given in Table 1.4.2.

Table 1.4.2 : Specifications of AMPS

Sr. No.	Feature / Specification	Value / Description
1.	Reverse channel frequency	824-849 MHz
2.	Forward channel frequency	869-894 MHz
3.	Multiplexing	FDMA
4.	Channel bandwidth	30 kHz
5.	Modulation	FM
6.	Number of channels	832
7.	Spectral efficiency	0.33 bps/Hz
8.	Data transmission rate	10 kbps
9.	Duplexing technique	Frequency division duplex (FDD)
10.	Switching	Circuit

1.4.2 Narrowband-AMPS (N-AMPS) :

- With the help of FDMA and 10 kHz channel bandwidth N-AMPS provides access to three mobile subscribers in a 30 kHz bandwidth which results in three times increment in the capacity of user.
- For the existing AMPS channel one N-AMPS channel uses the carrier frequency and with remaining two channels the carrier frequencies are offset by ± 10 kHz.
- In narrowband-AMPS the FM deviation is reduced. Each sub channel having bandwidth 10 kHz is able to handle its own voice calls.
- As the channel bandwidth reduces, it degrades the quality of speech by reducing signal to interference ratio.
- Voice channels becomes more vulnerable to interference with narrow bandwidths.
- Similar to AMPS, N-AMPS uses ST and SAT signaling and blank and burst data signaling.
- In N-AMPS, signaling is called as DSAT and DST because SAT and ST signaling is sent by using a continuous 200 bps NRZ encoded FSK data.
- The binary inverse of the DSAT signal is DST signal.

- In short pre-defined code blocks DST and DSAT data signals are transmitted repetitively and digitally.
- In N-AMPS, there are seven 24 bit DSAT code words which can be selected by the MTSO.
- During a call both the mobile subscriber and best station repeat the DSAT code constantly.
- To provide a sufficient number of alternating 0's and 1's the seven DST and DSAT signals are designed.
- Because of this receiver can implement dc blocking conveniently.
- By using high pass filter of 300 Hz for every voice channel without blanking the voice DSAT and DST signaling data is transmitted.
- If the voice channel is busy, with 100 bps Manchester encoded FSK data signaling of the voice channel is carried out and in place of DSAT data is transmitted.
- As the AMPS is wideband signaling there are number of messages which can be passed between the base and subscriber unit.
- Using the same BCH codes in AMPS these messages are transmitted in Narrowband-AMPS (N-AMPS) on the forward voice channel with the format of a 40 bit blocks and on the reverse voice channel with a 48 bit blocks.
- For call setup and call termination N-AMPS system uses standard AMPS control channels.

1.4.3 CDMA IS-95 :

- IS – 95 stands for Interim Standard 95. It is a CDMA based system developed in United States.
- The IS-95 system has been designed to be compatible with the existing US analog cellular system (AMPS) frequency **band**.
- In IS-95 each user within a cell is allowed to use the same radio channel and the users in the adjacent cells also use the same radio channel because this system uses the direct sequence spread spectrum CDMA.
- The users data rate changes in real time. It depends on the voice activity and requirements of the network.
- IS-95 uses different modulation and spreading techniques for the forward and reverse links in order to avoid interference.

1.4.4 GSM (Global System for Mobile Communications) :

- The long form of **GSM** is global system for mobile communications, it is a digital mobile system and it uses **TDMA** for multiple access.
- A European group called CEPT began to develop the GSM-TDMA system in 1982.
- The first GSM system was implemented in Germany in 1992. It was named as D_2.
- GSM is a second generation cellular system standard.
- It was developed in order to solve the fragmentation problems of the first generation cellular systems.
- GSM is the world's first cellular system to specify the digital modulations.
- It was first deployed in Finland in December 1991. By the mid-2010s, it achieved over 90% market share, and started operating in over 193 countries.
- The GSM standard originally described a digital, circuit-switched network optimized for full duplex voice telephony.

1.4.5 UMTS (Universal Mobile Telecommunication Service) :

- The W-CDMA is based on the network fundamentals of GSM.
- Out of many 3G technologies the W-CDMA and CDMA 2000 are the most popular systems.
- W-CDMA stands for wideband CDMA. Whereas UMTS means Universal Mobile Telecommunication System.
- This system has evolved since 1996 and it has been developed by European Telecom Standards Institute (ETSI) and European carriers, manufactures, government regulators, collectively.
- UMTS in 1998 was submitted to ITU for consideration as a world standard and it was named as IMT-2000.

- UMTS or W-CDMA is designed to have a backward compatibility with the second generation systems such as GSM, IS-136 and PDC TDMA technologies as well as the 2.5G TDMA systems.

1.4.6 CDMA 2000 :

- The CDMA 2000 is updated technology of 2G and 2.5G CDMA technology.
- As compared to 2G and 2.5G systems, 3G systems supports much higher data rates.
- CDMA 2000 provides high data rate internet access in existing systems.
- The standards of CDMA 2000 are based on IS-95, IS-95 A and 2.5G IS-95 B standards.
- CDMA 2000 is designed for forward and backward compatibility in mobile phones.
- The existing CDMA operators can add the improved capabilities of 3G CDMA 2000 at each cell.
- This is an advantage over the W-CDMA system.
- There is no need to change the base stations entirely is an advantage of 3G CDMA 2000.

1.5 Examples of Wireless Communication Systems :

- We are familiar with a large number of mobile radio systems such as :
  1. Garage door openers
  2. Remote controllers for home appliances
  3. Cordless telephone
  4. Pagers or beepers
  5. Walky-Talky
  6. Cellular phones
- Each one of them are called as the mobile radio system but they are different as far as their cost, complexity, performance and type of service provided are concerned.
- The term **mobile** is used to indicate any radio terminal that can move during the operation at a rapid speed.
- The term **portable** is used for a radio terminal which can be handheld and used by a person who is walking i.e not moving too fast.
- **Subscriber** is the term used to define a mobile or portable user and the communication device of each subscriber is called as **subscriber unit**.
- **Users** or **mobiles** are the terms used for describing a group of users in a wireless system.

1.5.1 Important Definitions :

GTU : W-15, S-17, S-18, S-19, W-19

University Questions

Q. 1 Define the following terms regarding wireless communication:

1. Control channel 2. Half duplex channel
3. Base station 4. Mobile Switching Center
5. Simplex systems 6. Full duplex systems
7. Reverse channel **(W-15, 7 Marks)**

Q. 2 Define following tems :

1. Forward Channel 2. Reverse Channel
3. Control Channel 4. Paging System
5. Hand-off 6. Base Station
7. Full Duplex Systems **(S-17, 7 Marks)**

Q. 3 Define: Control Channel, Forward Channel, Reverse Channel, Roamer. **(S-18, 4 Marks)**

Q. 4 Define :

1. Control Channel
2. Mobile Switching Center
3. Full Duplex Systems **(S-19, 3 Marks)**

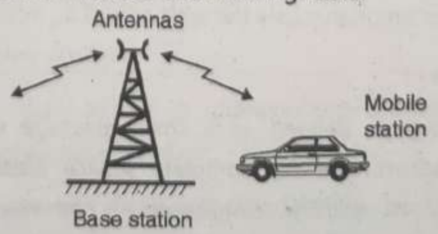
Q. 5 Define the following terms regarding wireless communication:

1. Full duplex channel
2. Mobile Switching Center
3. Base station **(W-19, 3 Marks)**

- Following are some of the important definitions of terms used in wireless communication systems.

1. Base station :

- It is defined as a fixed (non-moving) station in a mobile radio system, which communicates with the mobile stations as shown in Fig. 1.5.1.



(G-1556) **Fig. 1.5.1 : Base station**

- Base stations are located at the center or on the edge of a region being covered.
- It consists of transmitter antenna, receiver antenna and radio channels mounted on a tower.

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.

6. Hand-off :

- It is the process of transferring the connection with a mobile station from one base station to the other when the mobile station moves from the service area of one base station into that of the other.

7. Mobile switching center (MSC or MTSO) :

- It is defined as the center which is set up for coordinating the routing of calls.
- An MSC is also called as MTSO i.e. mobile telephone switching office.

8. Transceiver :

- It is a unit containing transmitter as well as receiver. It can simultaneously transmit as well as receive.

9. Page :

- A page is defined as a small message which is broadcast over the complete service area, in the simulcast manner, simultaneously by many base stations.

10. Roamer :

- A roamer is a mobile station which operates in a service area other than the one from where the service has been subscribed.

11. Subscriber :

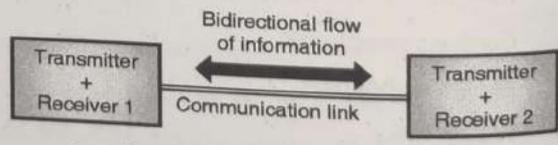
- We may define a subscriber as a user of a mobile communication system, who pays the subscription charges.

12. Half duplex system :

- A half duplex system is a bidirectional system i.e. it can transmit as well as receive but not simultaneously.
- At a time these systems can either transmit or receive, for example a transreceiver or walky talky set.
- The direction of communication will keep changing itself.

13. Full duplex systems :

- The full duplex systems are the truly bidirectional systems which allow the communication to take place in both the directions simultaneously.
- These systems can transmit as well as receive simultaneously, for example the telephone systems.
- The majority of electronic communication systems however are duplex in nature.
- The best example of full duplex communication system is the telephone system.
- Fig. 1.5.2 illustrates the concept of duplex communication.



(D-5) **Fig. 1.5.2 : Duplex communication**

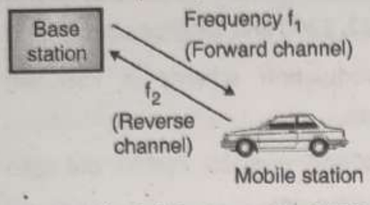
14. Simplex systems :

- The communication systems in which the information is communicated in only one direction are known as simplex systems.

15. FDD and TDD :

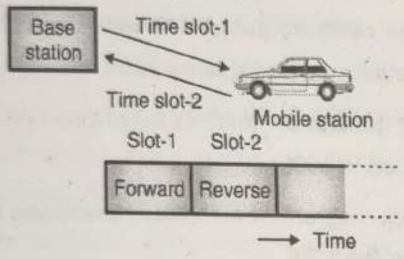
- In the full duplex systems simultaneous communication takes place between the base station and subscriber.
- This can be achieved by providing two simultaneous but separate channels operating at different frequency ranges as shown in Fig. 1.5.3.

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



(G-1557) **Fig. 1.5.3 : Concept of 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. 1.5.4 shows the principle of TDD.



(G-1558) **Fig. 1.5.4 : Concept of TDD**

1.5.2 Paging Systems : GTU : S-17, W-19

University Questions

Q. 1 Define following tems :

1. Forward Channel
2. Reverse Channel
3. Control Channel
4. Paging System
5. Hand-off
6. Base Station
7. Full Duplex Systems **(S-17, 7 Marks)**

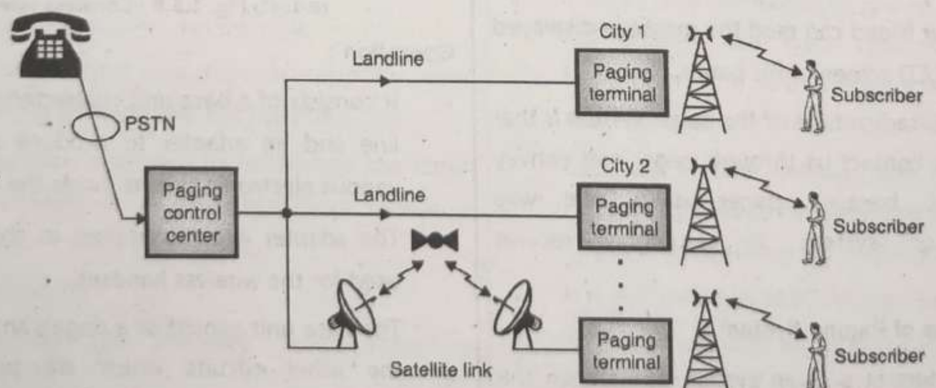
Q. 2 Explain paging system. **(W-19, 4 Marks)**

Concept :

- The paging systems are the communication systems which are used for sending a short message to the subscriber.
- This message can be of different types such as a numeric message (which contains only numbers) or alphanumeric one (containing numbers and text) or even voice message.
- The modern paging systems provide news headlines, stock information etc. to the subscriber.
- The message delivered to a subscriber is called as a page.
- Simple paging systems may cover very small area of the order of 2 to 5 km whereas wide area paging systems can provide a worldwide coverage.
- The paging receivers are simple in construction and inexpensive but transmitters are quite complex and sophisticated.

Block diagram :

- Fig. 1.5.5 shows the block schematic of a wide area paging system.



(G-1559) **Fig. 1.5.5 : Wide area paging system**

- As shown in Fig. 1.5.5, a wide area paging system consists of a telephone line network, a large number of paging terminals and transmission towers, satellite links and paging control center.
- The radio towers simultaneously broadcast a page from each base station.
- This process is called as **simulcasting**.

- The simulcast transmitters can be located in the same service area or different cities or countries depending on the size of the service area.
- The reliable paging systems can deliver the message (page) to the subscriber inside a building, travelling on a highway or flying in airplane etc.
- To ensure reliability, we have to use large transmitter power (few kW) and low data rates (1 to 2 kbps).

Procedure to Convey Message :

1. Amar is carrying his pager with him and his pager number is 9628576774.
2. When we want to convey him a message such as "Join us at Rahul", we have to simply dial up his pager number using our usual telephone set.
3. When we dial the pager number, call is established with an operator at the pager station. We have to give the message to the operator.
4. The operator will note the message and transmits it to Amar.
5. The pager hanging with Amars belt will pick up every transmitted signal and as soon the transmitted pager number matches with its own number stored in its memory, it starts giving a "beap".
6. Then our friend can read the message displayed on the LCD screen of his pager.

- The biggest disadvantage of the pager system is that Amar cannot contact us through pager and convey his reaction, because pager is a one way communication system. It can only receive messages.

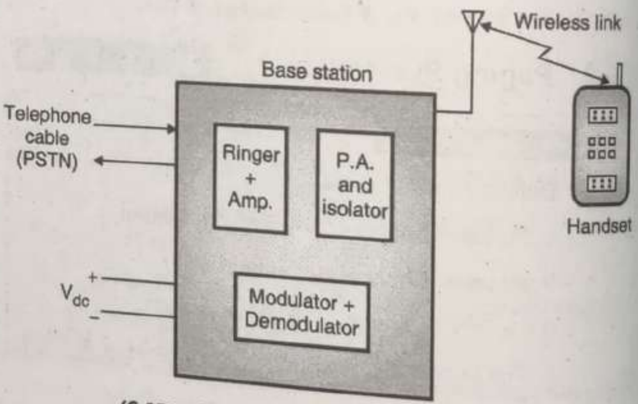
Important Features of Paging System :

- The transmitters in a given system operate on the same frequency, either in the VHF range of 152 MHz or 158 MHz or in the UHF range of 454.025 or 454.650 MHz.
- The multiple access method used for pagers is TDMA i.e. time division multiple access.
- The POCSAG can be transmitted at 3 different data rates 512, 1200 and 2400 bits/sec.
- The modulation scheme is FSK with ± 4 kHz deviation.
- The POCSAG protocol can handle upto two million pager addresses.

1.5.3 Cordless Telephone Systems :

Block diagram :

- The cordless telephone systems are full duplex communication systems.
- They use radio frequency EM waves to connect the base station to a portable handset.
- The first generation cordless telephone systems were introduced in 1980s.
- The block diagram of a cordless telephone system is shown in Fig. 1.5.6.



(G-1561) **Fig. 1.5.6 : Cordless telephone**

Operation :

- It consists of a base unit connected to the telephone line and an adapter to produce a dc supply for various electronic circuits inside the base unit.
- The adapter is also required to charge the battery used for the wireless handset.
- The base unit consist of a ringer, an amplifier and all the other circuits which are present inside a conventional telephone.
- In addition to that it consists of a transceiver i.e. combination of transmitter and receiver.
- The transmitter has a limited range (typically of 50 meters) of coverage.

- It radiates and receives the signals from the handset using the same antenna, which is an omnidirectional one.
- The handset also contains a transceiver along with an antenna, amplifier, microphone and loud speaker.
- Some type of modulation needs to be used.
- Generally FM used as it needs less power and ensures better quality.
- The base unit and the handset need to have the modulator as well demodulator.
- The early cordless phones operated only as extension telephones as discussed.
- But the second generation cordless phones which are introduced recently go much beyond this.
- They allow subscribers to use their handsets at many outdoor locations.
- The paging operation also is possible.
- The range of coverage of the second generation cordless phones is a few hundred meters.

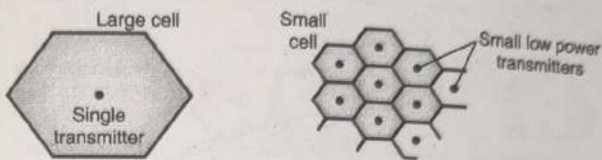
1.5.4 Cellular Telephone System :

Cellular Telephone System :

- The aim of the early mobile radio system was to provide coverage to a large area with the help of a single high power transmitter having an antenna mounted on a tall tower.
- This approach had the following disadvantages :
  1. Frequency reuse was not possible.
  2. Proper spectrum allocation in proportion with increasing demand was not possible.
- Hence it became necessary to restructure the radio telephone system so as to achieve the following objectives :
  1. High capacity.
  2. To utilize the available radio spectrum effectively.
  3. Coverage of large areas.

Cellular concept :

- The major breakthrough in this field was the introduction of the **cellular concept** which is shown in Fig. 1.5.7.
- In the **cellular systems,** a single high power transmitter is (large cell) is replaced by many low power transmitter (small cells).
- Note that each small cell provides coverage to a small portion of the entire large service area (large cell).



(G-1562) **Fig. 1.5.7 : The cellular concept**

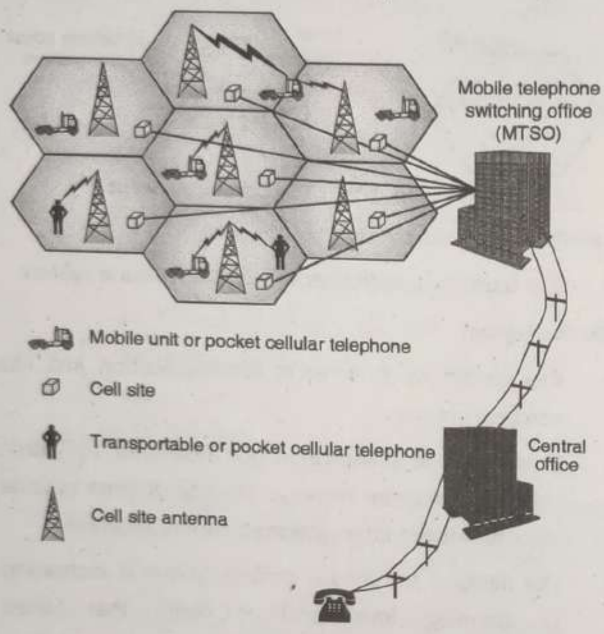
Cellular telephone system:

- It is basically a multiuser wireless telephone system.

Block diagram :

- Cellular phone is wireless communication 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).
- The cells are normally thought of hexagons. Because cell phones and base stations use low power transmitters, the same frequencies can be reused in non-adjacent cell.
- Each cell is (The cellular network is as shown in Fig. 1.5.8) linked to central location called the Mobile Telephone Switching Office **(MTSO).**
- It is also called as **MSC** (Mobile Switching Center).
- MTSO coordinates all mobile calls between an area which consists of several cell sites and the central office.
- Time and billing information for each mobile unit is accounted for by MTSO.
- At the cell site base station is provided to transmit, receive, and switch calls to and from any mobile unit within the cell to the MTSO.

- A cell covers only few square kilometre area, thus reducing the power requirement necessary to communicate with cellular telephones.
- In this manner heavily populated areas can be serviced by several stations, rather than one as used by conventional mobile techniques.



(G-1025)Fig. 1.5.8 : The cellular network

- At the cell site base station is provided to transmit, receive, and switch calls to and from any mobile unit within the cell to the MTSO.
- A cell covers only few square kilometer area, thus reducing the power requirement necessary to communicate with cellular telephones.
- In this manner heavily populated areas can be serviced by several stations, rather than one as used by conventional mobile techniques.
- Communication between the base station and mobiles is defined by a standard called **Common Air Interface (CAI)**. This standard specifies the following four different channels :
  1. Forward voice channels (FVC)
  2. Reverse voice channels (RVC)
  3. Forward control channels (FCC)
  4. Reverse control channels (RCC)
- Forward Voice Channels (FVC) is defined as the channels used for voice transmission from base station to mobile whereas the Reverse Voice Channel **(RVC)** is defined as the channels used for voice transmission from mobiles to base station.
- The **FCC** and **RCC** are the forward and reverse control channels and they are responsible for initiating the mobile calls.
- The control channels only set up the calls so they are also called as **set up channels**.
- The control channels are used for transmitting and receiving data messages carrying call initiation and service requests.

How a Cellular Telephone Call is Made ?

- When we turn on a cellular phone and it is yet to be engaged in a call, it will first scan the group of forward control channels in order to find which one is having strongest signal, and then continues to monitor that control channel until the signal drops below a usable level.
- Then it again searches all the control channels so as to find the strongest base station signal.
- When a telephone call is placed to a mobile user, the MTSO or MSC will send the request to all the base stations in the system.
- The subscribers telephone number called as **mobile identification number (MIN)** is then broadcast as a paging message over all the forward control channels (FCCs) in the system.
- The desired mobile receives the paging message sent by the base station and in response it identifies itself over the reverse control channel (RCC).
- The base station relays the acknowledgement sent by the mobile and informs the MTSO about the handshake.
- MTSO tells the base station to move the call to a free voice channel i.e. the channel which is not being used at that time.
- Once the call is in process, the MTSO will adjust the transmitted power of the mobile and changes the channel of mobile unit and base stations so as to maintain call quality even when subscriber moves

out of the coverage area of a cell. This process is called as the **handoff process.**

Mobile originates a call :

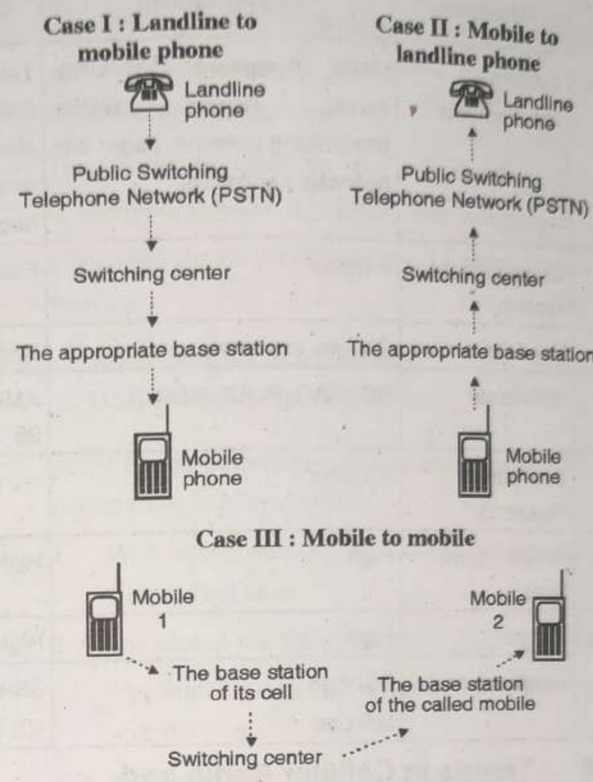
- When a mobile originates a call, then a request for call initiation is sent on the reverse control channel (RCC).
- After receiving the request the mobile unit transmits its telephone number (MIN), electronic serial number (ESN) and the telephone number of the party being called.
- The mobile also sends the station class mark (SCM). This indicates the permitted maximum power level for that particular user.
- Then base station receives this data and conveys it to MTSO which validates the request, makes connection to the party being called through PSTN and begins the conversation.

Roaming :

- All cellular systems provide the roaming service. Due to this service subscribers can operate in the service areas other than their own service areas.

Call Routing :

- The call routing taking place under different operating circumstances is explained in Fig. 1.5.9.



(G-1030) **Fig. 1.5.9 : Call routing in a mobile communication system**

1.5.5 Comparison of Wireless Systems :

- The comparison of different wireless systems is as shown in Table 1.5.1.

Table 1.5.1 : Comparison of Wireless Systems

Sr. No.	Parameter	Paging system	Cellular phone system	Cordless telephone system
1.	Capacity	Very limited. It can communicate only using short messages.	Unlimited. Messaging as well as two way talking is possible.	Few hundred meters
2.	Operation	The message given by the caller is routed through the telephone lines, operators and PABX system to the server. It is then sent to the receiving person via pager switches and transmitting antenna	The call is routed from caller to receiving person through PSTN, MTSO, base stations, and antennas.	Early cordless telephones was operated only on extension telephone to a transceiver connected to a subscriber line on the PSTN but modern systems are sometimes combined with paging receivers so that subscriber can be first paged and then it respond to page with the help of cordless telephone system.
3.	Applications	It is used for sending a message to a mobile party	It is used for texting, sending and receiving pictures, files and two way voice communication.	Used in residential cordless setups, public telepoint systems, wireless PBX systems.

Sr. No.	Parameter	Paging system	Cellular phone system	Cordless telephone system
4.	System requirements	PABX, Telephone line, UNIX server, paging switch, transmitting antenna, pager and necessary software.	Telephone, PSTN, MTSO, Cellular network with base stations and antennas, mobile handset and necessary software.	Telephone PSTN, radio to connect handset to a dedicated base station.
5.	Communication system	Simplex	Full duplex	Full duplex
6.	Used for	Country to country	Within network	Short distance
7.	Standards	POCSAG, FLEX, GSC	AMPS, N-AMPS, USDC, IS-95	CT2, DECT, GSM, PACS
8.	Operating frequency	< 1 GHz	< 2 GHz	< 1-3 GHz
9.	Infrastructure level	High	High	Low
10.	Range	High	High	Low
11.	Hardware cost	BS-High MS-Low	BS-High MS-Medium	BS-Medium MS-Low

1.6 Trends in Cellular Radio and Personal Communications :

- Since early 1990s, scientists and engineers throughout the world are working to develop personal wireless systems.
- These systems posses the network intelligence of PSTN and the digital signal processing and RF technology.
- The concept of Personal Communication Services (PCS), originated in the U.K. when three companies were given the task to develop Personal Communication Networks (PCN) throughout Great Britain.
- Presently, the entire world is carrying out field trials to determine which modulation; multiple-access, and networking techniques will be suitable for future PCN and PCS systems.
- Even though, the terms PCN and PCS are often used interchangeably, they carry different meanings.

Definition of PCN :

- PCN is defined as a wireless networking concept, where any user can make or receive calls, irrespective of his location, using a light-weight, personalized communicator.

Definition of PCS :

- PCS is defined as new wireless systems that incorporate more network features and are more personalized than existing cellular radio systems.
- Every day new indoor wireless networking products are emerging and within a decade from now, they will become major part of the telecommunications infrastructure .
- The international standards are being developed for wireless communication between computer inside a building by an international standards body, IEEE 802.11, and the European Telecommunications Standard Institute (ETSI).
- Since 1990 the products such as Motorola's 18 GHz Altair WIN (wireless information network) modem and AT&T's waveLAN computer modem are available in markets as wireless Ethernet connections.
- As the next step, by the end of the 20th century, the telecommunication industry developed products, that allow users to link their phone with their computer within an office environment, as well as in public places like malls, gardens airports or train stations.

- In mid 1995 a worldwide standard, named International Mobile Telecommunication 2000 (IMT-2000) was formulated by the International Telecommunications Union (ITU).
- IMT-2000 is a third generation universal, multi-function, globally compatible digital mobile radio system, which can integrate various systems like paging, cordless, and cellular systems, as well as low earth orbit (LEO) satellites, into one universal mobile system.

Frequency band :

- The frequency bands allocated for this system extend between 1885 MHz to 2025 MHz and 2110 MHz to 2200 MHz , which makes a total of 230 MHz.
- The next step was to develop worldwide standards for emerging LEO satellite communication systems.
- The satellite based cellular systems can never have the capacities provided by land-based microcellular systems.
- However, satellite mobile systems have been advantageous for data collection, and emergency communications, as well as for global roaming before deployment of IMT-2000.
- In early 1990, a small satellite was successful launched from a jet aircraft in the low earth orbit.
- This launch is less expensive than conventional ground-based launches and can be deployed quickly.
- Therefore, now it is possible to rapidly deploy a network of LEOs for wireless communications around the globe.
- Already, several companies have proposed such systems and some have already deployed them for worldwide paging, cellular telephone, and emergency navigation and notification .
- In some emerging nations, where, the landline telephone service is almost nonexistent, the fixed cellular telephone systems are being installed at a rapid rate.
- This is because, developing nations find the installation of cellular telephone systems, quicker and more affordable for fixed home use, rather than the wired landline system.
- The world is now on the verge of a major telecommunications revolution that will provide an integrated communication access to users, wherever they are.

1.6.1 Advantages of Wireless Communication Systems :

- Some of the advantages of wireless communication systems are as given below :
  1. With high speed any information or data can be transmitted faster.
  2. The cost of maintenance and installation is low.
  3. The Internet can be accessed from anywhere and anytime.
  4. It is very useful for doctors, workers working in remote areas as they can be in touch with medical centres.

1.6.2 Disadvantages of Wireless Communication Systems :

- Some of the disadvantages of wireless communication systems are as given below :
  1. The wireless signals which spread through air can be easily captured by an unauthorized person.
  2. Radio signal interference.
  3. Less secure.
  4. High level of RF energy can damage the health.

1.6.3 Applications of Wireless Communication Systems :

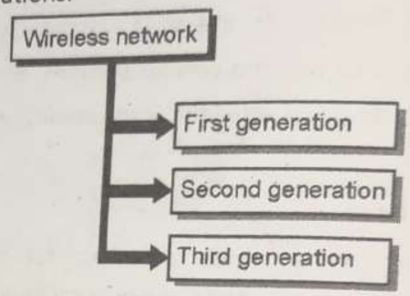
- Some of the applications of wireless communication systems are as given below :
  1. Security systems
  2. Television remote control
  3. Wi-fi
  4. Cell phones
  5. Computer interface device.

1.7 Wireless Generations : GTU : S-16

University Questions

Q. 1 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

- 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 1.7.1 shows classification of wireless network generations.



(G-2543) **Fig. 1.7.1 : Classification of evolution of generations**

1.7.1 First Generation Cellular Networks :

- 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.

Frequency bands :

- AMPS uses the ISM 800-MHz band for its operation.
- It uses two separate channels for forward i.e. base station to mobile station and for reverse i.e. from mobile station to base station communication.
- The frequency bands allotted for the forward and reverse communication are as follows :
- Reverse Communication : 824 MHz to 849 MHz.
- Forward Communication : 869 MHz to 894 MHz.

- Each band has been divided into 832 channels. But two providers are allowed to share an area.
- That each provider is allowed to use 416 channels in each cell.
- Out of 416, 21 channels are used for control and the remaining 395 channels for information.

Transmission :

- AMPS makes use of FSK and FM systems for modulation.
- FM stands for frequency modulation while FSK is frequency shift keying.
- FM is used for the modulation of voice signals whereas FSK is used for the control channels.
- The coverage area of first generation systems was 2100 square km.
- The other 1G technologies developed to provide only analog voice communication were Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS).
- 1G technology was developed only for providing the voice communication but **paging networks** also are considered as 1G technology.
- Pager system provides only one way messaging.

Drawbacks of 1-G System :

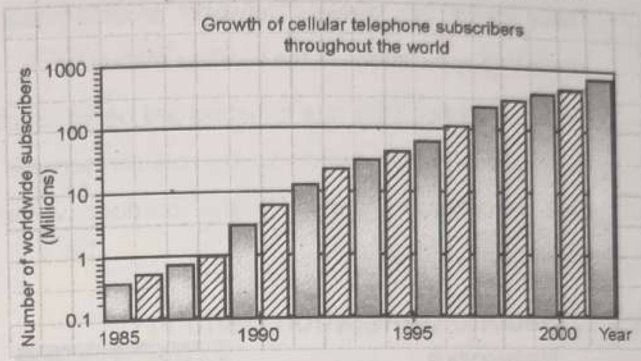
1. Poor voice quality. 2. No security.

Features of First Generation :

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

1.8 Growth of Cellular Communication :

- Since the mid 1990, the cellular communication industry has seen an explosive growth.
- The wireless communication networks have become more important than anyone imagined, when the cellular concept was first introduced.
- Refer Fig. 1.8.1, which shows that the number of worldwide cellular and personal communication subscribers surpassed 600 million users in 2001.



(G-2794) **Fig. 1.8.1 : Growth of cellular and PCS subscribers throughout the world**

- This number reached 2 billion by the end of 2006.
- The worldwide adoption of wireless communications got accelerated in the mid 1990.
- This rapid worldwide growth of cellular subscriber indicates that wireless communication is a robust and viable transport mechanism of voice and data.
- The worldwide success of cellular technology has led to the development of new wireless systems and standards for different types of telecommunication traffic besides voice telephone calls.
- The next generation cellular networks are designed for high speed data traffic in addition to the voice calls.
- New standards and technologies are being implemented to replace the fiber optic lines and copper wires by the wireless networks.
- Wireless networks are increasingly being used as replacement for wires within homes and offices through deployment of wireless local area networks (WLANs).
- Similarly the evolving Bluetooth modem standard allows its users to replace the chords used for appliance communication with wireless connections within a person's personal workspace.

- Wireless LANs and Bluetooth are used for the applications within the buildings.
- They use low power levels and do not require any license for the spectrum use as they operate in the ISM frequency band.
- These license free wireless networks provide many interesting applications in the wireless market.
- Since the ad-hoc data rate networks are being used by individual within buildings, the cellular services have focused on providing the outdoor voice coverage.

1.9 Second Generation Cellular Networks : GTU : W-13, S-16

University Questions

Q. 1 Explain (i) Concept of frequency reuse (ii) 2G and 3G wireless networks. **(W-13, 6 Marks)**

Q. 2 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

- 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 (2G) cellular systems provide more features as compared to the first generation (1G) systems.
- As stated earlier, the first generation cellular systems were based on analog transmission of voice on FDMA/FDD and analog FM.
- The second generation (2G) cellular systems are based on the digital modulation formats along with the TDMA/FDD and the CDMA/FDD multiple access techniques.
- The second generation mobile systems are digital systems.

1.9.1 Types of 2G Standards : GTU : S-16

University Questions

Q. 1 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

Q. 2 What is the difference between 2G, 2.5G and 3G? Describe GPRS architecture. **(S-16, 7 Marks)**

- Following are some popular second generation standards.
  1. Global System Mobile (GSM)
  2. Interim Standard 136 (IS-136)
  3. Pacific Digital Cellular (PDC)
  4. Interim standard 95 CDMA (IS-95)
- Out of these, the first three i.e. GSM, IS-136 and PDC are **TDMA** standard whereas, IS-95 is the **CDMA** standard.
- In the three TDMA standards, time axis is subdivided into many time slots.
- Each user is allotted its own time slot to transmit its data. These time slots form TDMA frames.
- The cellular traffic congestion is minimized by this technology.

Features of TDMA standard :

- A few important features of the TDMA are :
  1. Operates at faster data rates.
  2. Utilizes the spectrum efficiently.
  3. Needs synchronization for its operation.
  4. It has guard intervals for better operation.
  5. The TDMA standards use half duplex methods

1. GSM Standard :

- Out of all the 2G standards, GSM is the most popular standard.
- It is a TDMA based standard which uses eight time slots for users with each user assigned a bandwidth of 200 KHz.
- It is deployed in Europe, Asia, Australia, South America and few parts of the U.S. for cellular as well as PCS applications.

2. Interim Standard IS-136 :

- This standard is also called as North American Digital Cellular(NADC) or US Digital Cellular (USDC).

- It is a TDMA standard which uses three time slots for users with each one assigned a channel bandwidth of 30 MHz.
- It is deployed in Australia, South America and North America for cellular as well as PCS applications.

3. Pacific Digital Cellular PDC :

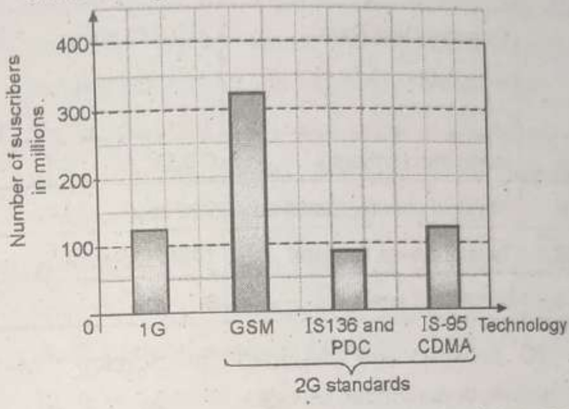
- It is a digital TDMA standard which is used by over 50 million people in Japan.
- It is similar to the IS-136 standard.

4. Interim Standard IS-95 :

- The interim standard IS-95 is a very popular CDMA based 2G standard which is also called as **cdmaOne**.
- In the CDMA standard (IS-95) every subscriber is assigned an n-bit code and assures a high degree of security than other access methods.
- IS-95 standard does not use TDMA. Hence it allows up to 64 users to transmit simultaneously.
- All these users are coded in an orthogonal manner and they transmit simultaneously over a 1.25 MHz channel.
- It is deployed in Japan, Koria, China, South America and Australia for cellular as well as PCS applications.
- The simultaneous transmission from several users can be differentiated from each other by a unique code word that has been assigned to every subscriber.
- These 2G standards are the first set of digital standards that make use of digital modulation and digital signal processing techniques in their handsets as well as the base stations.
- The handset manufactures are producing handsets, that support both TDMA and CDMA standards for cellular and PCS applications.

Graphical comparison of 1G and 2G standards :

- A simple comparison with respect to the number of mobile users for the 1G and 2G standards in 2001 is shown in Fig. 1.9.1.



(G-2544) **Fig. 1.9.1 : Growth of number of users in late 2001**

- The GSM-2G standard had the highest number of users in 2001.

1.9.2 Technical Specifications :

GTU : S-14, W-17

University Questions

Q. 1 Compare GSM, IS-136 and IS-95 standards in terms of modulation schemes, multiple access schemes, frequencies used, physical channel bandwidth, number of users/ physical channel and typical power radiated by mobile stations using these standards. Give your answer in tabulated form. **(S-14, 6 Marks)**

Q. 2 Give Comparisons between GSM, IS-136 and IS-95. **(W-17, 7 Marks)**

- Table 1.9.1 gives the technical specifications of GSM, CDMA and IS-136/PDC 2G standards.

Table 1.9.1 : Technical specifications of leading 2G technologies

Sr. No.	Parameter	GSM	IS-136/PDC	IS-95 CDMA
1.	Duplexing	FDD	FDD	FDD
2.	Multiple Access	TDMA	TDMA	CDMA
3.	Uplink frequencies	890-915 MHz (Europe) 1850-1910 MHz (US PCS)	800 MHz, 1500 MHz (Japan) 1850-1910 MHz (US PCS)	824-849 MHz (US cellular) 1850-1910 MHz (US PCS))

Sr. No.	Parameter	GSM	IS-136/PDC	IS-95 CDMA
4.	Downlink frequencies	935-960 MHz (Europe) 1930-1990 MHz (US PCS)	869-894 MHz (US cellular) 1930-1990 MHz (US PCS) 800 MHz, 1500 MHz (Japan)	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)
5.	Carrier separation	200 kHz	30 kHz (IS-136) 25 kHz for PDC	1.25 MHz
6.	Voice channels per carrier	8	3	64
7.	Channel Data Rate	270.833 kbps	48.6 kbps (IS-136) 42 kbps for PDC	1.2288 Mchips/sec
8.	Modulation scheme	GMSK	DQPSK	QPSK
9.	Physical channel bandwidth	200 kHz	30 KHz	1.25 MHz
10.	Typical power radiated	1000/125 mW	600/200 mw	600 mW
11.	Number of users	8	6	20 to 35

- 2G networks are designed for development of conventional mobile service.
- In-order to provide fixed telephone service to businesses in the developing nations and the residential areas the newer cellular systems are being installed.
- In the countries that have poor telecommunication infrastructure, it is cost effective to provide **plain old telephone service (POTS)** with the cellular phones.
- Advantage of using 2G network over 1G is that digital encryption of phone conversation is possible.
- With the help of 2G technologies the spectrum efficiency has increased by three folds as compared to 1G technology.
- With the development in GSM, several countries like Japan and US decided to abandon the IS-136 and PDC standard

1.9.3 Features of 2G Systems :

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

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

Performance :

- Although 2G systems provided a huge improvement over 1G and increased the number of subscribers, the standards of 2G systems were poor.
- This is because, 2G systems were unable to handle complex data and they could not use the available bandwidth efficiently.
- Therefore the 2G standards were upgraded first to 2.5G standards and subsequently to the 3G standards.

1.9.4 Evolution to 2.5G Mobile Radio Networks : GTU : S-16, S-18, S-19, W-19

University Questions

Q. 1 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

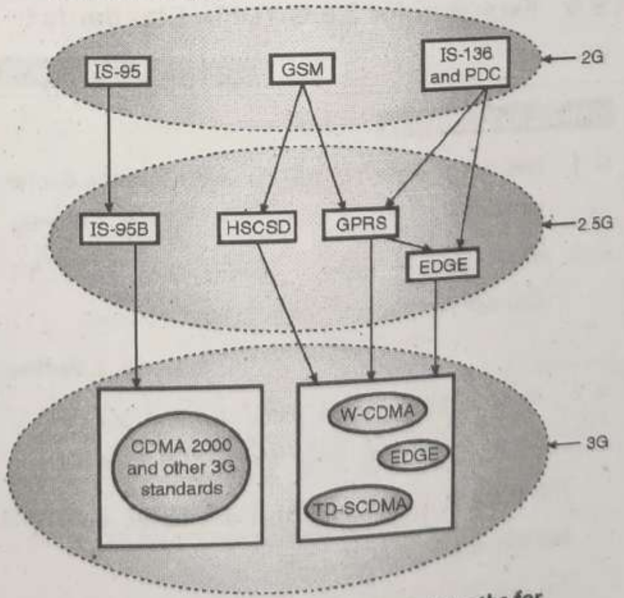
Q. 2 Illustrating the upgrade paths briefly describe 2G and 3G cellular network. **(S-18, 4 Marks)**

Q. 3 With diagram explain various 2.5G and 3G upgrade paths for the major 2G technologies. **(S-19, 7 Marks)**

Q. 4 Illustrate the upgrade paths 2G and 3G cellular networks and describe in brief. **(W-19, 4 Marks)**

Why 2.5 G?

- The 2G digital standards were being used widely by wireless carriers for cellular and PCS applications since the 1990s.
- However these standards use circuit-switched data modems that limit the data users to a signal circuit-switched voice channel.
- Hence, in 2G standards, the data transmission rates are generally limited to the data throughout rate of an individual user.
- Each 2G standard specifies a different coding scheme and error protection algorithm for data transmission and voice transmissions.
- All the 2G networks only support single user data rates of the order of 10 kbps.
- Such a low data rate is not sufficient for sending email rapidly and for Internet browsing applications.
- With low data rates, the 2G standards can support limited internet browsing and short messaging service (SMS) with the help of switched circuit method.
- The **short messaging service (SMS)** is a an important feature of GSM.
- The subscribers can send short real time messages to the other subscribers in the same network by dialing the receiver's mobile phone number.
- In order to make the 2G standards support the increased throughput data rate requirement for modern Internet applications, new standards have been developed.
- These new standards are upgraded upon the existing 2G standards and they are called as 2.5 G technology.
- They support the higher data rates by allowing the use of existing 2G handsets with some modifications and by using new base station add-ons and subscriber unit software upgrades.
- Hence the 2.5 standards can support for web browsing, e-mail traffic mobile commerce (m-commerce), and location-based mobile services.
- The 2.5G technologies also support a popular new web browsing format language, called **Wireless Application Protocol (WAP).**
- WAP allows the web pages to be observed in a compressed format because it has been designed for small, portable hand held devices.
- For a specific wireless network the 2.5G upgrade must be compatible with the earlier 2G technology at the base station.
- A wide range of 2.5G standards have been developed in order to upgrade each 2G technology (IS-136, GSM, CDMA) for faster Internet data rates.
- Fig. 1.9.2 shows various upgrade paths for different 2G technologies.



(G-1584) Fig. 1.9.2 : Various upgrade paths for 2-G technologies

- In other words it shows how a 2G standard evolves into 2.5 G and then into a 3G standard.

- Fig. 1.9.2 shows that CDMA IS-95 evolves into IS-95B as 2.5 G standard which further evolved into CDMA 2000 as the 3G standard.
- On the other side the GSM standard evolves into HSCSD and GPRS as 2.5 G standards which further evolved into W-CDMA, EDGE or and TD-SCDMA standards as shown.
- Finally IS-136 and PDC standards followed the evolution route of either GPRS--- W-CDMA, EDGE or and TD-SCDMA or GPRS---- EDGE-----W-CDMA as shown in Fig. 1.9.2.
- It is necessary to choose an appropriate upgrade path for any 2G standard.
- That means the 2.5 standard corresponding to the GSM standard must have a backward compatibility with the GSM air interface standard.
- This would ensure there is no need of complete change in the base station equipments.
- Hence all the 2.5-G standards provide a marginal improvement in the data rates over corresponding 2- G standard.

1.9.5 Evolution for 2.5-G TDMA Standards :

GTU : S-16, S-19, W-19

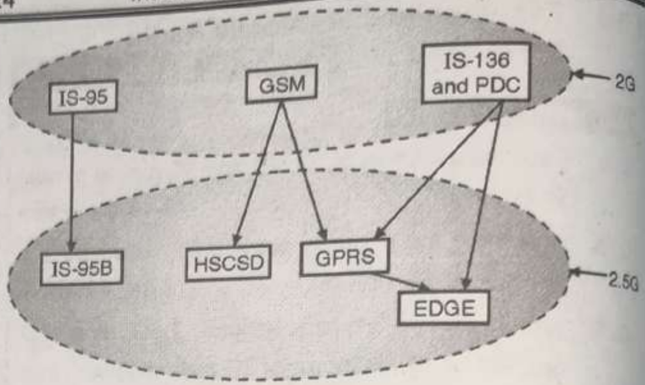
University Questions

Q. 1 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

Q. 2 With diagram explain various 2.5G and 3G upgrade paths for the major 2G technologies. **(S-19, 7 Marks)**

Q. 3 Illustrate the upgrade paths 2G and 3G cellular networks and describe in brief. **(W-19, 4 Marks)**

- The three 2-G standards that are based on TDMA technique are: GSM, IS - 136 and PDC.
- As shown in Fig. 1.9.3(a) three different upgrade paths are developed for the GSM, out of which two also support IS - 136 and PDC.



(G-1584(a)) **Fig. 1.9.3(a) : Evolution path for GSM to 2.5G**

- Following are the three upgrade solutions for 2G TDMA standards :
  1. High speed circuit switched Data (HSCSD)
  2. General Packer Radio Service (GPRS)
  3. Enhanced Data rates for GSM Evolution (EDGE)
- These improvements increase the data rates of the 2-G standards significantly and also support development of Internet ready cell phones.

1.9.5.1 HSCSD for 2.5-G GSM :

Principle :

- HSCSD is a high speed circuit switched data technique.
- It allows a single mobile user to use consecutive time slots in the GSM standard.
- In GSM, one user is allowed to use only one TDMA slot, but in HSCSD a user can use more than one consecutive TOMA slots to improve the data rates.
- This standard relaxes the error control algorithm in GSM to further increase the data rates.
- The amount of increase in data rates depends on the number of consecutive time slots used by a user.
- With four consecutive TDMA slots allotted to a single user the HSCSD can increase the raw data rates up to 57.6 kbps which is a remarkable improvement over 9.6kbps data rate of GSM.

Implementation :

- HSCSD can be employed if the service provider implements a simple software change at the GSM base station.

Applications :

- HSCSD can be used for :
  1. Dedicated streaming Internet access
  2. Real time interactive web sessions.

1.9.5.2 GPRS for 2.5- G GSM and IS-136 :

- GPRS is a packer based technique which could be the next step in evolution of GSM as well as IS-136 and PDC standards as shown in Fig. 1.9.3.

Principle :

- GPRS operates by supporting a multiple user network sharing of individual channels and time slots.
- This is different than the principle of HSCSD. Due to this technique. GPRS can support many more users than HSCSD but in **a burst manner** (non-continuous manner)
- The GPRS standard provides a packet network on dedicated GSM or IS-136 radio channels.

Air interface :

- The modulation formats specified in the original 2G TDMA standards CGSM and IS-436 are retained in GPRS.
- But it uses a completely redefined air interface (as compared to GSM or IS-136) for better handling of data.
- GPRS has dedicated radio channels and particular time slots that allow an always on access to the network
- The GPRS subscribers are instructed automatically, to tune to the above mentioned channels and time slots.

Data rates :

- If all the eight time slots of a GSM channel are dedicated to GPRS, it is possible for an individual user to achieve a data rate of 171.2 kbps.
- However these data rates decrease with increase in the number of users trying to use the GPRS network.

Error correction :

- In GPRS the applications are required to provide their own error correction schemes.

GPRS Implementation :

- Refer Table 1.9.2 which compares the current and future 2.5-G and 3-G communication standards.
- It shows how easy the GPRS implementation was, because for implementation of GPRS, the GSM operator needs to install new routers and gateways the base station.
- A new software that redefines the base station air interface and time slots, also needs to be installed at standard the base station
- A new RF base station hardware is also required.

Applications :

- Some important applications of GPRS are :
  1. Non-real time Internet applications.
  2. Retrieval of e-mails, faxes
  3. Asymmetric web browsing (more downloading and less uploading).

Table 1.9.2 : Technical features of the emerging 2.5G and 3G data communications standards

Sr. No.	Wireless Data Technology	Generation	Channel Bandwidth	Duplex method	Need of new spectrum	Change in Infrastructure	Need of a new handset
1.	HSCSD	2.5G	200 kHz	FDD	No	Needs software upgrade at the base station	Yes
2.	GPRS	2.5G	200 kHz	FDD	No	Needs new packet overlay in addition to routers and gateways	Yes
3.	EDGE	2.5G	200 kHz	FDD	No	Needs new transceiver at the base station and software upgrades to base station controller and base station.	Yes

Sr. No.	Wireless Data Technology	Generation	Channel Bandwidth	Duplex method	Need of new spectrum	Change in Infrastructure	Need of a new handset
4.	W-CDMA	3G	5 MHz	FDD	Yes	Needs entirely new base stations	Yes
5.	IS-95B	2.5G	1.25 MHz	FDD	No	Needs new software in base station controller	Yes
6.	CDMA 2000 1xRTT	3G	1.25 MHz	FDD	No	Needs new software in backbone and new channel cards at base station. They also need to build a new packet service node.	Yes
7.	CDMA 2000 1xEV (DO and DV)	3G	1.25 MHz	FDD	No	It needs software and digital card upgrade on the 1xRTT networks.	Yes
8.	CDMA 2000 3xRTT	3G	3.75 MHz	FDD	May be	They need backbone modifications and new channel cards at base station.	Yes

1.9.5.3 EDGE for 2.5-G GSM and IS-136 :

- The long form of EDGE is Enhanced Data Rates for GSM or Global Evolution.
- This is a more advanced upgrade to both GSM and IS 136 2G standards, as shown in Fig. 1.9.3.
- The development of EDGE, provides a common evolution path for both GSM and IS-136 which eventually learn to 3G high speed data access.

Modulation format :

- EDGE uses a new modulation format called 8.Psk (octal PSK) in addition to GSM's standard GMSK modulation.
- There are nine different air interface formats that the EDGE technology offers to the user.
- These formats are rapidly selectable and are known as multiple modulation and coding schemes **(MCSs).**
- Each MCS stale uses the **GMSK** for low data rate and **8-PSK** for high data rates.
- EDGE is sometimes also called as the Enhanced GPRS or EGPRS.

Range of coverage :

- The range of coverage in EDGE is smaller than that as compared to GPRS and the other systems, due to the following reasons :
  1. EDGE supports higher data rates.
  2. EDGE allows a relaxed error control.

Incremental redundancy :

- For each time slot in GSM, the EDGE technology uses the 8- PSK modulation and multiple
- This allows each user (in that time slot) to adaptively determine the best MCS setting for itself,
- This adaptive capability of selecting The best possible air interface is defined as the **incremental redundancy.**
- In the incremental redundancy, the packets are first sent with maximum error protection and maximum data rate through put.
- The error protection and data rate through put are reduced progressively for the subsequent packets until the wireless link faces an unacceptable outage or delay.
- The previously acceptable air interface is then restored with the help of rapid feedback between the base station and user.

Advantages of incremental redundancy :

- Following are some of the benefits of incremental redundancy:
  1. Each radio link uses minimum overheads

2. It maximizes the user capacity.
3. It provides an acceptable link quality for each user.

Data rate :

- we can obtain a raw peak throughput data rate of 547.2 kbps if EDGE uses the 8-PSK modulation without any error protection, with all the eight time slots in GSM dedicated to a single user.
- However the practical maximum raw through put data rare in EDGE is restricted to 384 kbps for a single dedicated user on a single GSM channel due to EDGE slotting schemes. network contention issues and error coding requirements.
- EDGE can provide the through put data rates of several mbps to individual users, by combining the capacity of different radio channels.

EDGE Implementation :

- EDGE requires a few hardware as well as Software upgrades at the existing GSM on IS-136 base Station.
- It requires new transceivers at the base stations and software upgrades at the base station and base station controller.

1.9.6 IS-95 B for 2.5-G CDMA :

- The 2-G TDMA standards (GSM and IS - 136) have multiple evolutionary paths.
- But 2-G CDMA standard (IS-95 or cdmaOne) has only one evolutionary path which is from IS-95 to IS.95 B.
- IS - 95 B, like GPRS is being used all over the world.

Principle :

- IS-95 B dedicates multiple orthogonal user channels (Walsh functions) to different users simultaneously, similar to IS-95.
- It uses high speed packer and circuit switched data on a common CDMA channel.

Data rates :

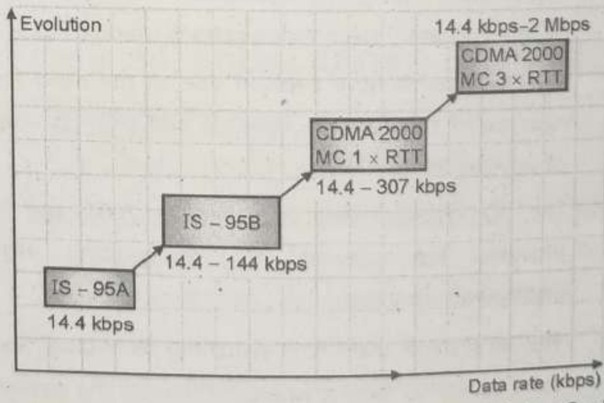
- The maximum data rate of IS-95 is 9.6 kbps which was improved to 14.4 kbps in IS-95A which is further improved to 115.2 kbps to a dedicated user (8 x 14.4 kbps)
- This is achieved by allowing a dedicated user to command eight different user Walsh codes simultaneously and in parallel.
- However, due to the slotting techniques used by IS-95 B standard, the maximum practical data rate at the most equal to 64 kbps.

Better Link Quality :

- IS-95 B standard improves the link quality experienced by the users to a great extent.
- This improvement results due to the **hard hand- off procedure** specified by the IS-95 B standard.
- In hard hand-off procedure, subscriber units are allowed to search different radio channels in the network, without instructions from the switch.
- Due to this the subscriber units can tune rapidly to different base stations to maintain a high link quality.
- The link quality in IS-95 is inferior, because it used the soft handoff procedure.

Applications :

- IS-95B standard, supports 64 simultaneous subscribers and it is used for the medium data rare **(MDR)** services.
- Fig. 1.9.4 illustrates the evolution path for the only 2-G CDMA standard.



(G-2546) **Fig. 1.9.4 : Evolutionary path for IS-95 A (cdma One) standard**

1.9.7 Comparison of HSCSD, GPRS and EDGE :

GTU : W-14

University Questions

Q. 1 Compare HSCSD, GPRS & EDGE in terms of their channel bandwidth (in KHZ), duplexing technique (FDD or TDD), maximum raw data rate supported and name of carrier modulation used. **(W-14, 7 Marks)**

Sr. No.	Parameter	HSCSD	GPRS	EDGE
1.	Channel bandwidth	200 KHz	200 KHz	200 KHz
2.	Duplexing technique	FDD	FDD	FDD
3.	Maximum raw data rate	57.6 kbps	171.2 kbps	547.2 kbps
4.	Carrier modulation	GMSK	GMSK	GMSK / 8-PSK

1.10 Third Generation (3-G) Wireless Networks : GTU : W-13, S-16

University Questions

Q. 1 Explain (1) Concept of frequency reuse (2) 2G and 3G wireless networks. **(W-13, 6 Marks)**

Q. 2 Describe evolution of 1G, 2G and 3G mobile phone systems **(S-16, 7 Marks)**

- The third generation of wireless mobile communication systems have been developed to meet the International Mobile Telecommunication - 2000 (IMT - 2000) specifications which are defined by International Telecommunications Union (ITU).
- The 3G systems have evolved due to the need for high speed, fast data transmission and better quality of service (QoS).
- The 3G systems were launched in 2001 and it provides the network for transporting rich **multimedia** contents.
- The 3G systems use circuit switching technology for voice calls/SMS facility, whereas they use the packet switching for the high speed data.
- The well known examples of 3G systems are :
  1. W-CDMA.
  2. CDMA - 2000
  3. TD - SCDMA
- 3G systems are compatible with the other cellular standards like CDMA, GSM and TDMA.
- The frequency range used by the 3G standards is 2100 MHz and it has a bandwidth of 15-20 MHz.
- 3G standards facilitate the users to use high speed internet services, as well as video chatting.
- The international roaming has become possible due to 3G standard.
- Universal Mobile Telecommunications System (UMTS) was adopted by Europe which uses W-CDMA as its standard.
- UMTS is based on the GSM infrastructure. Hence UMTS is the most popular 3G technology.

1.10.1 Features of Third Generation :

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

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

- Aim of the third generation technology is to combine the services such as internet, telephony and multimedia into a single device.

1.10.2 Services Provided by 3G Systems :

1. **Voice :**
   - 3G system will provide good speech quality as compared to the telephone network.
2. **Messaging :**
   - E-mail attachments are allowed in 3G system.
3. **MMSC multimedia messaging services :**
   - 3G supports MMS which are designed for rich text, icons, logos, animated clips etc.

4. Medium multimedia :

– In 3G system, for web surfing, games, location based maps its downstream data rate is suitable.

5. Interactive high multimedia :

3G supports for this service which is used for high quality videophones, videoconferencing etc.

1.10.3 Advantages of 3-G Networks :

– The third generation of wireless networks (3G systems) provide a wireless access, that the earlier networks could never provide in ways that have never been possible earlier.

– Some of the advantages of the 3G networks are as follows :

1. They provide data rates of multiple mbps for Internet access
2. Communication using Voice over Internet Protocol (VoIP) is possible
3. Voice activated calls
4. Very high networks capacity
5. The access to data networks is "always-on" type

– The 3G equipment are designed in such a way that the users can receive live music, conduct interactive web sessions and have simultaneous voice and data access with multiple parties at the same time using a single mobile handset, either moving or stationed at one place.

– In order to facilitate the operation of 3G systems, the International Telecommunications Union (ITU) prepared a plan called as **International Mobile Telephone 2000 (IMT-2000)**.

– IMT 2000 standard uses a global frequency band in the 2000 MHz range that supports a wireless communication standard for all countries throughout the world.

– This ITU plan has been successful in initiating an active debate and technical analysis for new high speed mobile telephone solutions in comparison to the 2G.

– However, the hope for a single worldwide standard has not materialized, because the worldwide user community remains divided between two standards: GSM/IS-136/PDC and CDMA IS-95.

– The cdma2000, a 3G standard was eventually developed by following the path: IS-95, IS-95B and cdma 2000 as shown in Fig. 1.9.4.

– Several variants of CDMA 2000 are currently being developed, that are all based on the fundamentals of IS-95 and IS-95B technologies.

– The evolution of the 2G TDMA standards(GSM, IS-136 and PDC systems) has eventually lead to the Wideband CDMA (W-CDMA), or Universal Mobile Telecommunication Service (UMTS) as shown in Fig. 1.9.2.

– W-CDMA is based on the network fundamentals of GSM, as well as the merged versions of GSM and IS-136 through EDGE.

– The ITU 200 MT - 2000 standard organizations are separated into two organizations (see Fig, 1.9.3, according to the two 3G camps :

1. 3GPP and 2. 3GPP2

– The 3GPP stands for 3G Partnership project for wideband CDMA standard and it is backward compatible with GSM and IS-136/PDG 2-G standards.

– 3GPP2 stands for 3-G Partnership Project for cdma 2000 standard which is backward compatible to IS-95.

1.10.4 3G W-CDMA (UMTS) : GTU : W-17, S-19

University Questions

Q. 1 Explain in brief W-CDMA (UMTS)

(W-17, 3 Marks, S-19, 4 Marks)

– UMTS stands for Universal Mobile Tele - communication system. It evolved since 1996.

– In its early days UMTS was known as UMTS Terrestrial Radio Access (UTRA).

– However, around year 2000, many other competing wideband CDMA proposals decided to merge into a single W.CDMA standard which resulted in the UMTS standard

Compatibility :

– W-CDMA or UMTS standard is backward compatible with GSM, IS-136/PDC (2-G) and 2.5-G TDMA standards (HSÇSD/GPRS).

– Table 1.10.1 gives some features of the IMT-2000 standards.

Table 1.10.1 : IMT 2000 standards features

Air interface	Operating mode	Duplexing	Features
CDMA2000 US TIA	Multi-carrier and direct spreading DS-CDMA	FDD and TDD	Auxiliary carrier to help with downlink channel estimation in forward link beam forming. Backward compatibility with IS-95A and IS-95B. Uplink can support a simultaneous combination of multi-carrier or direct spreading.
UTRA (UMTS Terrestrial Radio Access)	DS_CDMA	FDD and TDD	Minimum forward channel bandwidth of 5 MHz Wideband DS_CDMA system Backward compatibility with GSM Connection dedicated pilot bits assist in downlink beamforming. Upto 2.048 Mbps on downlink in FDD mode
W-CDMA			
CDMA-II (South Korea TTA)			
WIMS/W-CDMA			
CDMA-I (South Korea TTA)	DS_CDMA	FDD and TDD	Upto 512 kbps per spreading code, code aggregating upto 2.048 Mbps.
TD-SCDMA (CATT)	DS_CDMA	TDD	RF channel bit rate upto 2.227 Mbps Uses small antenna technology
DECT	TDMA	TDD	Enhanced version of 2G DECT
UWC-136	TDMA	FDD (Outdoor/Vehicular TDD (Indoor office)	Fits into IS-136 and GSM Backward compatibility with IS-136 and GSM Explicit plans to support adaptive antenna technology.

Explanation :

– The W-CDMA retains the network structure and bit level packaging of GSM data.

– It adds capacity and bandwidth to GSM by using the new CDMA air interface.

– Fig. 1.9.2 shows how different 2G and 2.5G standards evolve into the unified W-CDMA standard.

– The 3G W-CDMA air interface standard has been designed to supports the **always on** packet based wireless service.

– This would allow the computers, entertainment devices and mobile telephones to simultaneously share the same network and connect themselves to the Internet anytime, anywhere.

Packet data rates :

– W-CDMA can support the packet data rates up to 2.048 Mbps per stationary user which is a huge improvement as compared to the data rates supported by the 2G and 2.5 G standards.

– Due to these high data rates the users can get a high quality data, multimedia, streaming audio, streaming video and broadcast type services from the Internet.

– In the future version of W-CDMA the packet data rates for a stationary user will be increased four folds to 8 Mbps per user.

Applications of W-CDMA :

– Due to this high data rate , W-CDMA can be used for the following applications :

- The W-CDMA is designed to support the public and private network features, video conferencing and virtual home entertainment (VHE).
- With W-CDMA, a user can do the broadcasting, mobile commerce, games, interactive video, all over the world, using a small handset.
- The minimum spectrum requirement of W-CDMA is 5 MHz, which is different from the other 3G standards.
- Due to this wider band-width the W-CDMA system has to use a completely different RF equipment at each base station (as compared to the 2-G equipments).
- With W-CDMA, it is possible to support the data rates from 8 kbps to 2 Mbps.
- Each channel can carry 100 to 350 simultaneous voice calls at any given instant of time.
- Generally speaking using W-CDMA will result in at least six times increase in the spectral efficiency as compared to the GSM system.
- As W-CDMA needs to use new base station equipment, which takes time and money the installation of W-CDMA is going to take place gradually.

Features of W-CDMA (UMTS) :

- The key features of W-CDMA or UMTS are as given below :
  1. It is a wideband DS-CDMA system
  2. Backward compatibility with GSM
  3. Packet Data Rate on downlink : 2.048 Mbps
  4. Minimum forward channel bandwidth : 5 MHz.
  5. Frame structure : 16 slots per frame.

1.10.5 Comparison of GSM and W-CDMA :

GTU : S-12

University Questions

Q. 1 Differentiate between 2G-GSM and 3G-W-CDMA cellular wireless communication systems in terms of channel bandwidth, modulation technique and frame duration. **(S-12, 6 Marks)**

Sr. No.	Parameter	2-G-GSM	3-G-W-CDMA
1.	Channel bandwidth	200 KHz	5 MHz
2.	Modulation technique	GMSK	Downlink-QPSK Uplink- BPSK
3.	Frame duration	4.615 ms	10 ms

1.10.6 Comparison of Various Mobile System Generations :

- The comparison of various mobile system generations is as shown in Table 1.10.2.

Table 1.10.2 : Comparison of mobile system generations

Sr. No.	Feature	Generation		
		1G	2G	3G
1.	Generation	First	Second	Third
2.	Year of introduction	1970	1990	2001
3.	Technology	Analog cellular	Digital cellular	Broadband, IP, FDD,TDD
4.	Standard	AMPS	CDMA, TDMA, GSM	CDMA,UMTS, W-CDMA
5.	Switching	Circuit	Circuit/packet	Circuit/Packet
6.	Frequency band	824-894 MHz	850-1900 MHz	1.6-2.5 GHz
7.	Data speed	2.4 kbps	9.6 kbps	2 Mbps
8.	Multiplexing	FDMA	CDMA, TDMA	CDMA
9.	Core network	PSTN	PSTN	Packet Network
10.	Services	Only voice or only message	Digital voice, Data, SMS	High speed data, Voice, Video

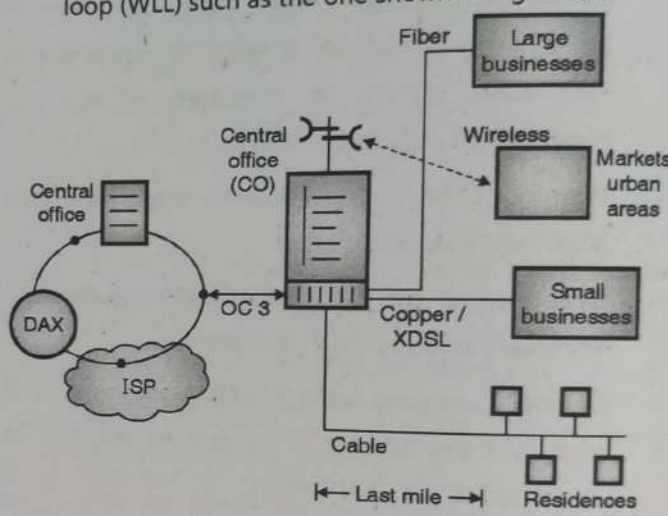
1.11 Fixed Wireless Networks :

- Due to rapid growth in the Internet users, the demand for broadband Internet and computer access has increased.
- In the developing nations like India, there is a tremendous need of inexpensive, reliable broadband connectivity.
- Due to the invention of voice over Internet protocol (VoIP) a single broadband internet connection can provide for all the needs of communication services such as telephone service, TV, radio, Fax and Internet.
- Fixed wireless equipments prove to be very well suited for the broadband applications mentioned earlier.
- They can provide the broadband local loop access or redundant point to point or point to multipoint private networks.
- The fixed wireless communication systems of modern era operate in the microwave or millimeter radio frequencies that means in the 28 GHz band and higher.
- At such high frequencies, the wavelengths are very small.
- So it possible to use very high gain directional antennas of very small size.
- These antennas reject the distortion and disturbance due to multipath reception and allows the wideband transmission.
- Also due to very high carrier frequencies, the radio channel behaves more like an optical channel.
- So if an antenna can be **seen** then the transmission is successful.
- But if you **cannot see** the antenna, then the transmission will fail.
- This shows that the fixed wireless networks at very high microwave frequencies can work well only if there are no obstructions, such as relatively flat suburban or rural areas.
- In the following subsection we will discuss two fixed wireless networks WLL and LMDS.

1.11.1 Wireless Local Loop (WLL) :

Block diagram and operation :

- WLL stands for wireless local loop. Microwave wireless links can be used to create a wireless local loop (WLL) such as the one shown in Fig. 1.11.1.



(G-1580) Fig. 1.11.1 : WLL

- The local loop can be viewed as the **last mile** of the telecommunication network which exists between the central offices (CO) and the individual homes, small businesses and markets, and big businesses near the CO as shown in Fig. 1.11.1.
- In the developed countries the copper (co-axial) cables or optical cables for the homes and businesses are already laid down.
- But in many developing nations it is not so. There the cables are too expensive or can take a long time to get installed.
- A great advantage of the wireless equipments however is that it can be deployed within a few hours.
- One more advantage of WLL technology is that we have to pay only once for the wireless equipment.

- After that there are no additional costs involved.
- The WLL technology is capable of competing with the copper wire based Digital subscriber loop (DSL) technology which is growing very fast.
- The WLL can greatly improve the telecommunication facilities and services in an inexpensive way.

Features of WLL :

- Some of the major features of WLL are as follows:
  1. It is scalable.
  2. Good quality of service.
  3. Compatible with other cellular technologies.

Advantages of WLL :

- Some of the major advantages of WLL are as follows:
  1. Less expensive as compared to wired systems.
  2. WLL can be installed quickly.
  3. Good scale of installation.

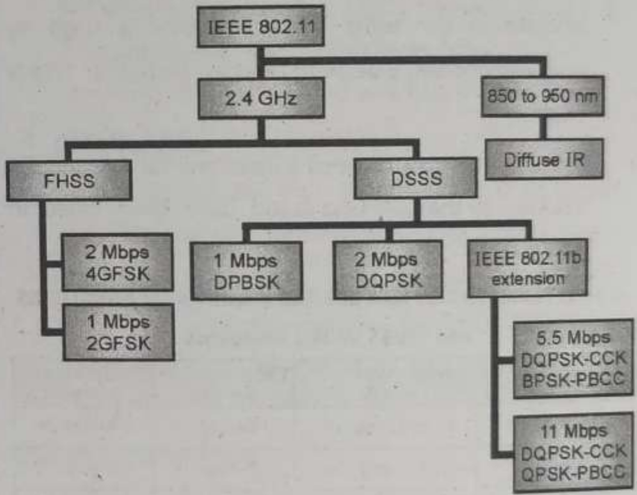
1.11.2 Wireless Local Area Network (WLAN) :

Allocation of frequency band :

- In 1997, the FCC allocated 300 MHz of unlicensed spectrum in the Industrial Scientific and Medical **(ISM)** bands of 5.150-5.350 GHz and 5.725-5.825 GHz to support low-power license-free spread spectrum data communication.
- Such a license-free spectrum was allocated by the FCC to encourage competitive development of spread spectrum equipment, individual WLANs and other low-power short range devices which would facilitate private computer communications in the workplace.
- In 1987 the IEEE 802.11 Wireless LAN working group was founded which began standardization of spread spectrum WLANs in the ISM bands.
- However, despite all favorable conditions, the WLANs did not gain momentum until the late 1990s.
- After late 1990s, WLANs became popular and started growing rapidly, when the popularity of the Internet got combined with portable, laptop computers.
- The wireless LAN standard IEEE 802.11 was finally standardized in 1997 and provided interoperability standards for WLAN manufacturers.
- After this in 1999, the IEEE 802.11b standard called as the high rate standard was approved, which provided an improved data rate capabilities of 11 Mbps, 5.5 Mbps.
- This new standard was compatible with the original IEEE 802.11.

Evolution of IEEE 802.11 Standard :

- The evolution of IEEE 802.11 is as shown Fig. 1.11.2, which also include infrared communications.



(G-2778) **Fig. 1.11.2 : Overview of the IEEE 802.11 Wireless LAN standard**

- In the original IEEE 802.11, both frequency hopping and direct sequence approaches of the spread spectrum.
- The IEEE 802.11a standard, is not shown in Fig. 1.11.2, which provides up to 54 Mbps throughput in the 5 GHz band.

Wi-Fi (IEEE 802.11b standard) :

- The IEEE 802.11b standard makes use of DS-SS (Direct Sequence Spread Spectrum) has been named Wi-Fi.
- IEEE 802.11g is developing Complimentary Code Keying Orthogonal Frequency Division Multiplexing

(CCK-OFDM) standards in both the 2.4 GHz (802.11lb) and 5 GHz (802.11a) bands.

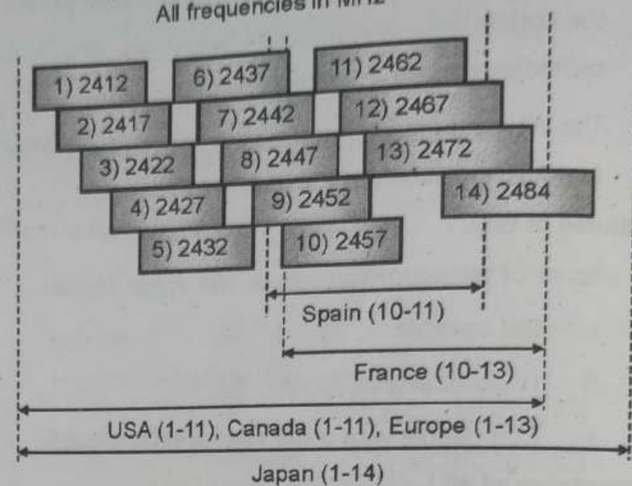
- It will support roaming capabilities , dual-band use for public WLAN networks, and will also have the backward compatibility with 802.11b technology.
- There is a frequency-hopping spread spectrum (FH-SS) group of IEEE 802.11, which gas formed the **Home RF standard** that supports frequency hopping equipment.
- In 2001, Home RF developed a 10 Mbps FH-SS standard called Home RF 2.0.
- Note that WLANs using either DS or FH, must operate in the same ISM band that is used by cordless phones, Bluetooth devices, and other WLAN users.
- The international channel allocations for DS and FH WLANs in the 2.4 GHz band have been listed in Table 1.11.1.

(G-2777) Table 1.11.1 : IEEE 802.11B channels for both DS-SS and FH-SS WLAN standards

Country	Frequency range available	DSSS channels available	FHSS channels available
United states	2.4 to 2.4835 GHz	1 through 11	2 through 80
Canada	2.4 to 2.4835 GHz	1 through 11	2 through 80
Japan	2.4 to 2.497 GHz	1 through 14	2 through 95
France	2.4465 to 2.4835 GHz	10 through 13	48 through 82
Spain	2.445 to 2.4835 GHz	10 through 11	47 through 73
Reminder of Europe	2.4 to 2.4835	1 through 13	2 through 80

Unique WLAN channels :

- The unique WLAN channels specified in the IEEE 802.11b standard in the 2400-2483.5 MHz band have been shown in Fig. 1.11.2.
- This is known as the channelization scheme.
- All WLANs operate on any one of these specified channels and the network operator makes such assignment when the WLAN system is first installed.
- The channelization scheme such as the one shown in Fig. 1.11.2 used by the network installer becomes very important if the WLAN installation has a high density.



(G-2779)Fig. 1.11.2 : The unique WLAN channels for IEEE 802.11b in 2400 to 2483.5 Hz band

- Because then, the access points in the neighbouring WLANs must be separated from one another in frequency domain, to avoid interference and performance degrading.

Designing a WLAN :

- It is essential to design all wireless systems with knowledge of the interference and propagation environment.
- The placement of transmitters in a WLAN and their frequency assignments be done systematically to minimize impact.
- WLAN networks are designed to work in a noisy environment.
- However, the access points placed at specific locations can improve the cost effectiveness and end user data throughputs in a heavily loaded system.
- The user throughput performance can change radically, when access points or clients are located near an interfering transmitter.
- One can use the tools like new computer-aided design (CAD) measurement and prediction software to deploy WLAN very rapidly without any trial and error.
- One may load the blueprint of the building or campus in a computer and use the propagation

modeling techniques along with radio signal strength and interference prediction algorithms to predict user data throughput.

- Thus, it is possible to rapidly fine the proper placement for WLAN access points before ever setting foot in the building.
- In this way, the network operator can quickly prepare and plan the channelization scheme, as well as the locations of the access points, before doing an actual network deployment.
- After completing the WLAN deployment, it is possible to use the same CAD environment to archive the following :
  1. Exact physical locations
  2. Cost and maintenance records of the network
  3. Channelization schemes for future use and
  4. Provision for the modification as network growth occurs.
- Hen01 is one of the radio signal strength and interference prediction algorithms.
- We can use it to make measurements and model the end user's throughput data as a function of signal strength and interference.

The HIPERLAN standard :

- HIPER-LAN stands for High Performance Radio Local Area Network standard.
- It was developed in Europe in the mid 1990s, to provide a similar capability to IEEE 802.11.
- The HIPER-LAN was intended to provide individual wireless LANs for computer communications.

Features of HIPERLAN :

- Some of the important features of HIPERLAN are as given below :
  1. It used the 5.2 GHz and the 17.1 GHz frequency bands.
  2. HIPERLAN is able to provide asynchronous user data rates from 1 to 20 Mbps, along with time bounded messaging at rates of 64 kbps to 2.048 Mbps.
  3. It was designed to operate up to vehicle speeds of 35 km/hr,
  4. It can provide a throughput of 20 Mbps at 50 m range.

BRAN :

- The standard organizations in Europe, North America, and Japan started coordinating spectrum allocations and end user data rates in order to facilitate convergence in the WLAN industry
- As a result Europe's ETSI established a standardization committee for Broadband Radio Access Networks (BRANs) in the year 1997.
- BRAN had the goal to develop a set of broadband WLAN-type protocols which would allow user interoperability, within both short range (e.g., WLAN) and long range (e.g., fixed wireless) networking.

The HIPERLAN/2 :

- HIPERLAN/2 is the next generation European WLAN standard, which can provide data speeds up to 54 Mbps to various networks, such as the ATM backbone, IP based networks, and the UMTS core.
- HIPERLAN/2 is anticipated to operate in the 5 GHz band.

IEEE 802.11a Standard :

- Meanwhile, IEEE 802.11a is emerging as North America's next generation WLAN, which can also supports user data rates up to 54 Mbps for integration into backbone ATM, UMTS, and IP networks.
- It will use the 5.15-5.35 GHz ISM band for its operation.

A 25 Mbps WLAN :

- Japan's Multimedia Mobile Access Communication System (MMAC) is developing high data rate (25 Mbps) WLAN standards which also will operate in the 5.15-5.35 GHz ISM band.

Resent ideas :

- With increase in wireless data rates speeds, it is possible to use WLANs for various new applications.

- One such novel application is a public LAN (publan) concept in which, a nationwide Wireless Internet Service Provider (WISP) provides and maintains a nationwide infrastructure of WLAN access points.
- These access points are located in selected hotels, restaurants, airports, or coffee shops, etc. to provide the interested users the paid Internet access.
- Other recent ideas is to use WLANs to provide access for the last 100 meters into homes and businesses.
- This would put the WLANs in direct competition with fixed wireless access, and in competition with IMT-2000.

Advantages of WLANs :

- One of the advantages of WLANs is that the WLAN hardware is much cheaper than the 3G base stations and fixed wireless millimeter wave equipment.

Disadvantages of WLANs :

- The major disadvantage of a WLAN is that it operates in the unlicensed spectrum.
- Therefore, a judicious frequency planning and radio engineering is needed to avoid saturation of neighbourhoods due to careless WLAN deployments in buildings.

The futuristic WLANs :

- In a futuristic WLAN system the WLAN access points could be mounted on lamp poles along the street.
- Some measurements in such prototype systems were actually made in several homes and in different types of foliage in the 5.8 GHz band.
- The WLAN signal strength was measured outside and inside the house with an externally mounted Customer Premises Equipment (CPE) antenna at roof height and at head height.
- If we know the specific signal loss values throughout a home or neighborhood, it is possible to determine the coverage, capacity, and cost of a contemplated system.

1.12 Bluetooth and Personal Area Networks :

GTU : W-17, S-18

University Questions

Q. 1 Write a short note on Bluetooth. **(W-17, S-18, 4 Marks)**

- Due to the rapid development in the field of wireless technology during the past two decades, electronics manufacturers realized that they can use it for various electronic applications.
- The most important feature of wireless technology is its ability to replace the connecting cords to connect devices to one another.
- Instead it is possible to connect devices such as printer, headphone, computer, keyboard mouse to each other with an invisible, low power short-range wireless connection.
- The wireless connectivity would provide convenience and flexibility.
- Furthermore, due to wireless connectivity it would be possible to move equipment throughout an office.
- It would also allow collaborative communication between individuals, their appliances, and their environment.

The Bluetooth standard :

- Bluetooth is an open wireless standard which is used by thousands of manufacturers of electronic appliances.
- Bluetooth uses an ad-hoc approach to enable various devices to communicate with one another within a range of 10 meter.
- It has been named after King Harald Bluetooth, the 10^{th} century Viking who united Denmark and Norway.
- The Bluetooth standard allows various appliances within the personal workspace of an individual to communicate with each other without any connecting wires.

Frequency band :

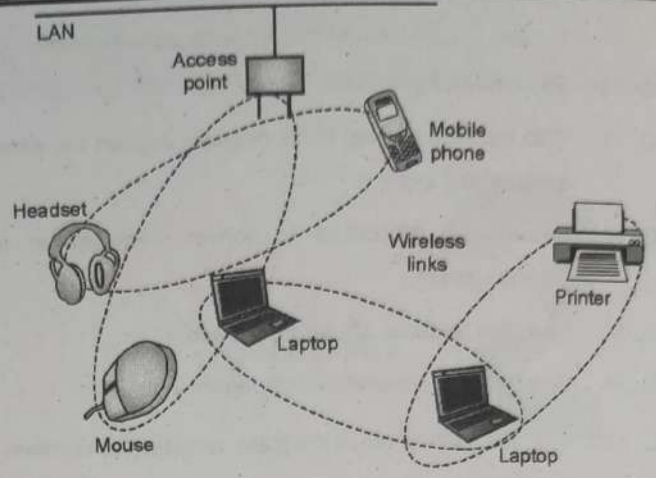
- Bluetooth uses the 2.4 GHz ISM Band (2400-2483.5 MHz) for its operation and uses a frequency hopping TDD scheme for each radio channel.

Radio interface :

- Bluetooth has the following radio interface specifications :
  1. Bandwidth of each Bluetooth radio channel is 1 MHz
  2. The hopping rate of each Bluetooth radio channel is approximately 1600 hops per second.
  3. A single packet is transmitted over a single slot which measures 625 microsecond.
  4. Users may occupy multiple slots using the same transmission frequency to transmit long data.
  5. A cyclic code of length $2^{27} - 1$, is used to determine the frequency hopping scheme of each Bluetooth user.
  6. The channel symbol rate of each user is 1 Mbps using GFSK modulation.
  7. Bluetooth standard is designed to support operation in very high interference levels.
  8. It supports a raw channel bit error rate (BER) of about 10^{-3} by using a number of forward error control FEC) coding and automatic repeat request (ARQ) schemes.
  9. Various channels have been allocated in different countries Bluetooth operation. In the US and most of Europe, the FHSS 2.4 GHz ISM band is allocated to Bluetooth.

Applications of Bluetooth :

- Bluetooth standard can support a wide range of applications, appliances, and potential users of the Personal Area Network.
- As shown in Fig. 1.12.1, Bluetooth can support the communication of audio, text, data, and even video information.
- In Fig. 1.12.1 access point (IEEE 802.11b) is connected to the wired LAN and provide a wireless access for various devices like mobile phone, laptop computer etc.



(G-2776) **Fig. 1.12.1 : Example of a personal area network (PAN) as provided by the Bluetooth standard**

IEEE 802.15 Standard :

- The IEEE 802.15 standard provides an international standard for developing Bluetooth and other PANs.
- Such personal area networks(PANs) can wirelessly interconnect pocket PCs, personal digital assistants PDAs), cell phones, light projectors, and other appliances.
- Due to rapid development of wearable computers, such as PDAs, cell phones, smart cards, and position location devices, we can use PANs to provide the connection to an entire new era of remote retrieval and monitoring of the users.

Review Questions

Q. 1 What is mobile communication ?

Q. 2 Explain the evolution of mobile radio communications.

Q. 3 Name the important mobile radio systems around the world.

Q. 4 Compare AMPS, NAMPS, GSM and IS-95.

Q. 5 State various wireless communication systems.

Q. 6 Define the following :

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

Q. 7 Explain the concept of half duplex communication.

Q. 8 What is a simplex communication ? Give one example.

Q. 9 Explain the concept of full duplex communication.

Q. 10 Explain FDD and TDD.

Q. 11 With the help of neat block diagram explain the wide area paging system.

Q. 12 Explain the procedure to convey message in a paging system.

Q. 13 State the features of paging system.

Q. 14 What are the advantages of pagers ?

Q. 15 With the help of block diagram, explain the cordless telephone system.

Q. 16 Explain the concept of cellular telephone system.

Q. 17 Define the following :

1. FVC 2. RVC 3. FCC 4. RCC

Q. 18 Explain the steps in which a call is established between a mobile telephone and landline subscriber.

Q. 19 What is roaming ?

Q. 20 Draw general block diagram of mobile phone system and explain its operation.

Q. 21 What are the types of multiplexing techniques used in mobile communication system ?

Q. 22 What is MTSO ?

Q. 23 Define cell and cluster.

Q. 24 State the frequencies used in cellular telephony.

Q. 25 Compare GSM, IS-136 and IS-95 standards.

Q. 26 Compare 1G, 2G and 3G systems.

Q. 27 Differentiate between 2G-GSM and 3G-W-CDMA cellular wireless communication systems.

Q. 28 With diagram explain various 2.5G and 3G upgrade paths for the major 2G technologies.

Q. 29 Describe evolution of 1G, 2G and 3G mobile phone systems.

Q. 30 Explain various 2.5G technologies.

Q. 31 Explain the HSCDC.

Q. 32 Explain the GPRS.

Q. 33 Explain the EDGE.

Q. 34 State the important features of first generation of wireless communication.

Q. 35 State the important features of second generation of wireless communication.

Q. 36 State the important features of third generation of wireless communication.

Q. 37 Explain the 3G system W-CDMA.

Q. 38 Write a short note on : WLAN.

Q. 39 Explain the frequency allocation plan in WLAN.

Q. 40 Explain what is HIPERLAN.

Q. 41 Write a short note on : Bluetooth.

Q. 42 State the important features of Bluetooth.

□□□

Chapter 2 : The Cellular Concept 2-1 to 2-42

Syllabus : The Cellular Concept : System Design Fundamentals : Cellular system, Hexagonal geometry cell and concept of frequency reuse, Channel Assignment Strategies, Distance to frequency reuse ratio, Channel and co-channel interference reduction factor, S/I ratio consideration and calculation for Minimum

Co-channel and adjacent interference, Handoff Strategies, Umbrella Cell Concept, Trunking and Grade of Service, Improving Coverage and Capacity in Cellular System-Cell splitting, Cell sectorization, Repeaters, Micro cell zone concept, Channel antenna system design considerations.

Syllabus : Mobile Radio Propagation Model, Small Scale Fading and diversity : Large scale path loss : Free Space Propagation loss equation, Path-loss of NLOS and LOS systems, Reflection, Ray ground reflection model, Diffraction, Scattering, Link budget design, Maximum Distance Coverage formula, Empirical formula for path loss, Indoor and outdoor propagation models, Small scale multipath propagation, Impulse model for multipath channel, Delay spread, Feher's delay spread, Upper bound Small scale, Multipath Measurement parameters of multipath channels, Types of small scale Fading, Rayleigh and Rician distribution, Statistical models for multipath fading channels and diversity techniques in brief.

Chapter 2

The Cellular Concept

Syllabus

The Cellular Concept : System Design Fundamentals : Cellular system, Hexagonal geometry cell and concept of frequency reuse, Channel Assignment Strategies, Distance to frequency reuse ratio, Channel and co-channel interference reduction factor, S/I ratio consideration and calculation for Minimum Co-channel and adjacent interference, Handoff Strategies, Umbrella Cell Concept, Trunking and Grade of Service, Improving Coverage and Capacity in Cellular System-Cell splitting, Cell sectorization, Repeaters, Micro cell zone concept, Channel antenna system design considerations.

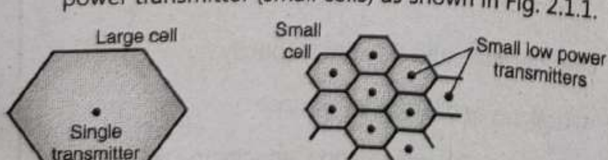
Chapter Contents

2.1 Cellular Concept :

- The aim of the early mobile radio system was to provide coverage to a large area with the help of a single high power transmitter having an antenna mounted on a tall tower.
- This approach had the following disadvantages :
  1. Frequency reuse was not possible.
  2. Proper spectrum allocation in proportion with increasing demand was not possible.
- Hence it became necessary to restructure to radio telephone system so as to achieve the following objectives :
  1. High capacity.
  2. To utilize the available radio spectrum effectively.
  3. Coverage of large areas.
- The major breakthrough in this field was the introduction of the **cellular concept.**

2.1.1 Advantages of Cellular Concept :

- The cellular concept offered the following advantages :
  1. Improved user capacity.
  2. No spectral congestion.
  3. No major technological changes.
  4. Efficient utilization of the available spectrum.
- In the **cellular systems,** a single high power transmitter is (large cell) is replaced by many low power transmitter (small cells) as shown in Fig. 2.1.1.



(G-1562) **Fig. 2.1.1 : The cellular concept**

- Note that each small cell provides coverage to a small portion of the entire large service area (large cell).

2.2 The Basic Cellular System :

GTU : W-12, W-13, S-18

University Questions

Q. 1 Define following terms:
1. Cluster 2. RSSI 3. MAHO 4. Channel Capacity 5. Dwell Time. **(W-12, 5 Marks)**

Q. 2 Why is hexagonal cell shape preferred over square or triangular cell shape to represent the cellular architecture **(W-13, 2 Marks)**

Q. 3 Define: Cluster, Hand off, Co-channel cells **(S-18, 3 Marks)**

- Cellular telephone system is a wireless telephone system. It is a multiuser system.
- In this section we are going to study the second type of multiuser system called mobile radio system or wireless communication system.

Concept :

- Cellular phone is wireless communication 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 kilometer (depends upon power of base station).

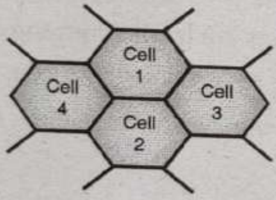
MTSO or MSC :

- The cells are normally thought of hexagons. Because cell phones and base stations use low power transmitters, the same frequencies can be reused in non-adjacent cell.
- Each cell is linked to central location called the Mobile Telephone Switching Office (MTSO).
- It is also called as Mobile Switching Center (MSC).
- MTSO coordinates all mobile calls between an area which consists of several cell sites and the central office.

- Time and billing information for each mobile unit is accounted for by MTSO.
- At the cell site base station is provided to transmit, receive, and switch calls to and from any mobile unit within the cell to the MTSO.
- A cell covers only few square kilometer area, thus reducing the power requirement necessary to communicate with cellular telephones.
- In this manner heavily populated areas can be serviced by several stations, rather than one as used by conventional mobile techniques.

Cell :

- The basic geographic unit of a cellular communication system is called as a **cell**.
- Its shape is hexagonal as shown in Fig. 2.2.1(a). Cells have the base stations transmitting over small geographic areas.

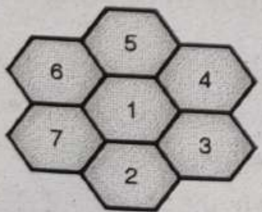


(G-1026) **Fig. 2.2.1(a) : Cell**

- The size of a cell is not fixed. Practically the shape of the cell may not be a perfect hexagon.
- The hexagonal shape has been adopted universally because it allows easy and manageable analysis of a cellular system.

Cluster :

- A group of cells is called as a **cluster**. Fig. 2.2.1(b) shows the cluster of seven cells or a seven cell cluster. (n = 7)



(G-1027) **Fig. 2.2.1(b) : Cluster**

- The cluster size (n) is not fixed. It depends on the requirements of a particular area.

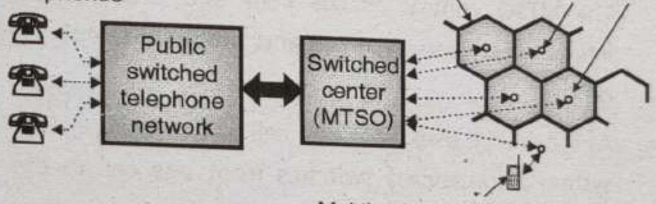
Received Signal Strength Indicator RSSI :

- RSSI (Received Signal Strength Indicator) is a measurement of the Radio Frequency (RF) power present in a received radio signal at the mobile device.

2.2.1 Structure of Cellular Phone System :

Block diagram :

- In the communication systems discussed so far, the transmitter and the receiver both were stationary.
- In the **mobile communication** which we are going to discuss now, either the transmitter or the receiver or both are going to be movable.
- As the points between which the communication takes place are movable, the communication channel has to be air, that means it is a wireless communication.
- The structure of the mobile phone network along with the public switched telephone networks is shown in Fig. 2.2.2.
- Cellular telephone system is a wireless telephone system. It is a multiuser system.



(G-1028) **Fig. 2.2.2 : Basic structure of mobile telephone network**

Description :

- The mobile telephone system has hexagonal shaped cells as shown in Fig. 2.2.2. 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**. 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. 2.2.2, 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.

Functions of MTSO :

- The MTSO control all the cells and provides the interface between each cell and the main telephone office.
- As the mobile user from one cell to the next cell, the system automatically switches from one cell to the next.
- The computer at MTSO causes transmission from the mobile user to be switched from the weaker cell to the stronger cell within a very short time.

Advantages of using MTSO :

- There are certain advantages of using MTSO over the older MTS system :
  1. It operates at a much higher frequency. So more spectrum space is available and so more number of channels can be accommodated.
  2. Due to MTSO, the cellular system can use the concept of frequency reuse. This will allow the cells to use the same frequency without the fear of interference.
  3. And the third advantage is that the cells of different size can be accommodated in the system.

Conditions Controlled by MTSO :

- Let us discuss the important conditions/things controlled by MTSO in the mobile phone system.

1. Control of transmitter output power :

- The transmitter output power is not constant but it is controllable by the cell site and MTSO.
- Special control signals picked up by the receiver are sent to an automatic power control (APC) circuit.
- The APC circuit then sets the transmitter output power to one of the eight power output levels.

2. Monitoring of the received signal strength :

- The MTSO monitors the strength of the received signal by checking the RSSI (received signal strength indicator) signal generated by the receiver.
- Based on this signal, the MTSO makes a decision about switching to another cell.

3. Frequency division ratio :

- The MTSO logic section sends the numbers corresponding to frequency division ratio.
- These numbers are loaded into the frequency divider blocks of the frequency synthesizer.
- This sets the transmit and receive channel frequencies.
- With increase in the number of users or increase in the demand for service, the number of base stations can be increased.
- The transmitter power for each base station is reduced in order to reduce the interference.
- Thus we can increase the radio capacity without any additional radio spectrum.
- This fundamental concept is used for all the modern wireless systems.

2.2.2 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.
8. No technological challenges in deployment.

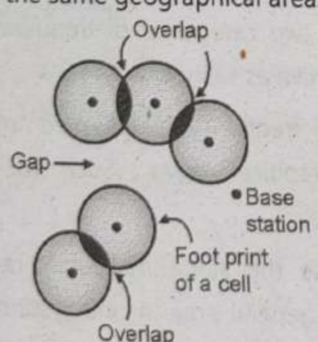
2.3 Hexagonal Cell Geometry :

GTU : S-16

University Questions

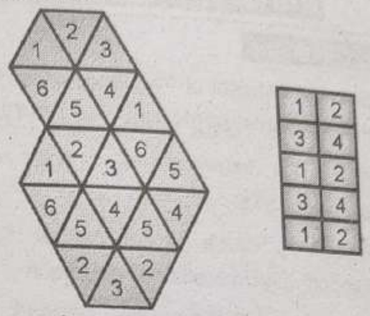
Q. 1 Explain GSM network's hexagonal cellular concept and frequency reuse concept. **(S-16, 7 Marks)**

- The signal strength decreases as it travels away from the base station.
- The **coverage area** of a BS is defined as the region over which the signal strength is higher than the threshold value say X dB.
- If the antenna at BS is assumed to be isotropic then the coverage area must be a circular region.
- **Footprint** is defined as the actual radio coverage of a cell.
- We can find out the footprint either from the field measurements or the propagation prediction models.
- Fig. 2.3.1 shows the footprints of different cells present in the same geographical area.

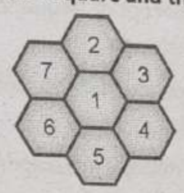


(G-2663) Fig. 2.3.1 : Footprint of cells showing the overlaps and gaps

- As shown in Fig. 2.3.1 there may be an overlap between the adjacent circular coverage areas or there may be a gap between the coverage areas of two adjacent cells.
- Therefore we cannot use such a circular geometry, as a regular shape to describe cells.
- It is important that for the cells of same shape in the same geographical area, there are no ambiguous areas belonging to multiple cells or to no cell.
- These requirements are satisfied if each cell is having one of the following shapes : equilateral triangle, square or regular hexagon.
- Fig. 2.3.2 demonstrates the triangular and square shapes of the cell whereas Fig. 2.3.3 shows the hexagonal cells.



(G-2660) Fig. 2.3.2 : Square and triangular cells



(G-2661) Fig. 2.3.3 : Hexagonal cells

- Out of these shapes, the hexagonal cell is the closest approximation of a circle. It is used for the cellular system.

Why hexagonal shape?

- Following are the reasons for selecting the hexagonal shape over square or triangular cell shape :
  1. Hexagonal shape makes the analysis of a cellular system easy and manageable.
  2. The circular cell pattern allows either overlap or gaps in the adjacent cells. This is avoided if hexagonal shape is selected.
  3. A hexagon closely approximates the circular radiation pattern and provides greater coverage without creating ambiguous areas.
  4. With the hexagon used as cell geometry, we need less number of cells to cover a large area as compared to the triangular or square cell geometry.
- It is not mandatory to place the BS always at the center of the cell. If the BS is at the center of a cell then it is called as a center-excited cell.

- Sometimes the directional antennas are placed in corner excited cell for better coverage at the edges of the cell whereas the omni-directional antennas are used in centre excited cells.

2.4 Frequency Reuse :

GTU : W-12, W-13, W-15, S-16, S-18, S-19

University Questions

Q. 1 Explain the concept of frequency reuse for cellular communication systems. **(W-12, 4 Marks)**

Q. 2 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach
(v) Dwell time vi) Cell dragging **(W-13, 6 Marks)**

Q. 3 Explain (i) Concept of frequency reuse (ii) 2G and 3G wireless networks. **(W-13, 6 Marks)**

Q. 4 (1) With figure explain the concept of frequency reuse in detail **(W-15, 7 Marks)**

Q. 5 Explain GSM network's hexagonal cellular concept and frequency reuse concept **(S-16, 7 Marks)**

Q. 6 Explain the concept of frequency reuse in cellular system. **(S-18, 4 Marks)**

Q. 7 With figure explain Frequency Reuse concept in detail. Define cluster size and write the equation for system capacity. **(S-19, 4 Marks)**

Concept :

- 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.

2.4.1 Advantages of Frequency Reuse :

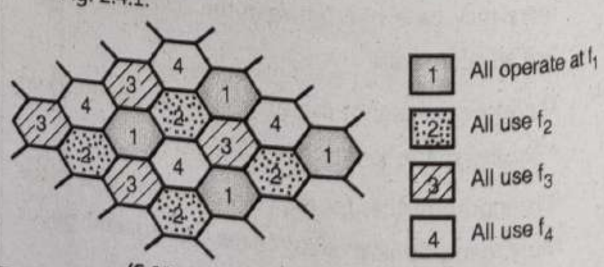
1. A single transmitter of high power need not be used to cover the entire area.
2. Many transmitter of small power working at the same frequency can be used.
3. This technique reduces the minimum height of the antenna.
4. The users located in different geographical areas i.e. different cells can use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

2.4.2 Frequency Reuse Schemes :

- We can use the concept of frequency reuse in either time domain or in the space domain.
- In the time domain the same frequency is used by different users in different time slots. This is called as time division multiplexing (TDM).

Frequency Reuse Patterns :

- There are two categories of frequency reuse in the space domain as follows :
  1. Same frequency is assigned in two different geographical areas. (Such as two different cities.)
  2. To use the same frequency repeatedly in a same general area in one system. This scheme is popularly used in cellular systems.
- The second scheme is illustrated in Fig. 2.4.1. The total available frequency spectrum is divided into 4 co-channel cell groups in the system as shown in Fig. 2.4.1.



(G-1031) **Fig. 2.4.1 : Frequency reuse**

- The cells marked-1 will use the same frequency say f_1, the cells marked-2 will use same frequency f_2 and so on.

Frequency reuse ratio :

- It is defined as 1/N where N is the cluster size. It is 1/N because each cell within a cluster is assigned only 1/N of the total available channels(frequencies) in the system.

2.4.3 Analysis of Frequency Reuse Concept :

- Let a cellular system has a total of S duplex channels available for use.
- Let each cell be allocated a group of k channels ($k < S$) and S channels be divided into N cells.

$\therefore$ S = Total number of channels.

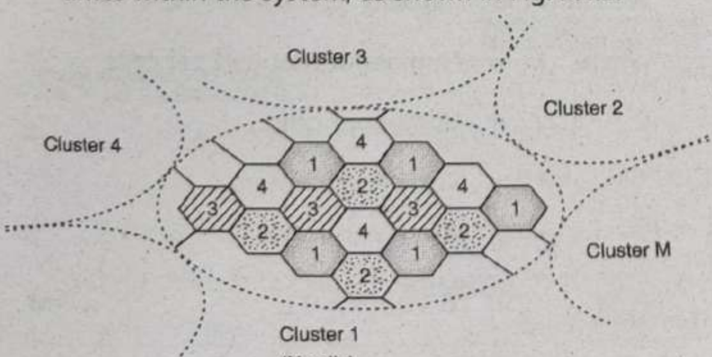
N = Number of cells.

K = Number of channels per cell.

- Then the relation between these three parameters is as follows :

$$S = kN$$

- The N number of cells collectively use all the available frequencies (f_1 through f_4 in Fig. 2.4.1) and called as a **cluster.**
- We can replicate the cluster (group of N cells) M times within the system, as shown in Fig. 2.4.2.



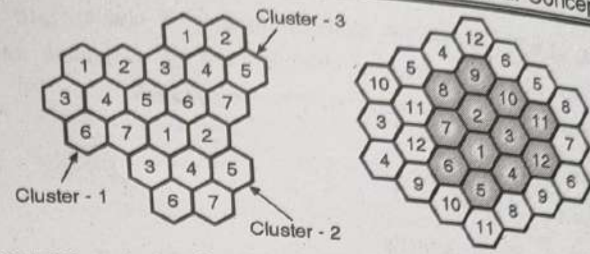
(G-1563) **Fig. 2.4.2 : A system with M cluster**

Ex. 2.4.1 : Draw the frequency reuse pattern with cluster size 7 and 12. State the advantages of frequency reuse.

Soln. :

Frequency reuse patterns :

- Fig. P. 2.4.1 shows the frequency reuse patterns with cluster size 7 and 12.



(a) With a cluster size 7 **(b) With a cluster size 12**

(G-2368) **Fig. P. 2.4.1 : Frequency reuse patterns**

2.4.4 Capacity of Cellular System (C) :

GTU : W-12

University Questions

Q. 1 Define following terms:

(i) Cluster (ii) RSSI (iii) MAHO (iv) Channel Capacity (v) Dwell Time. **(W-12, 5 Marks)**

Definition :

- The channel capacity of a cellular system is defined as the maximum number of duplex channels that it can provide for a particular fixed frequency band.
- For a cellular system of Fig. 2.4.2, the total number of duplex channels or **capacity** of the cellular system (C) is given by,

$$C = M \times k \times N = M \times S$$

- Thus the channel capacity of a cellular system is directly proportional to the value of M i.e. number of times we replicate the cluster in a fixed service area.
- N is called as the cluster size and its typically value are 4, 7 or 12.
- If we reduce the cluster size N then there will be more number of clusters (M increases) and so the capacity of the cellular system also will increase.
- But smaller cluster size (small N) leads to increased co-channel interference.
- Hence the value of cluster size N is decided based on these two factors i.e. system capacity and interference.
- From the design point of view, the size of N should be as small as possible in order to increase the capacity.

2.4.5 Frequency Reuse Distance :

- The closest distance between the centers of two cells (in different clusters) using the same frequency is called as the frequency reuse distance.

Ex. 2.4.2 : Calculate system capacity if cluster size is 7 and per cell number of channels are 72. Calculate total system capacity if 14 such clusters are available.

Soln. :

Given : N = 7, K = 72, M = 14

To find : Total capacity

- For a cellular system, the capacity of the cellular system (C) is given by,

$$C = M \times k \times N = M \times S$$

- Where M i.e. number of times we replicate the cluster in a fixed service area and k is number of channels.
- Substituting the values we get,

$$C = 14 \times 72 \times 7$$

$$\therefore C = 7056 \quad \text{...Ans.}$$

Ex. 2.4.3 : Describe the concept of 'frequency reuse' used in cellular systems. Also calculate the capacity for cluster size of 7 in cellular system which has 504 radio channels available for handling traffic. Calculate number of channels per cell. If number of clusters available in cellular systems are 15, then calculate capacity of system.

Soln. :

Given : N = 7, Number of channels = 504.

To find : 1. Number of channels per cell (K)

2. Capacity if M = 15.

Step 1 : Number of channels per cell :

$$K = \frac{\text{Total number of channels}}{\text{Cluster size}}$$

$$= \frac{504}{7} = 72 \quad \text{...Ans.}$$

Step 2 : Capacity of system if M = 15 :

$$C = M \times K \times N = 15 \times 72 \times 7 = 7560 \quad \text{...Ans.}$$

Ex. 2.4.4 : If 20 MHz of total spectrum is available for duplex system which uses 225 kHz simplex channels to provide full duplex voice and control channels, compute number of channels available per cell if a system uses seven cell frequency reuse pattern.

Soln. :

Given : Total available spectrum = 20 MHz,

Number of cells = 7,

Simplex channel B.W. = 225 kHz.

To find : Number of channels / cell.

1. Channel B.W. :

$$\text{Channel B.W. of a duplex channel} = 2 \times 225 \text{ kHz} = 450 \text{ kHz}$$

2. Total number of channels :

$$\text{Total number of channels} = \frac{\text{Total BW}}{\text{B.W. of a duplex channel}}$$

$$= \frac{20 \times 10^3 \text{ kHz}}{450 \text{ kHz}}$$

$$= 44.44$$

3. Number of channels / cell :

$$\text{Number of channels / cell} = \frac{\text{Total channels}}{\text{Number of cells}}$$

$$= \frac{44.44}{7} = 6.3 \quad \text{...Ans.}$$

Ex. 2.4.5 : Determine :

1. The channel capacity for a cellular telephone area comprised of 7 macrocells with 16 channels per cell.
2. Channel capacity if each macrocell is further split into 4 minicells.
3. Channel capacity if each mini-cell is further split into 4 microcells.

Soln. :

Part I : Find C if N = 7 and k = 16

We know that, Capacity $C = k \times M \times N$,

Where, k = Number of channels per cells

N = Number of cells.

M = Number of clusters = 1

$$\therefore C = k \times M \times N$$

$$= 16 \times 1 \times 7 = 112 \quad \text{...Ans.}$$

Part II : Find C if N = 7 × 4 = 28 and k = 16

$$\therefore C = 16 \times 1 \times 28$$

$$= 448 \quad \text{...Ans.}$$

Part III : Find C if N = 28 × 4 = 28 and k = 16

$$\therefore C = 16 \times 28 \times 4$$

$$= 1792 \quad \text{...Ans.}$$

Ex. 2.4.6 : If 20 MHz of total spectrum is allocated for a duplex wireless cellular system and each simplex channel has 25 kHz RF bandwidth, find:

(i) The number of duplex channels

(ii) The total number of channels per cell site if N=4 cell reuse is used. **S-15, 7 Marks**

Soln. :

Given : Total available spectrum = 20 MHz, Number of cells = 4, Simplex channel B.W. = 25 kHz.

To find : 1. Number of duplex channels

2. Total number of channels per cell

1. Channel B.W. :

$$\text{Channel B.W. of a duplex channel} = 2 \times 25 \text{ kHz} = 50 \text{ kHz}$$

2. Total number of duplex channels :

$$\text{Total no. of duplex channels} = \frac{\text{Total BW}}{\text{B.W. of a duplex channel}} = \frac{20 \times 10^3 \text{ kHz}}{50 \text{ kHz}} = 400$$

3. Number of channels / cell :

$$\text{Number of channels / cell} = \frac{\text{Total channels}}{\text{Number of cells}} = \frac{400}{4} = 100 \text{ channels...}\textbf{Ans.}$$

2.4.6 Selection of Cluster Size :

GTU : S-18, S-19

University Questions

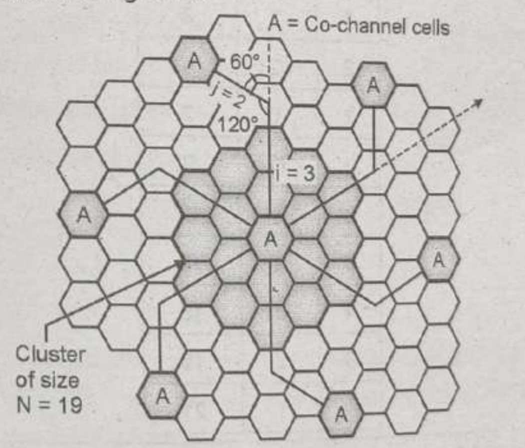
Q. 1 Define: Cluster, Hand off, Co-channel cells **(S-18, 3 Marks)**

Q. 2 With figure explain Frequency Reuse concept in detail. Define cluster size and write the equation for system capacity. **(S-19, 4 Marks)**

- For a cellular system of Fig. 2.4.2, the total number of duplex channels or **capacity** of the cellular system (C) is given by,

$$C = M \times k \times N = M \times S$$

- Thus the channel capacity of a cellular system is directly proportional to the value of M i.e. number of times we replicate the cluster in a fixed service area.
- N is called as the cluster size and its typically value are 4, 7 or 12.
- If we reduce the cluster size N then there will be more number of clusters (M increases) and so the capacity of the cellular system also will increase.
- But smaller cluster size (small N) leads to increased co-channel interference.
- Hence the value of cluster size N is decided based on these two factors i.e. system capacity and interference.
- From the design point of view, the size of N should be as small as possible in order to increase the capacity.
- A hexagonal cell has six equidistant neighbours and the lines joining the centers of any cell and its neighbours are separated by multiples of 60° as shown in Fig. 2.4.3.



(G-2659(a)) **Fig. 2.4.3 : Example of locating co-channel cells in cellular system with N = 19 (i = 3, j = 2)**

- Using the geometry of hexagon, we can find that the number of cells per cluster N is expressed by the following equation,

$$N = i^2 + ij + j^2 \quad ...(2.4.1)$$

- where i and j are non-negative integers and their significance is as follows.
- For a particular cell we can find the nearest co-channel cells (the cells operating at same frequency) as follows :

1. Move in any direction in straight line from that cell by i number of cells. In Fig. 2.4.3 we need to

move by three cells in order to turn counter clockwise to reach every co-channel cell marked as **A**. Therefore **i = 3.**

2. Then turn 60 degrees in counter clockwise direction and move by j number of cells to reach another co-channel cell. In Fig. 2.4.3 we need to move by two cells in order to reach every co-channel cell marked as **A**. Therefore **j = 2.**

– Substituting the values of i and j into Equation (2.4.1) we get the cluster size N equal to 19 and it is shown by a group of shaded cells in Fig. 2.4.3.

– By substituting different values of i and j we can obtain the cell clusters of different sizes as illustrated in Table 2.4.1.

Table 2.4.1 : Possible cluster size

i	j	N
1	1	3
2	0	4
2	1	7
3	0	9
2	2	12
3	1	13
4	0	16
3	2	19
4	1	21

Ex. 2.4.7 : Draw the frequency reuse pattern with cluster size 7.

Soln. :

Given : Cluster size N = 7, 12

To do : Draw the clusters

1. **Cluster size N = 7 :**

– We know that ,

$$N = i^2 + ij + j^2$$

– Assume i = 1

$$\therefore 7 = 1 + j + j^2$$

$$\therefore j + j^2 = 6$$

– Solving we get j = 2. Hence the cluster of size 7 is as shown in Fig. P. 2.4.7.

2. **Cluster size N = 12**

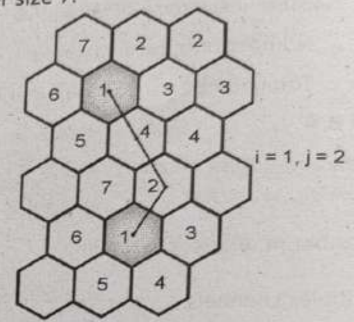
Assume i = 2

$$\therefore 12 = 4 + 2j + j^2$$

$$\therefore j^2 + 2j - 8 = 0$$

Solving we get j = 2 .

– Fig. P. 2.4.7 shows the frequency reuse patterns with cluster size 7.



A cluster with N = 7

(G-2662(a)) **Fig. P. 2.4.7 : Frequency reuse patterns**

Ex. 2.4.8 : 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.

S-20, W-20, 7 Marks

Soln. :

Given : Total bandwidth = 30 MHz,

Channel bandwidth = 25 kHz × 2 simplex channels = 50 kHz/duplex channel

$$\therefore \text{Total available channels} = \frac{30 \times 10^6}{50 \times 10^3} = 600 \text{ channels}$$

1. **Four-cell reuse:**

– Total number of channels available per cell

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

2. **Seven cell reuse:**

– Total number and channels available per cell

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

3. **12 cell reuse :**

– Total number of channels available per cell

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

– 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.

Ex. 2.4.9 : A particular FDD cellular system uses two 25 kHz simplex channels to provide full duplex voice and control channels. The total band allocated for the system is 33 MHz. Compute the number of channels available per cell if the system uses (a) 3-cell reuse (b) four-cell reuse (c) 12 cell reuse. If 2 MHz of the allocated spectrum is dedicated to control channels, determine the distribution of voice and control channels in each cell and in each of the three systems.

Soln. :

Given : Total bandwidth = 33 MHz,

Channel bandwidth = 25 kHz × 2 simplex channels

= 50 kHz/duplex channel

$$\therefore \text{ Total available channels} = \frac{33 \times 10^6}{50 \times 10^3} = 660 \text{ channels}$$

To find: Number of available channels per cell

Part-I : Number of voice channels per cell:

(a) Four-cell reuse :

Total number of channels available per cell is given by,

$$N = \frac{\text{Total available channels}}{4}$$

$$= \frac{660}{4} = 165 \text{ channels} \qquad \text{...Ans.}$$

(b) Three cell reuse:

Total number of channels available per cell = $\frac{660}{3}$

= 220 channels

...Ans.

(c) 12 cell reuse:

Total number of channels available per cell = $\frac{660}{12}$

= 55 channels

...Ans.

Part-II : Distribution of voice and control channels per cell:

– A 2 MHz spectrum is reserved for control channel.

– That means out of 33MHz now only 31 MHz spectrum is available for the voice channels .

– In the 2MHz spectrum there will be (2MHz/ 50 KHz) i.e. 40 control channels out of the 660 channels available.

– Hence the number of voice channels per cell is,

– No. of voice channels per cell = 660 – 40 = 620

– Practically only the 620 voice channels and 1 control channel will be allocated per cell.

(a) Four-cell reuse :

– Number of voice channels ,

$$N = \frac{\text{Total available voice channels}}{4}$$

$$= \frac{620}{4} = 155 \text{ channels}$$

– In addition to this, each cell needs a single control channel. Thus, one control channel and 155 voice channels will be assigned to each cell.

(b) Three cell reuse :

– Similarly for three cell reuse,

$$\text{Number of voice channels} = \frac{620}{3}$$

$$= 206 \text{ channels}$$

– In addition to this, each cell needs a single control channel. Thus, one control channel and 206 voice channels will be assigned to each cell.

(c) 12- cell reuse :

– Similarly for 12 cell reuse,

$$\text{Number of voice channels} = \frac{620}{12}$$

$$= 51 \text{ channels}$$

- In addition to this, each cell needs a single control channel.
- Thus, one control channel and 51 voice channels will be assigned to each cell.

Ex. 2.4.10 : If a total of 33 MHz of band width is allocated to a particular FDD cellular telephone system which uses two 25 KHz simplex channels to provide full duplex voice and control channels, compute the number of channel available per cell if a system uses: (l) four cell reuse (2) seven cell reuse and (3) 12 cell reuse. **S-19, 3 Marks**

Soln. : Refer the previous example.

Ex. 2.4.11 : Consider a cellular system In which total available voice channels to handle the traffic are 960. The area of each cell is 6 Km^2 and the total coverage area of file system is 2000km^2. Calculate

1. The system capacity if the cluster size,N= 4
2. The system capacity if the cluster size,N= 7

How many times would a cluster of size 4 have to be replicated to cover the entire cellular area?

Does decreasing the ruse factor N increase the system capacity? Justify your answer.

Soln. :

Given : Total available voice channels = 960,
Cell area= 6 km^2, Total coverage area of system = 2000 km^2

To find : System capacity for N = 4, N = 7.

Step 1 : System capacity for N = 4 :

- Cluster size N = 4

$\therefore$ Area of cluster with reuse = N× Cell area

$$= 4 \times 6 = 24 \text{ km}^2$$

$$\text{Number of clusters covering total area} = \frac{\text{total coverage area}}{\text{area of cluster}}$$

$$= \frac{2000}{24} = 83$$

$$\text{Number of channels per cell} = \frac{960}{4} = 240$$

System capacity C = Number of clusters × total available channels

$\therefore$ System capacity $C = 83 \times 960$

$= 79{,}680$ channels ...**Ans.**

Step 2 : System capacity for N = 7 :

- Cluster size N = 7

$\therefore$ Area of cluster with reuse = N× Cell area

$$= 7 \times 6 = 42 \text{ km}^2$$

$$\text{Number of clusters covering total area} = \frac{\text{total coverage area}}{\text{area of cluster}} = \frac{2000}{42} = 48$$

$$\text{Number of channels per cell} = \frac{960}{7} = 137$$

$\therefore$ System capacity C = Number of clusters × total available channels

$\therefore$ System capacity $C = 48 \times 960 = 46080$ ...**Ans.**

Step 3 : Effect of cluster size N :

- If the cluster size N is decreased from 7 to 4, the system capacity increases from 46,080 to 79680 channels.
- Thus, a decrease in N , increases the system capacity.

Ex. 2.4.12 : Consider geographical area of a cellular system is 480sqkm. A total of 910 radio channels are available for traffic handling suppose, area of a cell is 8 sq km.

1. How many times would the cluster size of 7 have to be replicated in order to cover the entire service area ? Calculate the number of channels per cell and system capacity.
2. It the cluster size is decreased from 7 to 4 then does it result into increase in system capacity.

Soln. :

Given : Service area of cellular system = 480km^2, Coverage area of cell = 8 km^2, $N' = 910$.

To find : Number of clusters, cell capacity and system capacity.

Step 1 : Number of clusters, cell capacity and system capacity.

Area of cluster = Number of clusters × area of cell

Area of cluster = $7 \times 8 = 56$ km^2

$$\text{Number of clusters} = \frac{\text{Service area of celluar system}}{\text{area of cluster}}$$

$$= \frac{480}{56} = 9$$ ...**Ans.**

- As total number of available channels are allocated to one cluster,

$\therefore$ Number of channels per cell $= \dfrac{N}{\text{Cluster size}}$

$$= \frac{910}{7}$$

$$= 130 \text{ channels / cell}$$

System capacity $= N \times$ Number of clusters

$\therefore$ $C = 910 \times 9$

$= 8190$ channels ...Ans.

Step 2 : New system capacity for reduced cluster size.

New cluster size = 4

$\therefore$ Area of cluster = Number of cluster × area of cell

$= 4 \times 8 = 32 \text{ km}^2$

$$\text{Number of clusters} = \frac{\text{Service area of cellular system}}{\text{area of cluster}}$$

$$= \frac{480}{32} = 15$$

System capacity $C = N \times$ Number of clusters

$= 910 \times 15$

$\therefore$ $C = 13650$ channels ...Ans.

Conclusion :

- If the cluster size is decreased from 7 to 4 there is an increase in the number of clusters.
- The system capacity also increases with increase in cluster size.
- Thus, decreasing the cluster size increases the system capacity.
- However, with this the average signal-to-channel interference also increases.

Ex. 2.4.13 : Calculate the total available channels for a cellular system having a total bandwidth of 60 MHz which uses two 50 kHz simplex channels to provide full duplex voice and control channels. Assume that the system has nine cell reuse pattern and 1 MHz of the total BW is allocated for control channels, Determine an equitable distribution of control channels. Also calculate the number of the control channels and voice channels/cell. Assume the area of the cell is 9 Sq Km and the area of the entire system is 3630 Sq Km. If the cluster size is reduced to 4, what is the system capacity. Comment on this. **W-13, 7 Marks**

Soln. :

Given : Total bandwidth = 60 MHz,

Channel bandwidth $= 50 \text{ kHz} \times 2$ simplex channels

$= 100$ kHz/duplex channel

To find:

1. Number of available channels
2. Distribution of control channels
3. Number of the control channels and voice channels/cell
4. System capacity

Step 1 : Number of available channels :

$$\therefore \text{Total available channels} = \frac{60 \times 10^6}{100 \times 10^3} = 600 \text{ channels}$$

Step 2 : Distribution of control channels per cell:

- A 1 MHz spectrum is reserved for control channel.
- That means out of 60 MHz now only 59 MHz spectrum is available for the voice channels.
- In the 1 MHz spectrum there will be (1 MHz/ 100 KHz) i.e. 10 control channels out of the 600 channels available.
- Hence the number of voice channels per cell is,
- No. of voice channels per cell = 600 – 10 = 590
- Practically only the 590 voice channels and 10 control channels will be allocated per cell.

(a) Nine-cell reuse :

- Number of voice channels,

$$N = \frac{\text{Total available voice channels}}{9}$$

$$= \frac{590}{9} = 65.55 \text{ channels}$$

- In addition to this, each cell needs a single control channel.
- Thus, 10 control channels and 65 voice channels will be assigned to each cell.

Step 3 : Number of the control channels and voice channels/cell :

Nine-cell reuse :

- Total number of channels available per cell is given by,

$$N = \frac{\text{Total available channels}}{9} = \frac{600}{9}$$

$$= 66.66 \text{ channels}$$

– Number of control channels ,

$$N = \frac{\text{Total available voice channels}}{9}$$

$$= \frac{1 \text{ MHz}}{100 \text{ kHz}} = 10 \text{ channels}$$

– Number of voice channels ,

$$N = \frac{\text{Total available voice channels}}{9}$$

$$= \frac{590}{9} = 65.55 \text{ channels}$$

Step 4 : System capacity :

Given: Cell area = 9 km^2, Total coverage area of system = 3630 km^2

System capacity for N = 9 :

– Cluster size N = 9

$\therefore$ Area of cluster with reuse = N× Cell area

$$= 9 \times 9 = 91 \text{ km}^2$$

Number of clusters covering total area =

$$\frac{\text{total coverage area}}{\text{area of cluster}} = \frac{3630}{81} = 44.81 \cong 45$$

$$\text{Number of channels per cell} = \frac{600}{9} = 66.66 \cong 67$$

$\therefore$ System capacity C = Number of clusters × total available channels

$\therefore$ System capacity C= 45 × 600

= 27,000 Channels **...Ans.**

Step 2 : New system capacity for reduced cluster size N = 4 :

Cluster size N = 4

$\therefore$ Area of cluster with reuse = N× Cell area

$$= 4 \times 9 = 36 \text{ km}^2$$

$$\text{Number of clusters covering total area} = \frac{\text{total coverage area}}{\text{area of cluster}}$$

$$= \frac{3630}{36}$$

$$= 100.83 \cong 101$$

$$\text{Number of channels per cell} = \frac{600}{4} = 150$$

System capacity C = Number of clusters × total available channels

$\therefore$ System capacity C= 101 × 600

= 60,600 channels **...Ans.**

Ex. 2.4.14 : A cellular system has 32 cells; each cell has 1.6 km radius and the system reuse factor of 7. The system is to support 336 traffic channels in total. Determine the total geographical area covered, the number of traffic channels per cell and total number of simultaneous calls supported by this system. **W-14, W-17, 7 Marks**

Soln. :

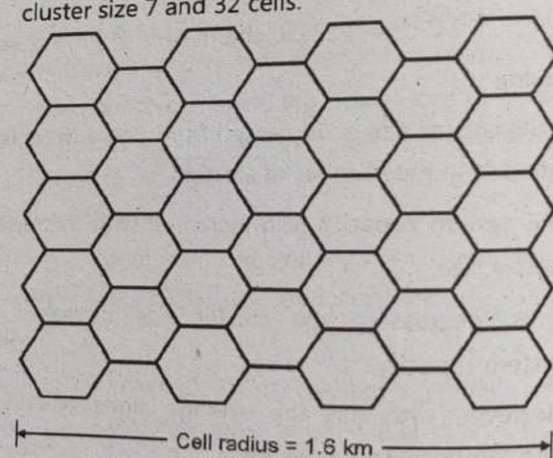
Given : Total cells = 32, R = 1.6 km, N = 7, Total traffic channels = 336

To Find :

1. Total geographical area covered
2. Number of traffic channels per cell
3. Total number of simultaneous calls supported by this system

Step 1 : Frequency reuse pattern :

– Fig. P. 2.4.14 shows the frequency reuse pattern with cluster size 7 and 32 cells.



(G-2801) Fig. P. 2.4.14 : Frequency reuse pattern

Step 2 : Total geographical area covered :

$$\text{The area of a hexagon} = \frac{3\sqrt{3}\,R^2}{2}$$

$$= \frac{3\sqrt{3}\,(1.6)^2}{2} = 6.65 \text{ km}^2$$

$\therefore$ The total area covered is 6.65 × 32 cells

= 213 km^2 **...Ans.**

Step 3 : Number of traffic channels per cell:

– For N = 7, the number of traffic channels per cell = 336/7 = 48 **...Ans.**

Step 4 : Total number of simultaneous calls supported by this system :

- Total number of simultaneous calls supported by this system = 48 × 32 = 1536 **...Ans.**

2.5 Channel Assignment Strategies :

GTU : W-12, S-14, S-17, S-18, W-19

University Questions

Q. 1 Explain channel assignment strategies for GSM Systems. **(W-12, 5 Marks)**

Q. 2 Explain in details about various channel assignment strategies. **(S-14, 7 Marks)**

Q. 3 Explain different channel assignment strategies in detail. **(S-17, 7 Marks)**

Q. 4 Briefly explain different channel assignment strategies. **(S-18, 3 Marks)**

Q. 5 Explain channel assignment strategies. **(W-19, 3 Marks)**

- In mobile communications the radio spectrum is a scares resource and therefore needs to be used efficiently.
- This can be achieved by using a frequency reuse method that will increase the capacity and minimize interference.
- In order to achieve these objectives, researchers have developed different channel assignment strategies as follows :
  1. Fixed channel assignment
  2. Dynamic channel assignment and
  3. Hybrid channel assignment strategies.
- The choice of assignment strategy is very important because it has a direct effect on the system performance.
- The quality of call management in the event of handing over a mobile user from one cell to the other depends on the choice of channel assignment strategy.

2.5.1 Fixed Channel Assignment (FCA) :

GTU : W-12, W-13, S-14, S-17, S-18, S-19, W-19

University Questions

Q. 1 Explain channel assignment strategies for GSM Systems. **(W-12, 5 Marks)**

Q. 2 Discuss the fixed channel allocation, Channel borrowing and dynamic channel allocation techniques in cellular systems. **(W-13, 7 Marks)**

Q. 3 Explain in details about various channel assignment strategies. **(S-14, 7 Marks)**

Q. 4 Explain different channel assignment strategies in detail. **(S-17, 7 Marks)**

Q. 5 Briefly explain different channel assignment strategies. **(S-18, 3 Marks)**

Q. 6 Explain: (1) static channel assignment strategy (2) dynamic channel assignment strategy **(S-19, 3 Marks)**

Q. 7 Explain channel assignment strategies. **(W-19, 3 Marks)**

- 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.

Channel borrowing :

- Channel borrowing is a process of borrowing channels from other cells or same cell.
- There are different methods of carrying out the channel borrowing.
- In one of these methods called as **borrowing strategy** a cell can borrow channels from its **adjacent cell** if all of its channels are occupied.
- The process of channel borrowing is carried out under the supervision of the Mobile Switching Centre (MSC) so that channel borrowing does not disturb or interfere with any ongoing calls in the donor cell.

Advantage :

- The channel borrowing has the advantage of preventing the costly process of cell splitting.

2.5.2 Dynamic Channel Assignment (DCA) :

GTU : W-12, W-13, S-14, S-17, S-18, S-19, W-19

University Questions

Q. 1 Explain channel assignment strategies for GSM Systems. **(W-12, 5 Marks)**

Q. 2 Discuss the fixed channel allocation, Channel borrowing and dynamic channel allocation techniques in cellular systems. **(W-13, 7 Marks)**

Q. 3 Explain in details about various channel assignment strategies. **(S-14, 7 Marks)**

Q. 4 Explain different channel assignment strategies in detail. **(S-17, 7 Marks)**

Q. 5 Briefly explain different channel assignment strategies. **(S-18, 3 Marks)**

Q. 6 Explain: (1) static channel assignment strategy (2) dynamic channel assignment strategy **(S-19, 3 Marks)**

Q. 7 Explain channel assignment strategies. **(W-19, 3 Marks)**

- 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).

Advantages :

- Advantages of dynamic channel assignment are as follows :
  1. Reduces the possibility of call blocking.
  2. Increases the trunking capacity of the system.
  3. Increases channel utilization.
  4. All available channels are accessible to all the cells.

Disadvantages :

1. Increases the storage load on the system.
2. Increases the computational load on the system.

2.5.3 Hybrid Channel Assignment :

GTU : W-12, S-14, S-17, S-18, W-19

University Questions

Q. 1 Explain channel assignment strategies for GSM Systems. **(W-12, 5 Marks)**

Q. 2 Explain in details about various channel assignment strategies. **(S-14, 7 Marks)**

Q. 3 Explain different channel assignment strategies in detail. **(S-17, 7 Marks)**

Q. 4 Briefly explain different channel assignment strategies. **(S-18, 3 Marks)**

Q. 5 Explain channel assignment strategies. **(W-19, 3 Marks)**

- 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%.

2.5.4 Difference Between FCA and DCA :

Sr. No.	Parameter	FCA	DCA
1.	Concept	Each cell is assigned with a predetermined set of voice channels.	There is no such permanent assignment of voice channels.
2.	Procedure for a call	If a number within a cell is called, then it is served by allotting an unused channel.	If a number within a cell is called, then the BS requests a channel from MSC.
3.	Blocking of a call	A call is blocked if all channels in a cell are in use.	A call is generally not blocked.
4.	Call blocking rate	Higher	Lower
5.	Borrowing strategy	A cell can borrow channels from adjacent cells under the supervision of MSC.	MSC allocates the borrowed channel after verifying certain aspects.
6.	Cannel utilization	Low	Higher

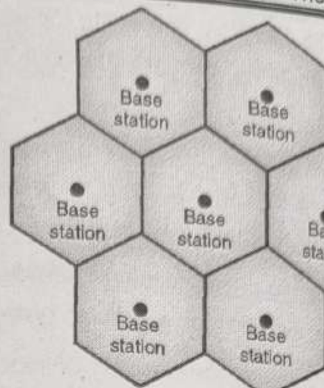
2.6 Cellular System Operation and Planning :

- The functionality, operation and system planning will be dependent on the standards that are used by a mobile system,
- However, some of the principles applicable to cellular systems are as stated below.

2.6.1 System Architecture :

Block diagram :

- The block diagram of a cellular system is as shown in Fig. 2.6.1 which shows the presence of several low power transmitters each provides coverage to a small part of service area or cells.
- Each cell is assigned a **base station (BS)** as shown in Fig. 2.6.1.



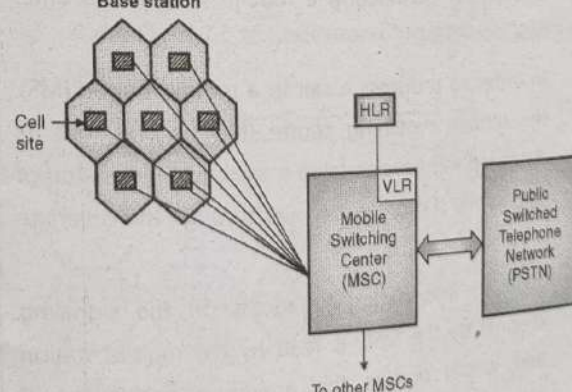
(G-1590) **Fig. 2.6.1 : Cellular system concept**

1. **Base station :**

- It is defined as a fixed (non-moving) station in a mobile radio system, which communicates with the mobile stations.
- Base stations are located at the center or on the edge of a region being covered.
- It consists of transmitter antenna, receiver antenna and radio channels mounted on a tower.
- Base stations provide a radio connection between the mobile station and the **mobile switching centre (MSC)**.

2. **Mobile switching center (MSC or MTSO) :**

- It is defined as the center which is set up for coordinating the routing of calls.
- An MSC is also called as MTSO i.e. mobile telephone switching office.



(G-1591) **Fig. 2.6.2 : Cellular system architecture**

Functions of MCS :

- The MTSO control all the cells and provides the interface between each cell and the main telephone office.

- As the mobile user from one cell to the next cell, the system automatically switches from one cell to the next.
- The computer at MTSO causes transmission from the mobile user to be switched from the weaker cell to the stronger cell within a very short time.
- Some of the important features considered while planning the activities of a cellular system are as follows :
  1. Appropriate cell size.
  2. Correct allocation of location to the cells
  3. To assign a radio channel to each cell.
- For the systems using FDMA/TDMA/CDMA, one radio channel is assigned to each cell, to carry signaling information.
- This signaling channel is a bidirectional channel.
- It carries information about mobile originated calls, location updating, paging responses etc. in the forward direction(mobile station to base station).
- In the reverse direction (base station to mobile) the signaling channels carries the information about call identity, call set up, location area identity and location updating.

2.6.2 Location Updating and Call Setup :

- As stated earlier the mobile switching centre (MSC) is used for connecting a mobile unit to the other MSCs or PSTN.
- In order to progress a call to a mobile station (MS), the mobile switching centre (MSC) along with its database will have to keep a track of the location of the mobile station as it moves through the coverage area.
- Such an information broadcast on the signaling channel by the MSC is read by the mobile station and it will update the operating parameters if necessary.
- The mobile station will also check the location information broadcast on the signaling channel.
- This information will be different than the earlier one if the mobile station has entered into a new cell.
- If so, the location information is updated in the mobile networks location register.
- The mobile switching centre (MSC) will use this information for processing calls.

Call initiated by telephone user :

- When a telephone user initiates a call to a mobile user, the mobile switching centre (MSC) sends this request to all the base stations in the system.
- The **mobile identification number (MIN)** of the subscriber (telephone number) i.e. is broadcast as a paging message on all the forward control channels of the cellular system.
- When the intended mobile receives this message, it responds by identifying itself over the reverse control channel.
- Next, the base station informs the MSC about the handshake after receiving the acknowledgement from the mobile.
- In response, the MSC instructs the base station to move this call on to an unused voice channel within the cell.
- Accordingly, the base station sends a signal to modify the frequencies to the unused forward and reverse voice channels.
- It also sends the **alert** (data message) over the forward voice channel to instruct the mobile telephone to ring and the other user to answer the ring
- After this the mobile switching center (MSC) adjusts the transmitted power (P_t) of the mobile unit as well as the base station in such a way that an adequate call quality is maintained, even though the mobile unit is on the move.
- 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 termination is called as **"hand-off"**.
- As the mobile moves away from a base station, the signal strength will reduce.
- Then the base station of the neighbouring cell in which the mobile station enters, will take control of the call.

- Thus a relay process takes place within several base stations for maintaining the call established between two users.

Call initiated by a mobile user :

- When a mobile station initiates a call to a stationary telephone user, a request signal is sent over the reverse control channel.
- In response to this request, the mobile unit will send its **Mobile Identification Number (MIN), Electronic Serial Number (ESN)** along with the telephone number of the called party.
- The mobile unit also transmits a **SCM (Station Class Mark),** that indicates its maximum transmitter power level..
- On receiving this information, the base station sends it to the mobile switching center (MSC) which checks if the signals sent by the mobile are valid.
- If so the MSC connects the mobile unit to the called subscriber through PSTN.
- It also tells the base station and mobile user to switch to an unused pair of forward and reverse voice channel frequencies to start the conversation.
- A facility called **Roaming** is provided by all the cellular systems that provides services to the users even in the service areas other than that from which the service is subscribed.

2.7 Hand Off :

GTU : W-13, S-16, S-17, W-17, S-18, W-19

University Questions

Q. 1 What is meant by Hand off and explain different Hand off strategies How handoff operation is performed while mobile moves into a different cell while a conversation is in progress. Discuss the cases for proper and improper handoff situations. **(W-13, 7 Marks)**

Q. 2 What is hand over in GSM? Give comparison of hard hand over and soft hand Over. **(S-16, 7 Marks)**

Q. 3 Define following tems: (1) Forward Channel (2) Reverse Channel (3) Control Channel (4) Paging System (5) Hand-off (6) Base Station (7) Full Duplex Systems **(S-17, 7 Marks)**

Q. 4 Define following terms (I) Dwell Time (2) Handover (3) RSSI (4) Trunking **(W-17, 4 Marks)**

Q. 5 Define: Cluster, Hand off, Co-channel cells **(S-18, 3 Marks)**

Q. 6 Define: (1) Cell Dragging (2) Handoff (3) Dwell Time (4) RSSI **(W-19, 4 Marks)**

Definition :

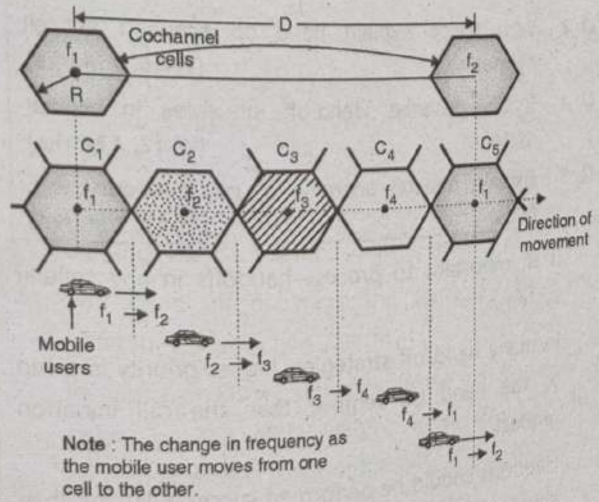
- The call in progress will continue even when the mobile station moves from one cell to the other.
- This process of continuing the call in progress without terminating it is called as **"hand-off"**.
- It is also called as **handover.**

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.

Explanation :

- Refer Fig. 2.7.1 to understand the handoff procedure clearly.



(G-1033) **Fig. 2.7.1 : Hand off procedure**

- Fig. 2.7.1 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. 2.7.1.
- 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. 2.7.1.
- The process of changing the frequency is done automatically by the system and the user does not even notice it.

2.7.1 Handoff Strategies :

GTU : W-12, W-13, W-15, W-17, S-19

University Questions

Q. 1 Briefly Describe Hand-off strategies in cellular system. Compare soft and hard Hand-off. **(W-12, 5 Marks)**

Q. 2 What is meant by Hand off and explain different Hand off strategies How handoff operation is performed while mobile moves into a different cell while a conversation is in progress. Discuss the cases for proper and improper handoff situations. **(W-13, 7 Marks)**

Q. 3 With figure explain hand off scenario at cell boundary. **(W-15, 7 Marks)**

Q. 4 Briefly describe Hand-off strategies in cellular system. **(W-17, 4 Marks)**

Q. 5 Explain handoff scenario at cell boundary with figure. **(S-19, 7 Marks)**

- It is important to process handoffs in any cellular system.
- In many hand off strategies, higher priority is given to the hand off request than the call initiation request.
- Handoffs should be performed successfully and they should not be repeated frequently.
- So as to satisfy these requirements, system designers should decide and specify an optimum signal level at which the handoff should be initiated.
- Fig. 2.7.1 illustrates handoff diagrammatically.

Handoff threshold :

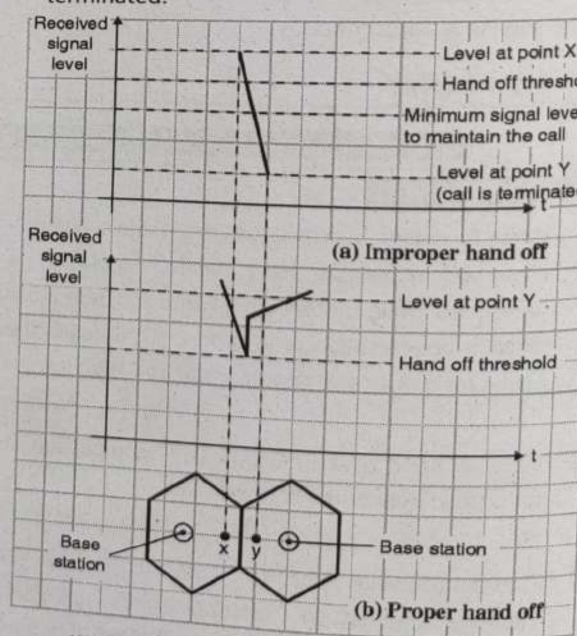
- First a minimum signal level for maintaining the call is decided.
- Then a slightly stronger signal level is used as the **handoff threshold**.
- The handoff will be made at this signal level.
- The margin between these two levels is denoted by Δ and given by,

$$\Delta = P_{r\,\text{hand off}} - P_{r\,\text{minimum usable}} \qquad \text{...(2.7.1)}$$

- Note the choice of the value of Δ is critical. Δ can not be too small and it can not be too large as well.
- If Δ is too large, then unnecessary handoffs will take place and if Δ is too small, there won't be sufficient time to complete the handoff and the call may lost due to weak signal.

Improper handoff :

- Refer Fig. 2.7.2(a) which illustrates the **improper handoff** situation i.e. handoff is not made and signal drops below the minimum signal level. The call is terminated.



(G-1564) **Fig. 2.7.2 : Illustration of improper and proper hand off**

- In Fig. 2.7.2(b), the hand off has taken place as soon as the received signal level drops to the hand off threshold.
- Note the increase in the signal level at point Y after handoff.
- Before initiating the handoff, it is necessary to ensure that the reduction in the measured signal level is not due to the momentary signal fading and that the drop in signal level is due to the actual movement of the mobile station

2.7.2 Dwell Time :

GTU : W-12, W-13, W-17, W-19, S-20, W-20

University Questions

Q. 1 Define following terms:
(i) Cluster (ii) RSSI (iii) MAHO (iv) Channel Capacity (v) Dwell Time. **(W-12, 5 Marks)**

Q. 2 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach v) Dwell time (vi) Cell dragging **(W-13, 6 Marks)**

Q. 3 Define following terms
(i) Dwell Time (ii) Handover (iii) RSSI (iv) Trunking **(W-17, 4 Marks)**

Q. 4 Define: (i) Cell Dragging (ii) Handoff (iii) Dwell Time (iv) RSSI **(W-19, 4 Marks)**

Q. 5 Define following terms: (i) Dwell time (ii) Soft handoff (iii) mobile assisted handoff (iv) Transceiver **(S-20, W-20, 4 Marks)**

- The time duration over which a call may be maintained within a cell without initiating a handoff is called as **dwell time**.
- The dwell time depends on propagation, interference, distance between the subscriber and base station etc.

2.7.3 Different Types of Hand Offs :

GTU : W-12, W-13, S-20, W-20

University Questions

Q. 1 Define following terms:
(i) Cluster (ii) RSSI (iii) MAHO (iv) Channel Capacity (v) Dwell Time. **(W-12, 5 Marks)**

Q. 2 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach (v) Dwell time vi) Cell dragging **(W-13, 6 Marks)**

Q. 3 Define following terms: (i) Dwell time (ii) Soft handoff (iii) mobile assisted handoff (iv) Transceiver **(S-20, W-20, 4 Marks)**

- Following are various types of handoffs, in relation with a mobile station (MS) :

1. Hard hand off
2. Soft hand off
3. Queued hand off
4. Delayed hand off
5. Forced hand off
6. MAHO
7. Inter cell hand-off
8. Intra cell hand-off

1. Hard hand off :

- The hand off is known as hard handoff if a mobile station transmits between two base stations operating on different frequencies.
- It means that all the old radio links in the MS are removed before the new radio links are established.
- It is generally used in GSM. We can say that it is a Break before Make strategy.
- Hence in this case higher rates of call drops is found.
- When mobile (in Call) switches to a new sector/Cell which is on different frequency , then it performs hard Handover.
- It is basically an inter-frequency handover.

2. Soft hand off :

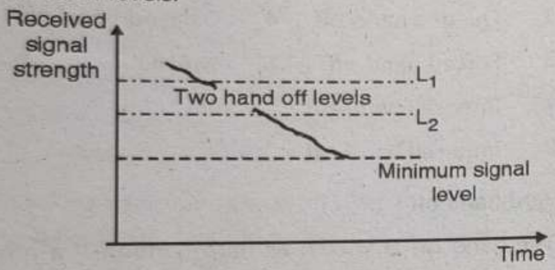
- The hand off is known as soft handoff if the MS starts communication with a new base station without stopping the communication with the older base station.
- In a soft hand off the operating frequencies of the old and new base stations are identical.
- Soft hand off enhances the signal by providing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

Softer hand off :

- If the handoff takes place within the same cell then it is known as softer hand off.

3. **Delayed hand off(Two level hand-off) :**

- In many situations, instead of one level, a two level handoff procedure is followed, in order to ensure a higher possibility of a successful handoff.
- A hand off can be delayed if no available cell could accept the call.
- Fig. 2.7.3 shows a graph of signal strength with two handoff levels.



(G-1415) **Fig. 2.7.3 : A two level handoff scheme**

- When the signal level drops below the first handoff level, the MS initiates a hand off request.
- If due to some reason the mobile unit is in a hole (Place in a cell with low signal level) or neighbouring cell is busy then the MS will repeat the handoff request after every 5 seconds.
- But if the signal strength drops down further and reaches the second handoff level (L2) then the handoff will take place without any condition, immediately.
- This process is called as **delayed hand off.**

Advantages :

1. It is possible to delay the handoff if neighbouring cells are busy.
2. The number of hand offs required to be carried out will reduce.

   This will allow the processor to handle calls more efficiently.
3. It makes the handoff occur at the proper location and eliminates the possible interference in the system.

4. **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.

5. **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.

6. **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.

7. **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.

8. **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.

2.7.4 Cell Dragging :

GTU : W-13, W-19

University Questions

Q. 1 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach (v) Dwell time vi) Cell dragging **(W-13, 6 Marks)**

Q. 2 Define: (i) Cell Dragging (ii) Handoff (iii) Dwell Time (iv) RSSI **(W-19, 4 Marks)**

- Cell dragging results from pedestrian users that provide a very strong signal to the base station.
- In urban areas when there is line of sight radio path between the subscribers and the base station as the user travel away from the base station at very slow speed, the average signal strength does not decay rapidly.
- Even when the user has travelled well beyond the designed range of the cell, the received signal at the station is above the handoff threshold, thus handoff is not made.
- But this creates a potential interference and traffic management problem, since the user has travelled deep within a neighbouring cell.
- This problem is called as cell dragging, which can be solved by adjusting handoff threshold and radio coverage parameters carefully.

2.7.5 Comparison of Hard and Soft Handoffs :

GTU : W-12, S-16

University Questions

Q. 1 Briefly Describe Hand-off strategies in cellular system. Compare soft and hard Hand-off. **(W- 12, 5 Marks)**

Q. 2 What is hand over in GSM? Give comparison of hard hand over and soft hand Over. **(S-16, 7 Marks)**

Sr. No.	Parameter	Hard hand off	Soft hand off
1.	Concept	The old radio link in MS is removed before the new one is established. It is a break before make strategy.	The old radio link is removed only after the new one is established. It is make before make strategy.
2.	Frequency	The frequencies of the two BSs are different.	The frequencies of the old and new BSs are same.
3.	Call drop rate	Higher	Lower
4.	Used by	GSM	CDMA

2.7.6 Comparison of Delayed and Queued Handoffs :

Sr. No.	Parameter	Delayed hand off	Queued hand off
1.	Principle	A hand-off request is delayed if no available cell could accept the call.	The MTSO arranges the hand off requests in a queue if no cell could accept the call.
2.	Process of repeating the hand-off requests	The MS repeats the hand-off request after every 5-seconds.	The hand-off requests are acted upon in a sequential manner.
3.	Effectiveness	Less effective.	More effective.
4.	Call drop rate	Higher	Lower

2.7.7 Umbrella Cell Approach :

GTU : W-12, W-13, S-17, W-19

University Questions

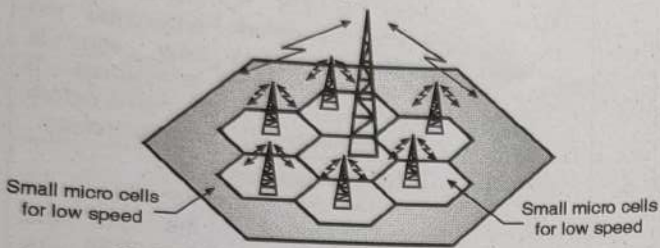
Q. 1 Explain the concept of Umbrella cell. **(W-12, 5 Marks)**

Q. 2 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach (v) Dwell time (vi) Cell dragging **(W-13, 6 Marks)**

Q. 3 Explain the concept of umbrella cell. **(S-17, 4 Marks)**

Q. 4 Explain the concept of umbrella cell. **(W-19, 4 Marks)**

- Fig. 2.7.4 shows umbrella cell approach. With the help of use of additional cell sites, capacity of cellular system can be increased.



(G-1928) **Fig. 2.7.4 : Umbrella cell approach**

- In urban areas to get new physical site is practically difficult. Instead of new cell sites, additional channels and base stations can be installed to increase the capacity of cellular system.
- To provide small and large cells located at single site, different power levels and different antenna heights can be used.
- This method is known as **umbrella cell approach.**
- The umbrella approach is suitable to provide large area coverage for high speed users, whereas for low speed users it provides small area coverage.
- It also ensures additional microcell channels for ordinary users.
- The speed of each user is estimated by base station by how rapidly the short term average signal strength on RVC changes over time.
- If high speed user in the large umbrella cell is approaching the base station and its velocity is rapidly decreasing, the base station may decide to hand the user into the co-located microcell without MSC permission.
- This approach is suitable for reducing the number of hand offs for high speed users.

Advantages :

- The advantages of umbrella cell approach are as follows :
  1. It provides large coverage area to high speed users.
  2. It minimizes the number of handoffs for high speed users.
  3. It provides additional microcell channels for the pedestrian users.
  4. If a high speed user in a large umbrella cell is near the base station and if its velocity is decreasing then the base station can hand the user into the co-located microcell without the intervention of the (MSC).

2.7.8 Prioritizing Handoffs :

1. **Guard channel concept :**

- One method for giving priority to handoffs is called the **guard channel concept**, in which a fraction of the total available channels in a cell is reserved exclusively for handoff requests from ongoing calls which may be handed off into the cell.
- However the disadvantage of this method is reduction in the total carried traffic, because fewer channels are allocated to originating calls.
- Guard channel method offers an efficient spectrum utilization when used with the dynamic channel assignment strategies.
- Because DCA minimizes the number of required guard channels by efficient demand based allocation.

2. **Queuing of handoff requests :**

- Queuing of handoff requests is another method of prioritizing handoffs to decrease the probability of forced termination of a call due to lack of available channels.
- However there is a tradeoff between the decrease in probability of forced termination and total carried traffic.
- Queuing of handoffs is possible because there is a finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated due to insufficient signal level.
- The delay time and size of the queue is determined from the traffic pattern of the particular service area.
- However, queuing does not guarantee a zero probability of forced termination.
- This is because, large delays will cause the received signal level to drop below the minimum required level to maintain communication and hence lead to forced termination.

2.8 Interference and System Capacity :

GTU : S-17

University Questions

Q. 1 What is interference? Explain the difference between co-channel interference and adjacent channel interference. Derive equation for signal to interference ratio. **(S-17, 7 Marks)**

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.

Causes of Interference :

- The interference can take place due to various reasons such as interference from another mobile in the same cell, or a call in progress in the neighbouring cell, or other base station making use of the same frequency band or some non-cellular system using cellular frequency band for its transmission.
- If interference takes place on the voice channels then the crosstalk will result.
- If it takes place on the control channels, then it will result in missed and blocked calls due to errors in the digital signaling.
- The radio frequency (RF) noise is high in the urban area so interference is more severe.
- The other reasons for greater interference are large number of base stations and mobiles present in the urban area.
- Due to interferences it is not possible to increase capacity and calls drop out more frequently.

System generated interferences :

- There are two important types of system generated interferences :
  1. Co-channel interference
  2. Adjacent channel interference
- These interferences are difficult to control practically due to the random propagation effects.
- The interferences caused by the out of band users are still more difficult to control.

2.8.1 Co-channel Interference and System Capacity :

GTU : W-13, W-14, S-15, S-16, W-17, S-19

University Questions

Q. 1 Prove that for a hexagonal symmetry, the co-channel reuse ratio is given by $Q = \sqrt{3N}$. **(W-13, W-14, W-17, 7 Marks)**

Q. 2 Explain the following terms with respect to wireless networks:
(i) Frequency Reuse (ii) Co-channel interference (iii) handoff (iv) Umbrella cell approach (v) Dwell time vi) Cell dragging **(W-13, 6 Marks)**

Q. 3 How co-channel interference and system capacity are related? **(S-15, 7 Marks)**

Q. 4 With respect to mobile networks, explain co channel and adjacent channel interference. **(S-16, 7 Marks)**

Q. 3 Define co-channel interference and adjacent channel interference. **(W-17, 3 Marks)**

Q. 4 With figure explain Frequency Reuse concept in detail. Define cluster size and write the equation for system capacity. **(S-19, 4 Marks)**

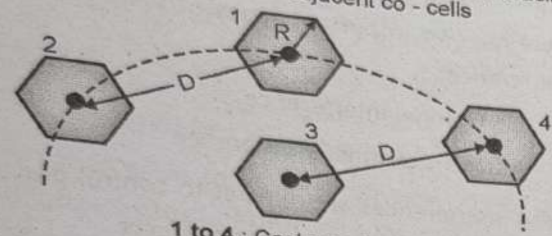
Q. 5 Describe co channel interference and adjacent channel interference. **(S-19, 3 Marks)**

Definition :

- As discussed in frequency reuse, 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. 2.8.1 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. 2.8.1 : Co-channel interference

Co-channel cells :

- In frequency reuse, a number of cells operate on the same set of frequencies. Such cells 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.

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. 2.8.1.
- 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.

Frequency reuse distance :

- The frequency reuse distance D is defined as the minimum distance of separation between the co-channel cells that allows the same frequency to be reused.
- Its value depends on factors like number of co-channel cells nearby the centre cell, the type of geographic terrain contour, antenna height and power transmitted at each cell etc.
- The expression for frequency reuse distance is as follows :

$$D = \sqrt{3N}\,R$$

- Where D = Distance between the centers of the nearest co-channel cells, and R = Radius of cell and N = Cluster size.

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.

Co-channel reuse ratio :

- A parameter Q called as **co-channel reuse ratio** is related to the D/R ratio and the cluster size N as follows :

$$Q = \frac{D}{R} = \sqrt{3\,N} \qquad ...(2.8.1)$$

- Where D = Distance between the centers of the nearest co-channel cells, and R = Radius of cell.

Effect of the value of Q :

- If the value of Q is small then the cluster size N will also be small and the **system capacity** will be **large**.
- On the other hand, if the value of Q is large, then the cluster size N will be large and the **system capacity** will be **low**.

- However a large value of Q will reduce the co-channel interference.
- Hence the selection of Q is based on these two factors i.e. system capacity and co-channel interference.

Effect of co-channel interference :

- If the value of Q is large, then the cluster size N will also be large, and will reduce the co-channel interference.
- But the large value of cluster size N will reduce the system **capacity.**
- On the other hand, if the value of Q is small, then the cluster size N will be small, co-channel interference will be more and the **system capacity** will be **higher**.

Effect of the cluster size(N) :

- If the value of cluster size N is small then it will increase the system capacity.
- But increasing the value of cluster size N will reduce the system capacity.

2.8.2 The S/I Ratio of a Mobile System :

GTU : W-12, S-17

University Questions

Q. 1 Derive the expression for S/I ratio for adjacent channel interference for cellular systems. **(W- 12, 5 Marks)**

Q. 2 What is interference? Explain the difference between co-channel interference and adjacent channel interference. Derive equation for signal to interference ratio. **(S-17, 7 Marks)**

- The signal to interference ratio in a mobile system is denoted by S/I.
- Ideally, this ratio should be infinite and practically it should be as high as possible.

Expression for (S/I) :

- We can express the signal to interference ratio (S/I) for a mobile receiver that observes a forward channel as,

$$\frac{S}{I} = \frac{S}{\sum_{i=0}^{i_0} I_i} \qquad ...(2.8.1)$$

- Where

i_0 : Number of interfering co-channel cells

S : Desired signal power from desired base station

I : Interference power from an interfering co-channel cell base station.

n : Path loss component.

- We can find the (S/I) ratio for the forward link if we know the signal levels of the co-channel cells.
- The average received power at any point in a mobile communication system decreases with increase in the distance of separation between the transmitter and the receiver.
- The average received power P_r is given by,

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n} \qquad ...(2.8.2)$$

$$\text{Or, } P_r\,(\text{dBm}) = P_0\,(\text{dBm}) - 10\, n \log\left(\frac{d}{d_0}\right) \qquad ...(2.8.3)$$

- Where,

d : distance from the transmitting antenna.

P_0 : power received at a close-in reference point in the far field region of the antenna at small distance d_0 from the transmitting antenna.

n : path loss component.

- Consider a forward link where the interference is occurring due to the co-channel base stations.
- Let D_i be the distance of the i^{th} interferer from the mobile, then the power received at a given mobile because of the i^{th} interfering cell is proportional to $(D_i)^{-n}$.
- If the path loss exponent is same throughout the coverage area and each base station transmits the same power then the (S/I) for a mobile is given by,

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} \qquad ...(2.8.4)$$

- If we consider the first layer of interfering and if each interfering base station is placed at an equal distance D from the cell center, then Equation (2.8.4) gets simplifies as follows:

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0} \qquad ...(2.8.5)$$

- This is the required expression for (S/I) ratio.

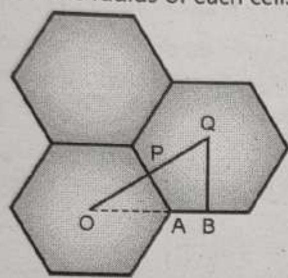
Ex. 2.8.1 : Prove that for a hexagonal symmetry, the co-channel reuse ratio is given by $Q = \sqrt{3N}$.

W-13, W-14, W-17, 7 Marks

Soln. :

Step 1 : Relation between d and R :

– Let "d" be the distance between the centers of the adjacent hexagonal cells as shown in Fig. P. 2.8.1(a) and let "R" be the radius of each cell.



(G-2795) **Fig. P. 2.8.1(a) : Distance between two adjacent cells**

– That means R is the distance between the center and a vertex of any hexagonal cell.

– From Fig. P. 2.8.1(a) we can write,

$$OA = R \quad \text{and } AB = \frac{R}{2}$$

$$\therefore OB = OA + AB$$

$$\therefore OB = R + \left(\frac{R}{2}\right) = \frac{3R}{2} \qquad ...(1)$$

– Consider the right angled triangle Δ OAP to write,

$$OP = OA \sin 60^\circ$$

$$\therefore OP = \frac{\sqrt{3}}{2} \cdot R \qquad ...(2)$$

– The distance between the centers of two adjacent hexagonal cells i.e. OQ is equal to "d".

$$\therefore OQ = OP + PQ \qquad ...(3)$$

$$\text{But } PQ = OP$$

$$\therefore OQ = 2\,OP \qquad ...(4)$$

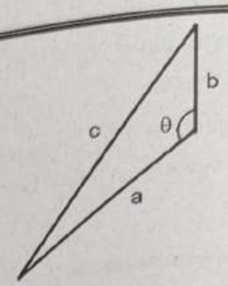
– Substituting Equation (2) into Equation (4) to get,

$$OQ = 2 \cdot \frac{\sqrt{3}}{2} \cdot R$$

$$\therefore d = \sqrt{3}\,R \qquad ...(5)$$

Step 2 : Procedure of locating a co-channel cell :

– Refer Fig. P. 2.8.1(b). We can obtain length "c" with the help of the cosine rule.



(G-2796) **Fig. P. 2.8.1(b) : Cosine rule**

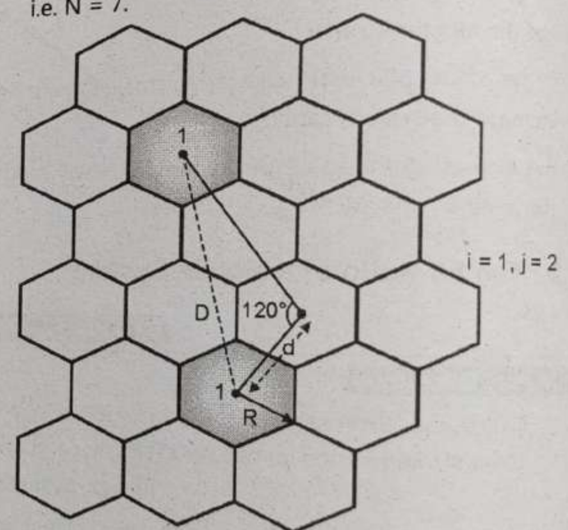
– The cosine rule is as follows :

$$c^2 = a^2 + b^2 - 2\,ab \cdot \cos\theta \qquad ...(6)$$

– Using this expression, we can obtain the value of "D", i.e. the distance between the adjacent co-channels.

Step 3 : Expression for D :

– Refer Fig. P. 2.8.1(c) which shows a cluster of size 7 i.e. N = 7.



A cluster with N = 7

(G-2802) **Fig. P. 2.8.1(c)**

– The cells marked by number "1" have the frequency. Therefore they are known as the **co-channel cells**.

– We need to obtain the distance "D" between the centers of these co-channel cells.

– Compare Fig. P 2.8.1(c) with Fig. P. 2.8.1(b), we have $a = i \times d$ and $b = j \times d$.

– Substituting these values into Equation (6) we get,

$$c^2 = D^2 = (i \times d)^2 + (j \times d)^2 - (2\,ij\,d^2 \cos 120)$$

$$\therefore D^2 = i^2 d^2 + j^2 d^2 + ij\,d^2$$

$$\therefore D^2 = d^2 (i^2 + d^2 + ij)$$

– We know that,

$$N = i^2 + ij + j^2$$

$$\therefore \; D^2 = d^2 N$$

– Substituting $d = \sqrt{3}\ R$ in the above expression we get,

$$D^2 = 3 R^2 N$$

$$\therefore \; \frac{D}{R} = \sqrt{3\ N}$$ ...Proved

Ex. 2.8.2 : Prove that for a regular hexagonal geometry, the frequency reuse ratio and cluster size are related by the relationship $Q = \sqrt{3\ N}$, where $N = i^2 + j^2 + ij$.

S-20, W-20, 7 Marks

Soln. : Same as the previous example.

Ex. 2.8.3 : For a regular cellular structure with equal size hexagonal cells, show that D/R= (21)½, Where D is the minimum distance between the centres of adjacent co-channel cells and R is the radius of each cell. Assume 7-cell reuse pattern. **S-12, 7 Marks**

Soln. :

Given : N = 7

– Refer Ex. 2.8.1 for the proof of the following expression ,

$$\frac{D}{R} = \sqrt{3N}$$

$$\therefore \frac{D}{R} = \sqrt{3 \times 7} = (21)^{1/2}$$ ...Ans.

Ex. 2.8.4 : For given path loss component n = 4 and frequency reuse factor of N = 7. Calculate S/I ratio in cellular system.

Soln. :

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,

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

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

$$= 10 \times 1.8660$$

$$= 18.66 \text{ dB}$$

...Ans.

Ex. 2.8.5 : Define co-channel cells. Determine distance from nearest co-channel cell having radius 0.64 km and co-channel reuse factor of 12.

Soln. :

Co-channel :

– In frequency reuse, a number of cells operate on the same set of frequencies. Such cells 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.

Determination of distance :

Given : R = 0.64 km, Q = 12,

$$Q = D/R = \sqrt{3N}$$

$$D = 12 \times 0.64 = 7.68 \text{ km}$$ ...Ans.

Ex. 2.8.6 : A cellular service provider decides to use a digital cellular method that can tolerate a signal to noise interference ratio 15 dB in the worst case. What is the frequency reuse factor and cluster size for maximum capacity if the path loss exponent is (a) n = 4 (b) n = 3 ? Assume that there are six co-channels in the first tier, and all of them are at the same distance from mobile.

W-15, S-20, W-20, 7 Marks

Soln. :

Given : Minimum (S/N) = 15 dB, n = 4, n = 3,

Capacity = maximum No. of co-channels $i_0 = 6$

To find : 1. Frequency reuse factor Q and

2. Cluster size N

(a) For n = 4 :

Find Q :

– Assume a seven cell reuse pattern (N=7) to write,

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

$$= 4.582$$

Find N :

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

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

$$\frac{S}{I} = 10 \log (73.46) = 10 \times 1.8660$$

$$= 18.66 \text{ dB}$$

As (S/N) is > 15 dB, we can use N = 7 ...**Ans.**

(b) For n = 3 :

- Consider a seven cell reuse pattern, and find S/I.

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(4.582)^n}{6} = 16.03$$

$$\frac{S}{I} = 10 \log (10.03) = 12.05 \text{ dB}$$

- As (S/N) is < 15 dB, i.e. minimum required value, we need to use large N.
- Let N = 12

$$\therefore \frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 12} = 6$$

$$\therefore \frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(6)^3}{6} = 36$$

$$\therefore \frac{S}{I} = 10 \log (36)$$

$$= 15.56 \text{ dB}$$

- As (S/N) > 15 dB i.e. the minimum required (S/N), we can use N=12.

Ex. 2.8.7 : Assuming six co-channel interfering cells, find the S/I ratio for path loss coefficients of n = 3 and n = 4. Consider cluster size N = 7. In which case 15 dB requirement is met? What needs to be changed to meet the same condition in second case? **W-12, 5 Marks**

Ans. : Refer Ex. 2.8.6.

2.8.3 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.

2.8.4 Adjacent Channel Interference :

GTU : S-16, W-17, S-19

University Questions

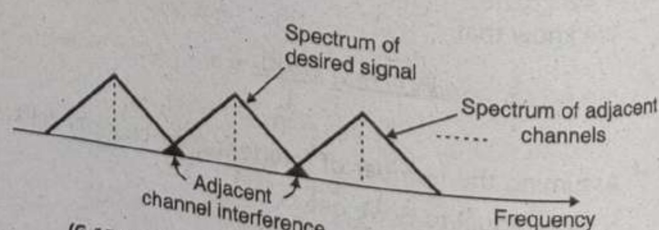
Q. 1 With respect to mobile networks, explain co channel and adjacent channel interference. **(S-16, 7 Marks)**

Q. 2 Define co-channel interference and adjacent channel interference. **(W-17, 3 Marks)**

Q. 3 Describe co channel interference and adjacent channel interference. **(S-19, 3 Marks)**

Definition :

- 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. 2.8.2.



(G-1565) **Fig. 2.8.2 : Adjacent channel interference**

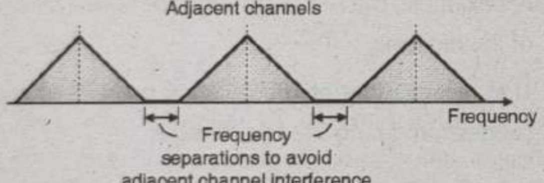
- Fig. 2.8.2 shows that due to imperfect receiver filters, the frequencies from adjacent channels interfere with the passband of the desired signal to create the adjacent channel interference.

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. 2.8.3.

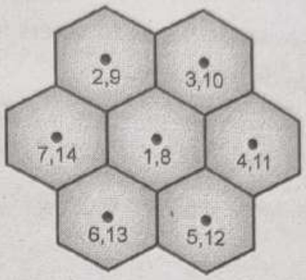


(D-1501) Fig. 2.8.3 : Frequency separation to avoid adjacent channel interference

- 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.

Sequential assignment of channels :

- We can reduce the interference by sequentially assigning the successive channels in frequency band to different cells.
- There are various allocation methods available to separate adjacent channels in a cell by N channel bandwidths.
- Fig. 2.8.4 shows an example of sequential assignment of successive channels to different cells in one cluster.



(G-2664) Fig. 2.8.4 : Sequential channel assignments to reduce adjacent channel interference

2.8.5 Power Control for Reducing Interference :

- In the practical cellular radio systems, the power transmitted by every handset or subscriber unit is under a constant control by the base station to which it is connected.
- Each handset should transmit the smallest power that is necessary to maintain a good quality of reception.
- Such a power control has two advantages :
  1. It increases the battery life of the subscribers handset.
  2. It reduces the interference.
- The power control is especially important for the CDMA spread spectrum systems because they allow every user in every cell to use the same frequency spectrum.

2.9 Trunking and Grade of Service:

2.9.1 Trunking :

GTU : W-17, S-19

University Questions

Q. 1 Define following terms
(i) Dwell Time (ii) Handover (iii) RSSI (iv) Trunking **(W-17, 4 Marks)**

Q. 2 Explain the concept of trunking and grade of service . **(S-19, 4 Marks)**

- Cellular radio systems use trunking to accommodate a large number of subscribers in the available radio spectrum.

- The concept of trunking makes it possible for a large number of users to share a small number of channels in a cell.
- Trunking allows each user to access to the available channel, on demand basis.
- In a trunked radio system, there is a pool of available channels.
- A Free channel is allocated to a user when it initiates a call.
- The channel is returned to the pool of channels as soon as the call is terminated.
- The concept of trunking that uses the **statistical behaviour** of the users to accomodalē a large number of users.
- The telephone companies determine the number of Telephone circuits, to be allotted to an office building having hundreds of relephones, with the help of **trunking theory.**
- The same concepts extended for designing a cellular radio system.

Blocking :

- In a trunked mobile radio system, if a user requests a service and all the available channels are busy, then the user is **blocked.**
- The meaning of blocking is to deny access to the system.
- Some systems use a **queue** to hold the requesting user until a channel becomes free.

2.9.2 Trunking and Queueing Theory :

- A trunked radio system is designed to handle a specific capacity at a specific **grade of service,** with the help of trunking theory and queuing theory.
- In the 19th century, a Danish mathematician **Erlang** developed the theory of trunking.
- Therefore the traffic intensity is measured in Erlang.

Definition of one Erlang :

- One Erlang is defined as the amount of traffic intensity carried by a completely occupied channel.
- One hour or one call minute per minute, an hour, then the traffic carried by it is equal to 0.5 Erlang.

2.9.3 Grade of Service (GOS) :

GTU : S-19

University Questions

Q. 1 Explain the concept of trunking and grade of service . **(S-19, 4 Marks)**

- The ability of a user to access a trunked system during the busiest hour is measured in terms of grade of service (GOS).
- GOS is used for defining the desired performance of a trunked radio system at the specified number of available channels and a desired likelihood of a user obtaining a channel access.
- In order to meet desired GOS, the radio engineer needs to estimate the maximum system capacity and allocate appropriate number of channels.
- Typically GOS is expressed as the likelihood that a call is blocked, or the likelihood that a call will experience a delay greater than a certain queing time.
- For example, the AMPS system is designed for a GOS of 2% blocking.
- That means 2 out of 100 calls will be blocked due to congestion during the busiest hour.

2.9.4 Definitions Related to Trunking Theory :

1. Set up time :

- Set up time is defined as the time required for the allocation of trunked radio channel to a requesting user.

2. Blocked call :

- A blocked call or a lost call is defined as the call which cannot be completed due to congestion.

3. Holding time (H) :

- Holding time (H) is defined as the average duration of a typical call, in seconds.

4. Traffic intensity (A) :

- It is the channel time utilization, which is equal to average channel occupancy in Erlang.
- Traffic intensity (A) does not have any units.

5. Load :

- Load is defined as the traffic intensity across the entire trunked radio system. Load is measured in Erlang.

6. **Grade of Service (GOS) :**

- GOS is a measure of congestion, which is the probility of a call being blocked (Erlang B), or the probability of a call being delayed beyond a specified time (Erlang C).

7. **Request rate (λ) :**

- The request rate is denoted by λ and defined as average number of calls requested per second.

2.9.5 Capacity of a trunked system :

- We need to use the definitions given earlier for estimation of a trunked radio system.
- The intensity of traffic offered by each user is equal to the product of call request rate and holding time

Traffic λ = Request rate and

H = Holding time

- A_U is measured in Erlang.
- The total traffic intensity offered by a system with U users and unspecified number of channels is given by,

$$A = U \times A_U \qquad \text{...(2.9.1)}$$

- If there are C number of channels in a trunked system and if the traffic is distributed equally, intensity per channel is given by,

$$A_C = \frac{U\,A_U}{C} \qquad \text{...(2.9.2)}$$

Note. : It is important to note that the offered traffic is not the actual traffic carried by a trunked system.

- If the offered traffic is higher than the maximum capacity of a trunked system, the actual carried traffic will be limited by the limited capacity ie. limited number of channels.
- The maximum possible value of the carried traffic is the total number of channels C in Erlang.

2.9.6 Types of Trunked systems :

- The trunked radio systems are of two types :
  1. Blocked calls cleared system.
  2. Blocked calls delayed system.

2.9.7 Blocked calls Cleared (BCC) System :

- This system does not offer any queuing time for call request. In other words, the set-up time for calling user is zero, if a channel is available.
- But the requesting user is **blocked** if no channel is available, and the user is free to call again.

Assumptions :

1. It is assumed that he arriving calls can be determined using **Poisson Distribution.**
2. The number of users is infinity.
3. All the users may request for a channel at any time.
4. The longer calls are less likely to occur
5. There are a finite number of channels available in the trundeing pool.

Erlang B formula :

- All the above assumptions lead to the derivation of the Erlang B formula or **blocked calls cleared formula** which is as follows :

$$P_r\,(\text{Blocking}) = \frac{A^C/C!}{\sum_{k=0}^{C}\frac{A^k}{k!}} = \text{GOS} \qquad \text{...(2.9.3)}$$

Significance :

- Erlang B formula, gives us the probability of a call getting blocked.
- It is a measure of GOS of a trunked service with no queueing for blocked calls.
- Table 2.9.1 gives the capacity of trunked radio system, in which the blocked calls are lost, for different values of number of channels (C) and GOS.

Table 2.9.1 : Capacity of an Erlang B system

Sr. No.	No. of channels (C)	Capacity (Erlang)	
		GOS = 0.01	GOS = 0.001
1.	2	0.153	0.046
2.	5	1.36	0.762
3.	10	4.46	3.09
4.	40	29	24.5
5.	100	84.1	75.2

Conclusion :

- Table 2.9.1 shows that the system capacity increases with increase in number of channels (C) and value of GOS.

2.9.8 Blocked calls Delayed (BCD) System :

- In this system, the blocked calls are held in a queue.
- A call request is delayed, if no channel is available, until a channel becomes available.
- The measure of GOS for blocked calls delayed system is defined as : It is the probability that a requested call is blocked, after it is held in the queue for a specific amount of time.

To find GOS :

- The GOS of this system is obtained by finding the likelihood that a call is initially denied the service.
- This can be obtained by using the Erlang C formula given below :

Erlang C formula :

$$P_r\,(\text{Delay} > 0) = \frac{A^C}{A^C + C!\left[1 - \frac{A}{C}\right]\sum_{k=0}^{c-1}\frac{A^k}{A!}} \quad ...(2.9.4)$$

- The probability that a call is made to wait for a time more than t seconds, is given by the following expression.

$$P_r\,[\text{Delay} > t] = P_r\,[\text{delay} > 0]\; P_r\,[\text{delay} > t]\ \text{delay} > 0]$$

$$= P_r\,[\text{delay} > 0]\ \exp\,(-(C - A)\,t/N) \quad ...(2.9.5)$$

- And the average delay for all the queued calls is equal to $H/(C - A)$.

Trunking efficiency :

- The trunking efficiency is a measure of the number of users to whom a particular GOS can be offered with a particular configuration of fixed channels.
- The number of users that can be handled by a trunked system depends largely on the way in which the channels are grouped.

2.10 Improving Coverage and Capacity in Cellular Systems : GTU : S-18

University Questions

Q. 1 Mention the techniques to improve the capacity in cellular system and explain any one. **(S-18, 3 Marks)**

Techniques used :

- With increase in the demand for wireless service, the number of channels assigned to a cell do not remain sufficient. The cell then cannot support the required number of users.
- Hence some design techniques are required for providing more channels per unit coverage area.
- This will increase the coverage and capacity of a cellular system.
- Some of such techniques are as follows :
  1. Cell splitting
  2. Sectoring
  3. Repeaters for range extension
  4. A microcell zone concept
- These techniques can expand the capacity of cellular systems to allow more channels per cell.

2.10.1 Cell Splitting :

GTU : W-15, S-17, W-17, S-18, S-19

University Questions

Q. 1 Explain the concept of Cell splitting in detail with figure. **(W-15, 7 Marks)**

Q. 2 Explain the concept of cell splitting with require figure. **(S-17, 7 Marks)**

Q. 3 Explain the Concept of cell sectoring and splitting in brief. **(W-17, 3 Marks)**

Q. 4 Mention the techniques to improve the capacity in cellular system and explain any one. **(S-18, 3 Marks)**

Q. 5 Explain (i) Cell splitting (ii) Microcell Zone concept to improve coverage and capacity of a system. **(S-19,7 Marks)**

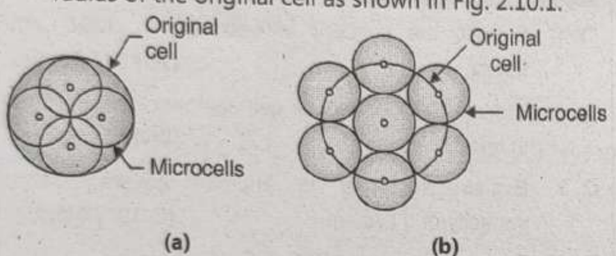
Definition :

- 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 earlier 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. 2.10.1.



(G-1032) Fig. 2.10.1 Cell splitting

Splitting techniques :

- There are two splitting techniques :
  1. Permanent splitting. 2. Dynamic splitting.

Dynamic cell splitting :

- This technique is based on utilizing the allocated spectrum efficiency in real time.
- In this of splitting techniques cells are not split permanently.
- Instead depending on requirement of traffic the splitting of the cells is carried out.
- After creating the microcells the transmitted power and antenna heights of the new base stations (one per microcell) are reduced accordingly.
- The same set of frequencies is used again (frequency reuse) as per the new plan.

Limitations of cell splitting :

1. Handoffs are more frequent.
2. Channel assignment becomes more difficult.
3. Since not all cells are split simultaneously, we need to take special care for proper allocation of problem.

Ex. 2.10.1 : Explain concept of cell splitting with neat diagram. Show that if cell radius is reduced by factor of 1/2 then traffic load increases by factor of 4. Assume shape of cell as circular.

Soln. :

- Please refer section 2.10.1 for concept of cell splitting.

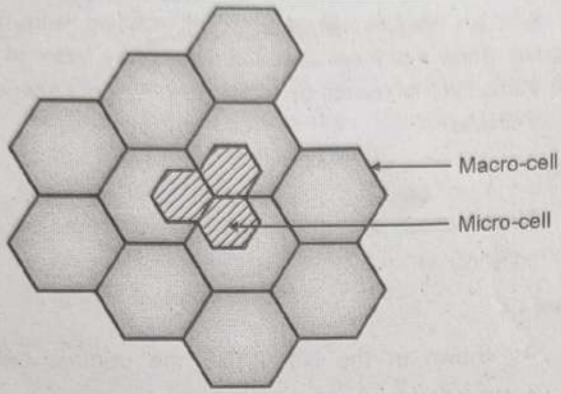
Proof :

- As shown in the Fig. 2.10.1 the original cell is surrounded by six new microcells.
- To preserve the frequency reuse plan of the system the smaller cells are added.
- Radius of new cell = (Radius of old cell) / 2.
- As the shape of cell is circular, the New Cell Area = (Old cell area) / 4.
- Assume that each new cell carries the same maximum traffic load of the old cell.
- Hence $\dfrac{\text{New Traffic Load}}{\text{Unit Area}} = 4 \times \dfrac{\text{Traffic Load}}{\text{Unit Area}}$
- Approximately four times as many cells will be required for covering the entire service area with smaller cells by considering a circle of radius R.
- By such a circle the area covered is four times as large area covered by a circle with radius R/2.

Ex. 2.10.2 : For an identical received power at the boundaries of original larger cell with radius R and the new split cell with half the radius of the original cell, show that transmitter power of any of the new split cell must be 12 dB less than the original large cell. **W-14, 7 Marks**

Soln.

- Refer Fig. P. 2.10.2 which shows that macrocell a cell is split into smaller micro-cells.
- Each microcell has a base station antenna. The radius of each microcell is half the radius of the macro-cell.
- In order to cover the entire service area of a macro-cell with the new microcells, we need to use four times as many microcells .
- The increased number of cells will increase the number of clusters over the coverage area and will increase the number of channels per unit area.
- This indicates that the capacity of the system is increased.



(G-2803)**Fig. P. 2.10.2 : Cell splitting (Macro and Microcells)**

- As the microcells are smaller in size, we need to reduce the transmitted.
- Let P_{r_0} be the received power at the large macro-cell boundary and P_{rN} be the received power at small microcell boundary.
- Then

$$P_{r_0} \propto P_{t1} R^{-n} \quad ...(1)$$

$$P_{rN} \propto P_{t2}\left(\frac{R}{2}\right)^{-n} \quad ...(2)$$

Where, P_{t1} : Transmit power of larger macro-cell.

P_{t2} : Transmit power of smaller microcell.

n : Path loss exponent.

- The received powers for both large and small cells should be the same.

$$\therefore P_{r_0} = P_{rN}$$

$$\therefore P_{t1} R^{-n} = P_{t2}\left(\frac{R}{2}\right)^{-n}$$

- The path loss exponent n = 4 as four microcells are required to cover the area of one macro-cell.
- Then

$$P_{t1} R^{-4} = P_{t2}\left(\frac{R}{2}\right)^{-4}$$

$$\therefore P_{t2} = \frac{P_{t1}}{16}$$

- This indicates that the transmitter power of any new microcell is 16 times less than that of the original macro-cell.
- This corresponds to a reduction by 12 dB, in order to fill in the original coverage area with microcells for maintaining the (S/I)requirement.

Ex. 2.10.3 : Illustrate the principle of cell splitting in a cellular system. Prove that the transmit power of the microcell must be reduced by 12 dB in order to fill in the original coverage area with microcells, while maintaining the S/I requirement for the path loss exponent n = 4

W-13, 6 Marks

Soln. :

- Refer Section 2.10.1 for the principle of cell splitting and Ex. 2.10.2 for the numerical.

2.10.2 Cell Sectoring :

GTU : W-15, W-17, S-19, W-19

University Questions

Q. 1 Explain the concept of sectoring in detail with figure. **(W-15, 7 Marks)**

Q. 2 Explain the Concept of cell sectoring and splitting in brief. **(W-17, 3 Marks)**

Q. 3 Explain sectoring to improve coverage and capacity of a system. **(S-19, 7 Marks)**

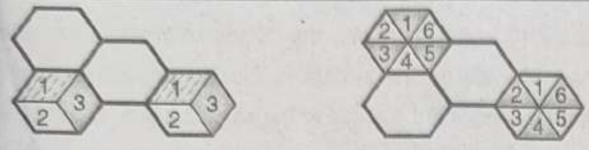
Q. 4 Explain the concept of Cell Sectoring. **(W-19, 3 Marks)**

Definition :

- **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.



(a) 120° sectoring (b) 60° sectoring

(G-1566) **Fig. 2.10.2 : Principle of sectoring**

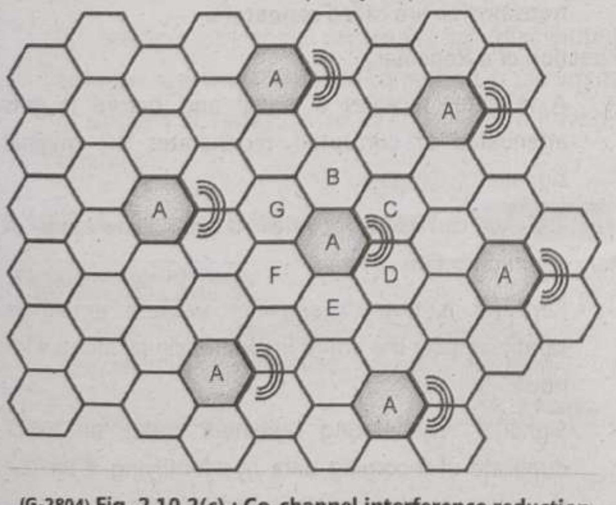
- The co-channel interference is reduced by replacing the omni-directional antenna at the base station by several directional antennas.
- Each directional antenna is allowed to radiate within a specific sector, so that that the transmitters in adjacent cells will not interfere with each other.
- The 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. 2.10.2(a) and (b) namely, 120° sectoring and 60° 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. 2.10.2(a) and (b).

Example :

- Fig. 2.10.2(c) shows a 7-cell reuse pattern (N=7) with 120° sectoring. The possible number of interferers in the first tier will be two (i.e. i_0 = 2).



(G-2804) **Fig. 2.10.2(c) : Co-channel interference reduction using 120° sectoring**

- Thus, the number of interfering cells gets reduced from 6 (without sectoring) to 2 with 120° sectoring.
- We can explain this with the help og Fig. 3.6.3. the Let us find out how many cells interfere with a mobile located in the central cell "A" of the right most sector.
- As shown in Fig. 2.10.2(c), there are three co-channel sectors marked "A" to the right of the central cell and three to the left of center cell.
- Out of these six co-channel cells, only two cells have sectors with antenna patterns that radiate into the central cell.
- Thus the number of interfering cells reduce from 6 to 2 in a a 7-cell reuse pattern (N=7) with 120° sectoring. This improves the (S/I) is improved.
- The (S/I) improvement allows the cellular provider to decrease the cluster size N in which improves the frequency reuse as well as the system capacity.
- In 60° sectoring, the number of interferers is reduced from 6 to 1. This will improve the (S/I) value further.
- The price paid for improvement in (S/I) and system capacity is that there is a decrease in cluster size N which increases number of antennas at each base station.
- The channel sectoring at the base station also reduces the trunking efficiency.
- Sectoring also reduces the coverage area of a specific group of channels. This increases the number of hand-offs.

Advantages :

1. It Improves the signal to interference ratio (SIR).
2. It increases the system capacity.
3. It reduces the interference.
4. It reduces the cluster size and provides freedom to assign channels.

Disadvantages :

1. It increases the number of directional antennas at each base station.
2. The coverage area is reduced which results in increase in number of handoffs.
3. The channel sectoring at the base station reduces the trunking efficiency.

Ex. 2.10.4 : Explain Co-channel interference in cellular system. A cellular system has a cluster size 7 and path loss exponent n = 4. Determine the S/I for the system. Now, if each cell is sectored in 120° sectors, what will be the improvement in S/I compared to non-sectored system in dB? **S-18, 7 Marks**

Soln. :

– Refer Section 2.8.1 for Co-channel interference in cellular system.

Part-I : S/I without sectoring :

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,

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

– Without sectoring, the number of interfering co-channel cells i_0 is equal to 6

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

$$\therefore \frac{S}{I} = 10 \log (73.46) = 10 \times 1.8660$$

$$\therefore \frac{S}{I} = 18.66 \text{ dB}$$ ...Ans.

Part-II : S/I with 120° sectoring :

Given : n = 4, N = 7

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

Find S/I :

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

– With sectoring, the number of interfering co-channel cells i_0 is equal to 2.

$$\therefore \frac{S}{I} = \frac{1}{2} \times (4.582)^4 = 220.5$$

$$\therefore \frac{S}{I} = 10 \log (220.5) = 23.43 \text{ dB}$$ ...Ans.

Part-III: Improvement in (S/I) :

Due to 120o sectoring the improvement in (S/I) is

Improvement in (S/I) = 23.43 – 18.66 = 4.77 dB ...Ans.

Ex. 2.10.5 : Determine the Signal-to-Interference (Co-channel) ratio for the system in Ex. 2.8.3 in dB, assuming path loss exponent n = 4. For the same system, if, each cell is sectored in 120° sectors, what will be the improvement in Signal-to-interference ratio compared to non-sectored system, in dB? Also, determine adjacent channel interference for the same system. **S-12, 7 Marks**

Soln. :

– Refer Section 2.10.2 and Ex. 2.10.4.

Ex. 2.10.6 : Compare the S/I ratio for a mobile radio for the following cases of cellular system with frequency reuse factor of 7 for 1. Omni directional antenna 2. 120° Directional antennas. **W-13, 7 Marks**

Soln. :

– Refer Ex. 2.10.4.

Ex. 2.10.7 : For a seven cell reuse pattern and hexagonal cell geometry show that 120° sectoring improves signal to interference ratio by about 5 dB. **S-14, 7 Marks**

Soln. :

– Refer Ex. 2.10.4.

2.10.3 Repeaters for Range Extension :

Definition :

– 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 :

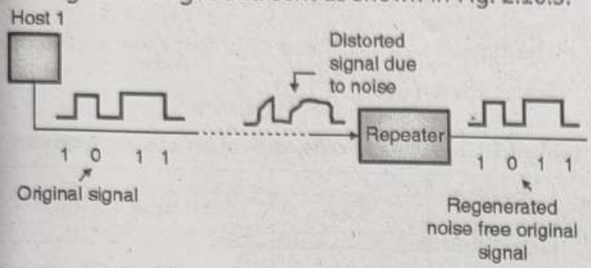
– A repeater receives a signal and before it gets attenuated or corrupted, regenerates the original signal.

– 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.

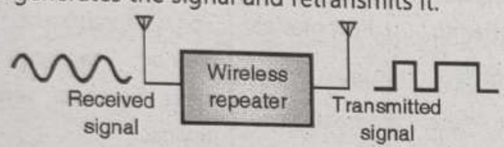
- The original signal is duplicated, boosted to its original strength and sent as shown in Fig. 2.10.3.



(G-352) **Fig. 2.10.3 : Function of a repeater**

Wireless Repeaters :

- Fig. 2.10.4 illustrates the concept of a 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.



(G-2397) **Fig. 2.10.4 : Concept of wireless repeater**

- We can overcome the signal impairment caused by RF attenuation, with the help of repeaters.

Demerit :

- As a repeater retransmits every received frame, the effective traffic on the network is doubled.
- This problem will further increase due to the use of multiple repeaters and therefore degrades the performance of a WLAN.
- Hence repeaters should be used carefully.
- In practice directional antennas or **distributed antenna systems (DAS)** are connected at the inputs or outputs of repeaters so as to achieve the range extension.

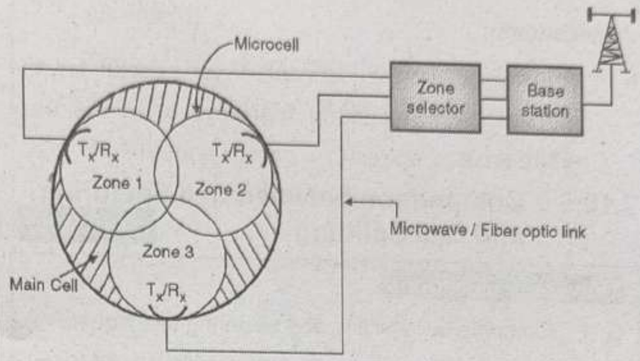
2.10.4 A Microcell Zone Concept : GTU : S-19

University Questions

Q. 1 Explain (i) Cell splitting (ii) Microcell Zone concept to improve coverage and capacity of a system. **(S-19, 7 Marks)**

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. 2.10.5.



(G-1568) **Fig. 2.10.5 : The microcell concept**

- As shown in Fig. 2.10.5, 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. 2.10.5) 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. 2.10.5, 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.

Advantages :

1. It reduces the co-channel interference.
2. It improves signal quality.
3. It increases the system capacity.
4. There is degradation in the truncking efficiency.

Applications :

- The microcell zone concept is very useful for the mobiles travelling along highways or in the busy urban areas.

2.10.5 Comparison between Cell Sectoring and Cell Splitting : GTU : W-12

University Questions

Q. 1 Compare cell splitting and sectoring techniques. **(W-12, 4 Marks)**

- Table 2.10.1 summarizes difference between cell sectoring and cell splitting.

Table 2.10.1

Sr. No.	Parameter	Cell sectoring	Cell splitting
1.	Definition	Sectoring is a method of increasing the number of channels per unit area.	Splitting is a method of dividing a larger cells to increase capacity in congested area.
2.	Types	60°, 120° sectoring.	Permanent, dynamic.
3.	Cell size	Remains same.	Cell is subdivided to form new cells of smaller radius.
4.	Antennas	Single omni directional antenna at the base station is replaced by many directional antennas.	Single omni directional antenna is used at the base station.
5.	Cell radius	D/R ratio is decreased by keeping cell radius constant.	New cell is one half of the radius of original cell.
6.	Structure	Refer Fig. 2.10.2.	Refer Fig. 2.10.1.

2.10.6 Types of Cells :

- Hierarchical cellular network consist of cells of four different sizes namely:
  1. Macrocell
  2. microcell,
  3. picocell and
  4. femtocell.
- Out of these, macrocells are the biggest while femtocells are the smallest in size.
- The typical sizes of these cells and their applications are as shown in Fig. 2.10.2.

Table 2.10.2 : 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

- The cells except the macrocells come under the category of small cells.
- They need low power and suited for domestic / clusters of houses /small businesses.
- Small cells have low investment, low space requirement, low cost and can be set up and configured easily.
- It is suitable for the cell operators, households and small businesses for extending the coverage and improving the signal strength.

2.11 Channel Antenna System Design Considerations :

- In this section we have taken an overview of antenna design considerations.
- These considerations are as given below :
  1. System requirements
  2. Antenna selection
  3. Antenna placement
  4. Antenna element design/simulation and
  5. Antenna measurements.

2.11.1 Antenna Requirements :

- Some of the important antenna requirements are as given below :

1. **Gain and communication range :**

- The first step in deciding the antenna requirements is to determine the desired communication range and terminal characteristics of the radio system such as transmit power, minimum receiver sensitivity level etc.
- From these parameters and by using the Friis Transmission formula we can ascertain the amount of antenna gain required for the given communication range.
- The antenna gain also depends on its directivity.

2. **Antenna size and clearance :**

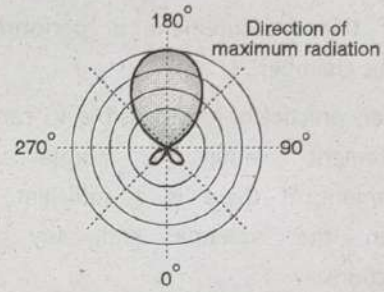
- In practice, the antenna gain is a trade-off between its desired performance and the physical realization constraints like size, placement and clearance (distance from obstructions).
- The antenna gain and its effective aperture area are directly proportional to its physical size.
- Larger antennas have higher gains. In mobile communications we need to use small yet high gain antennas to improve the system performance.

3. **Antenna gain details :**

- Antenna gain of an antenna is defined as the ratio of radiated power intensity by it relative to the radiated power intensity of an isotropic (omni-directional) radiator.
- For the same amount of radiated power, a directional antenna will have a higher gain in the desired direction than the isotropic radiator.
- The use of directional antennas also reduce the inter cell interference.

4. **Antenna radiation patterns :**

- We have defined a source called isotropic antenna as the source which radiates/receives equally in/from all the possible directions.
- However all the practical transmitting/receiving antenna are not isotropic antennas.
- They can transmit/receive "more" energy in some directions than the other directions.
- A graph or diagram which tells us about the manner in which an antenna radiates power in different directions is known as the "radiation pattern of antenna".
- For a receiving antenna the diagram is known as the "directional pattern" of the antenna.
- An antenna having a radiation pattern of Fig. 2.11.1 is called as the "**Directional** antenna".



(D-1362) **Fig. 2.11.1 : Radiation pattern of an antenna**

- The antenna patterns are displayed as 3D plots. An antenna should be selected based the desired radiation/direction pattern.

5. **Types of antennas :**

- There are many possible topologies or structures for an antenna.
- The base stations generally use the microwave dish antennas or horn antennas whereas, the mobile handsets use the micro strip patch antennas.

6. **Antenna design and simulation :**

- We can carry out the initial design of an antenna from a set of dimensional formulas based on closed-form electromagnetic relations.
- However, these antennas require some empirical adjustment and/or tuning steps before arriving at the final design..
- The electromagnetic relations associated with most antennas are not of a closed form and therefore do not yield dimensional synthesis equations.
- Therefore, in order to design and validate an antenna before its fabrication, it is necessary to simulate the antenna using a electromagnetic field solver in order to predict the behavior of radiating systems.

7. **Antenna design validation and measurement :**

- After synthesizing and realizing the antenna, the design must be validated through measurement.
- The measurements such as reflection coefficient of the antenna input port, and associated driving point impedance is carried out with a vector network analyzer (VNA).
- During this measurement it is necessary to ensure that the antenna is radiating and not being disturbed by any surrounding objects.
- Ideally, this measurement is performed in an anechoic chamber.
- However, practically it is possible to carry out this measurement within a normal laboratory environment, if there is a sufficient separation between the antenna and any perturbing obstructions.

Review Questions

Q. 1 Define cell and cluster.

Q. 2 State the frequencies used in cellular telephony.

Q. 3 What is frequency reuse ?

Q. 4 What is cell splitting ?

Q. 5 What is CDMA ?

Q. 6 State the advantages of cellular concept.

Q. 7 Draw general block diagram of mobile phone system and explain its operation.

Q. 8 Draw block diagram of mobile phone system and explain the operation of each block.

Q. 9 Name the conditions which are controlled by the MTSO in the transreceiver.

Q. 10 What are cells ?

Q. 11 Explain cell splitting.

Q. 12 What are the functions of MTSO ?

Q. 13 Explain the handoff procedure.

Q. 14 State the frequency bands used for mobile telephony.

Q. 15 Write a note on frequency reuse in cellular system.

Q. 16 Explain the concept of cell splitting.

Q. 17 Explain the handoff procedure in cellular system.

Q. 18 Define the capacity of a cellular system.

Q. 19 Define the frequency reuse factor and state its importance.

Q. 20 State various handoff strategies.

Q. 21 Define "Dwell time".

Q. 22 Define : 1. Hard handoff 2. Soft hand-off

Q. 23 Explain the concept of delayed hand off and state its advantages.

Q. 24 Explain : 1. Forced handoff. 2. Queued handoff.

Q. 25 Write a note on : Interfaces and system capacity.

Q. 26 Define :

1. Co-channel interference.

2. Adjacent channel interference.

Q. 27 Define co-channel reuse ratio Q.

Q. 28 Write a note on : Channel planning for wireless systems.

Q. 29 Explain what is adjacent channel interference and how to minimize it.

Q. 30 Explain the concept of sectoring and state its advantages and drawbacks.

Q. 31 Write a note on : Repeaters.

Q. 32 Explain the microcell concept and state its advantages.

Q. 33 Write a note on : Channel antenna design considerations.

□□□

Chapter 3 : Mobile Radio Propagation **3-1 to 3-68**

Syllabus : Mobile Radlo Propagation Model, Small Scale Fading and diversity : Large scale path loss : Free Space Propagation loss equation, Path-loss of NLOS and LOS systems, Reflection, Ray ground reflection model, Diffraction, Scattering, Link budget design, Maximum Distance Coverage formula, Empirical formula for path loss, Indoor and outdoor propagation models, Small scale multipath propagation, Impulse model for multipath channel, Delay spread, Feher's delay spread, Upper bound Small scale, Multipath Measurement parameters of multipath channels, Types of small scale Fading, Rayleigh and Rician distribution, Statistical models for multipath fading channels and diversity techniques in brief.

3

Mobile Radio Propagation

Syllabus

Mobile Radio Propagation Model, Small Scale Fading and diversity : Large scale path loss : Free Space Propagation loss equation, Path-loss of NLOS and LOS systems, Reflection, Ray ground reflection model, Diffraction, Scattering, Link budget design, Maximum Distance Coverage formula, Empirical formula for path loss, Indoor and outdoor propagation models, Small scale multipath propagation, Impulse model for multipath channel, Delay spread, Feher's delay spread, Upper bound Small scale, Multipath Measurement parameters of multipath channels, Types of small scale Fading, Rayleigh and Rician distribution, Statistical models for multipath fading channels and diversity techniques in brief.

Chapter Contents

Chapter Contents

3.1 Introduction :

- The mobile radio channel puts limitations on the best performance of a wireless communication system.
- The wired channels are stationary and predictable.
- On the other hand, mobile channels are random in their characteristics and difficult to analyze.
- Multiple factors such as speed of mobile station determine how rapidly the signal levels fade.
- Therefore modeling a mobile radio channel is a very difficult part of the mobile radio system design.

3.1.1 Radio Wave Propagation :

- The important mechanisms for EM wave propagation are : reflection, diffraction and scattering.
- Most mobile radio systems operate in the cities, where due to tall buildings, there is no direct Line of Sight (LOS) path between the transmitter and receiver.
- The tall buildings also introduce a heavy diffraction loss.
- The large scale propagation models predict the received power and the path loss, based on the physics of these propagation mechanisms.
- It is also possible to explain the small scale fading and multipath propagation by the physics of the three basic propagation mechanisms.

1. Reflection :

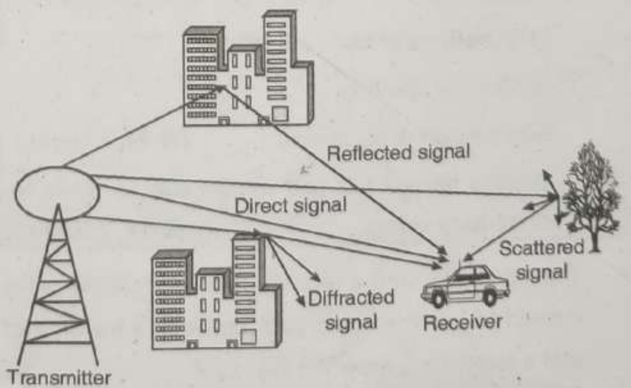
- If a propagating radio wave hits an object the size of which is very large as compared to its wavelength then the wave gets reflected by the object.
- The example of such a large object is a large building, furniture, wall, a hill etc.
- The phase shift between the incident and reflected wave is 180°.
- Diffraction depends on frequency, geometry of obstacle, amplitude, phase and polarization of incident wave at the point of diffraction.

2. Diffraction :

- A propagating wave gets diffracted when it hits an object or surface which cannot be penetrated and has sharp irregularities i.e. edges.
- 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.

3. 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.
- Now refer Fig. 3.1.1 which illustrates the three propagation mechanisms for EM waves, reflection, refraction and diffraction.



(G-2095) **Fig. 3.1.1 : Reflection, refraction and scattering**

- 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 that are discussed later on in this chapter.

3.1.2 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. 3.1.1.
- 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.

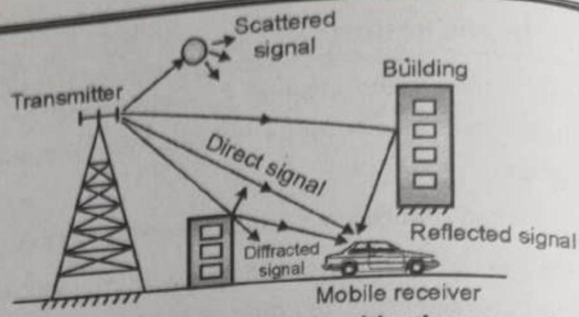
3.1.3 Multipath Fading : GTU : W-13, S-16

University Questions

Q. 1 Explain
(i) The effects of multipath fading
(ii) Doppler spectrum
(iii) Multipath delay spread **(W-13, 7 Marks)**

Q. 2 What is fading? List and explain various types of small scale fading. **(S-16, 7 Marks)**

- The signal reaching a receiver follows multiple paths instead of just the direct path between a transmitter and a receiver as shown in Fig. 3.1.2.
- This is called as the multipath reception.

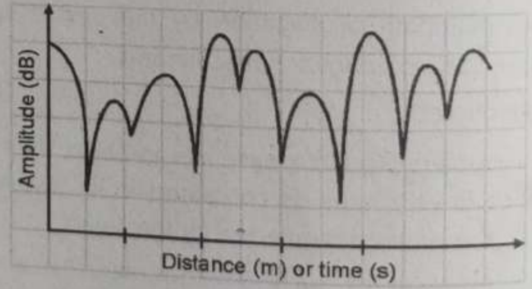


(O-903) **Fig. 3.1.2 : Concept of multipath propagation**

- 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.

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. 3.1.3.



(G-2807) **Fig. 3.1.3 : Fading/Multipath**

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

3.2 Propagation Models : GTU : S-16

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Need :

- Since the received signal strength in mobile communication changes continuously and randomly, it is necessary to have a propagation model for predicting the average strength of the received signal.

Types :

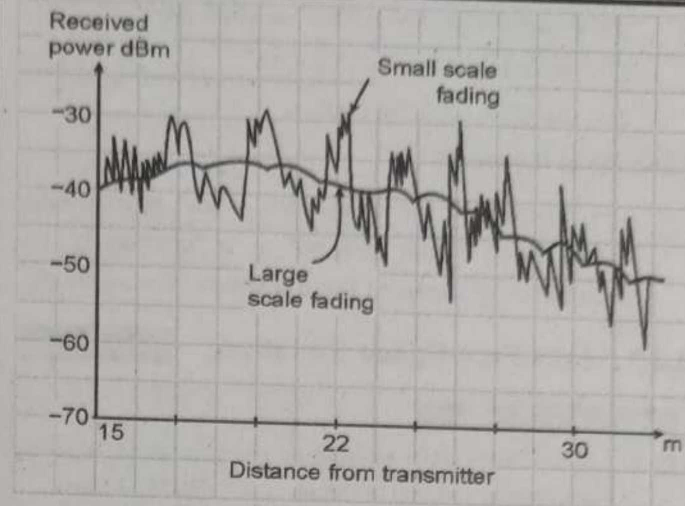
- There are two types of propagation models :
  1. Large scale models.
  2. Small scale or fading models.

1. Large scale models :

- The propagation models that predict the average signal strength at an arbitrary distance from the transmitter are called as large scale propagation models.
- These are useful in estimating the coverage area of the transmitter.
- They characterize the signal strength over large distances (several hundred kilometers) between a transmitter and receiver.

2. Small scale or fading models :

- 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.**
- In the small scale fading the signal strength may vary by 30 to 40 dB when a receiver moves by a fraction of wavelength.
- We can use the small scale model to predict these signal fluctuation.
- As the MS (mobile station) moves away from the transmitter, over much larger distances, the average received signal decreases gradually.
- A large scale model can be used to predict the variations in the average strength of signal.
- Fig. 3.2.1 illustrates the small scale fading and the slower large scale variations for an indoor radio communication system.



(G-2678) **Fig. 3.2.1 : Two types of fading**

Conclusion :

- From Fig. 3.2.1 we conclude that the signal fades quickly even with a small movement of the receiver but the average signal changes much slowly over a longer distance.
- In this chapter we will discuss the large scale propagation and different methods of predicting the received power.

3.3 Free Space Propagation Model :

GTU : W-15, S-16, S-17, W-19

University Questions

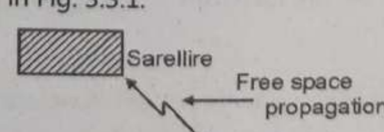
Q. 1 With necessary equations explain Free space propagation model in detail. **(W-15, 7 Marks)**

Q. 2 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 3 Explain Free space propagation model with necessary equations. **(S-17, 7 Marks)**

Q. 4 Explain Free space propagation model with necessary equations. **(W-19, 7 Marks)**

- 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. 3.3.1.



(G-2622) **Fig. 3.3.1 : 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.

3.3.1 Friis Free Space Equation : GTU : W-15

University Questions

Q. 1 With necessary equations explain Free space propagation model in detail. **(W-15, 7 Marks)**

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

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{P_t G_t G_r}{L}\left(\frac{\lambda}{4\pi d}\right)^2 \quad ...(3.3.1)$$

- 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,

$$G = \frac{4\pi A_e}{\lambda^2} \quad ...(3.3.2)$$

- 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.

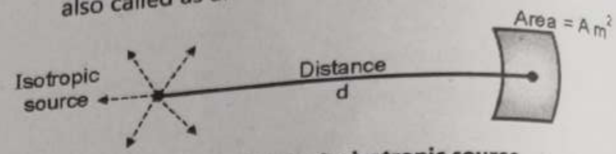
Conclusion :

- From the Friis equation we conclude that the received power is inversely proportional to the separation (d) between the transmitter and receiver.
- That means $P_r(d)$ decays at a rate of 20 dB / decade.

3.3.2 EIRP :

Isotropic radiator :

- If the transmitting antenna is assumed to be a point source which radiates equally in all the directions, then it is called as an **omnidirectional** antenna. It is also called as an isotropic source.



(G-2677) **Fig. 3.3.2 : An isotropic source**

EIRP :

- In practice we use a directional antenna having gain G_t.
- For a transmitter with output power P_t driving a lossless antenna with gain G_t, the flux density in the direction of antenna boresight, at a distance "d" m is given by,

$$F = \frac{P_t G_t}{4\pi d^2} \text{ W/m}^2 \quad ...(3.3.3)$$

- The product $P_t G_t$ of Equation (3.3.3) is called as the **Effective Isotropically Radiated Power** or **EIRP.**
- It describes the combination of transmitter and antenna in terms of an equivalent isotropic source with power $P_t G_t$ watts radiating uniformly in all the directions.

$$\therefore \quad EIRP = P_t G_t \text{ watts} \quad ...(3.3.4)$$

- In other words, EIRP represents the maximum transmitted power in the direction of maximum antenna gain as compared to the isotropic radiator.

ERP :

- In practice we don't have isotropic radiators. Hence we need to use ERP (Effective Radiated Power) instead of EIRP.
- ERP denotes the maximum radiated power as compared to the half wave dipole antenna instead of an isotropic antenna.

3.3.3 Path Loss :

- Path loss PL represents the signal attenuation in "decibels" across the entire communication link.
- It is defined as the difference (in dB) between the transmitted signal power P_t and received signal power P_r.

$\therefore$ Path loss PL $= 10 \log_{10} [P_t / P_r]$

$$= -10 \log_{10} (G_t G_r) - 10 \log_{10} \left[\frac{\lambda}{4\pi d}\right]^2 \quad ...(3.3.5)$$

- The RHS of the above expression contains two terms.
- Their meaning is as follows :
  1. $-10 \log_{10}(G_t G_r)$ = Represents the gain
  2. $10 \log_{10} \left[\frac{\lambda}{4\pi d}\right]^2$ = Represents the free space loss.
- The free space loss increases in square proportion with the increase in distance "d".
- In order to keep this loss to a manageable value, we have to increase λ (by reducing f) when the distance is increased.
- If the antenna gain are to be excluded, then the expression for path loss gets modified as follows :

$$P_{L\,(dB)} = -10 \log \left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \quad ...(3.3.6)$$

3.3.4 Validity of Friis Model :

- The Friis free space model is valid to predict the received power P_r provided the value of "d" lies in the **far field** or **Fraun-hofer region,** of the transmitting antenna.

3.3.5 Fraun-hofer Region :

- The Fraun-hofer region of a transmitting antenna is defined as the region beyond the far field distance d_f.
- Where d_f is given by,

$$d_f = \frac{2 D^2}{\lambda} \quad ...(3.3.7)$$

Where D = Largest physical dimension of the antenna

- The MR is said to be in the far, field region if the following conditions is satisfied.

$$d_f >> D \text{ and } d_f >> \lambda \quad ...(3.3.8)$$

3.3.6 Received Power in Terms of Reference Distance :

- The Friis free space expression is not true for d = 0.
- Hence we cannot use d = 0 as a reference point.
- Therefore a small distance d_0 is used as a received power reference point.
- Then the received power P_r (d) at any distance $d > d_o$ is related to the received power P_r at d_o.
- The reference distance d_0 should lie in the far-field region. That means,

$$d_o \geq d_f \quad ...(3.3.9)$$

- Then the received power at distance d which is greater than d_o is given by,

$$P_r(d) = P_r(d_o)\left(\frac{d_o}{d}\right)^2 \quad ...d \geq d_o \geq d_f \quad ...(3.3.10)$$

- In mobile radio systems, it is very common that P_r may fluctuate to a great extent over a typical area of many square kilometers.
- Due to large amount of signal strength fluctuations, the received power levels are expressed in dBm or dBW units.
- If we use the unit dBm to express the received power then Equation (3.3.10) gets modified as follows :

$$P_r(d)\ \text{dBm} = 10 \log\left[\frac{P_r(d_o)}{0.001\ \text{W}}\right] + 20 \log\left[\frac{d_o}{d}\right] \quad ...d \geq d_o \geq d_f \quad ...(3.3.11)$$

- Where $P_r(d_o)$ is expressed in Watts.

Typical values of d_o :

- For the practical systems with low gain antennas operating in the 1-2 GHz frequency range, the typical the values of the reference distance d_o are as follows :

Sr. No.	Type of environment	Value of d_o
1.	Indoor	1 m
2.	Outdoor	100 m to 1 km

Ex. 3.3.1 : For a transmitting antenna with an operating frequency of 1 GHz and maximum dimension of 1 m, find the value of far-field distance.

Soln. :

Given : D = 1 m, f = 1 GHz.

To find : d_f

- We know that the far-field distance is given by,

$$d_f = \frac{2 D^2}{\lambda}$$

– But $\lambda = \frac{C}{f}$

$$\therefore d_f = \frac{2D^2}{(C/f)} = \frac{2fD^2}{C}$$

$$\therefore d_f = \frac{2 \times 1 \times 10^9 \times (1)^2}{3 \times 10^8}$$

$$\therefore d_f = 6.67 \text{ m}$$ ...Ans.

Ex. 3.3.2 : Express the output power of 50 W of a transmitter in terms of dBm and dBW.

Soln. :

Given : $P_t = 50$ W

To find : P_t in dBm and dBW

1. **P_t in dBm :**

– dBm is the decibel unit with respect to a reference level of 1 mW.

$$\therefore P_t \text{ (dBm)} = 10 \log_{10} [P_t / 1 \text{ mW}]$$

$$= 10 \log_{10}\left[\frac{50 \times 10^3}{1}\right] = 47 \text{ dBm}$$ ...Ans.

2. **P_t in dBW :**

– dBW is the decibel unit with respect to a reference power level of 1 W.

$$\therefore P_t \text{ (dBW)} = 10 \log_{10} [P_t / 1 \text{ W}]$$

$$= 10 \log_{10} [50/1] = 17 \text{ dBW}$$ ...Ans.

Ex. 3.3.3 : If the output power of 50 W is applied to a transmitting antenna of unity gain and carrier frequency of 1 GHz, calculate the received power in dB m by a unity gain receiving antenna that is at a free space distance of 90 m from the transmitter. Also find the value of P_r (10 km).

Soln. :

Given : $P_t = 50$ W, $f_C = 1$ GHz, $G_t = G_r = 1$, $d_1 = 90$ m, $d_2 = 10$ km, Assume L = 1

To find : P_r (90 m) in dBm and P_r (10 km)

1. **Find P_r (90 m) :**

$$P_r \text{ (90 m)} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$\text{But } \lambda = \frac{C}{f_C} = \frac{3 \times 10^8}{1 \times 10^9} = 0.3 \text{ m}$$

$$\therefore P_r \text{ (90 m)} = \frac{50 \times 1 \times 1 \times (0.3)^2}{(4\pi)^2 \times (90)^2 \times 1}$$

$$= 3.518 \times 10^{-3} \text{ mW}$$ ...Ans.

$$\therefore P_r \text{ (90 m) (dBm)} = 10 \log_{10}\left[\frac{3.518 \times 10^{-3}}{1}\right]$$

$$= -24.54 \text{ dBm}$$ ...Ans.

2. **Find P_r (10 km) :**

– We know that

$$P_r \text{ (d) dBm} = 10 \log_{10}\left[\frac{P_r(d_o)}{1 \text{ mW}}\right] + 20 \log_{10}\left[\frac{d_o}{d}\right]$$

– Here we will substitute d = 10 km and $d_o = 90$ m.

$$\therefore P_r \text{ (10 km) (dBm)} = P_r \text{ (90 m) (dBm)} + 20 \log_{10}\left(\frac{90}{10 \times 10^3}\right) = -24.54 - 40.92$$

$$\therefore P_r \text{ (10 km) (dBm)} = -65.46 \text{ dBm}$$ ...Ans.

Ex. 3.3.4 : The received power at a distance of 100 km is 5 nW for a communication link. Determine the received power at a distance 200 km for the same link. Assume free space propagation mechanism. **S-14, 5 Marks**

Soln. :

Given : $P_{r1} = 5$ nW, $d_1 = 100$ km, Assume L = 1.

To Find : Received power P_{r2} at a distance $d_2 = 200$ km

–. The received power at 100 km is given by,

$$P_{r1} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_1^2 L} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_1^2}$$

$$\therefore 5 \times 10^{-9} \times 10^{10} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2}$$

$$\therefore \frac{P_t G_t G_r \lambda^2}{(4\pi)^2} = 50 \quad \text{...(1)}$$

Received power P_{r2} :

– The received power at 200 km is given by,

$$\therefore P_{r2} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_2^2} = 50 / (200 \times 10^5)^2$$

$$\therefore P_{r2} = 1.25 \times 10^{-13} \text{ W}$$ ...Ans.

Ex. 3.3.5 : If a transmitter produces 50 W of power, express the transmit power in units of (i) dBm and (ii) dBW. If 50 W is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna. What is P_r(10 km)? Assume unity gain for the receiver antenna. **S-15, W-17, 7 Marks**

Soln. :

Given : $P_t = 50$ W, $f_c = 900$ MHz, $G_t = G_r = 1$, $d_1 = 100$ m, $d_2 = 10$ km, Assume L = 1

To Find :

1. P_t in dBm 2. P_t in dBW
3. P_r (100 m) 4. P_r (10 km)

- Refer Ex. 2.2.2 for P_t in dBm and P_t in dBW.

Find P_r (100 m) :

- The received power at 100 km is given by,

$$P_r(100\text{ m}) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$\text{But } \lambda = \frac{C}{f_C} = \frac{3 \times 10^8}{900 \times 10^6} = 0.33 \text{ m}$$

$$\therefore P_r(100\text{ m}) = \frac{50 \times 1 \times 1 \times (0.33)^2}{(4\pi)^2 \times (100)^2 \times 1}$$

$$= 3.5 \times 10^{-3} \text{ mW} \quad \text{...Ans.}$$

$$\therefore P_r(100\text{ m})(\text{dBm}) = 10 \log_{10}\left[\frac{3.5 \times 10^{-3}}{1}\right]$$

$$= -24.5 \text{ dBm} \quad \text{...Ans.}$$

Find P_r (10 km) :

- We know that

$$P_r(d)\text{ dBm} = 10 \log_{10}\left[\frac{P_r(d_o)}{1 \text{ mW}}\right] + 20 \log_{10}\left[\frac{d_o}{d}\right]$$

- Here we will substitute d = 10 km and d_o = 100 m.

$$\therefore P_r(10\text{ km})(\text{dBm}) = P_r(100\text{ m})(\text{dBm}) + 20 \log_{10}\left(\frac{100}{10 \times 10^3}\right)$$

$$= -24.5 - 40$$

$$\therefore P_r(10\text{ km})(\text{dBm}) = -64.5 \text{ dBm} \quad \text{...Ans.}$$

Ex. 3.3.6 : Assume a receiver is located 10 km from a 50 W transmitter. The carrier frequency is 6 GHz and free space propagation is assumed, G_t = 1 and G_r = 1. Find the power at the receiver in dBm. **S-18, 4 Marks**

Soln. :

Given : P_t = 50 W, f_C = 6 GHz, $G_t = G_r = 1$,

Assume L = 1

To Find : P_r (10 km) in dBm

Find P_r (10 km) :

- The received power at 10 km is given by,

$$P_r(10\text{ km}) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$\text{But } \lambda = \frac{C}{f_C} = \frac{3 \times 10^8}{6 \times 10^9} = 0.05 \text{ m}$$

$$\therefore P_r(10\text{ km}) = \frac{50 \times 1 \times 1 \times (0.05)^2}{(4\pi)^2 \times (10000)^2 \times 1}$$

$$\therefore P_r(10\text{ km}) = 8 \times 10^{-12} \text{ W} \quad \text{...Ans.}$$

Conversion to dBm:

$$\therefore P_r(10\text{ km})(\text{dBm}) = 10 \log_{10}[P_r / 1 \text{ mW}]$$

$$\therefore P_r(10\text{ km})(\text{dBm}) = 10 \log_{10}\left[\frac{8 \times 10^{-12}}{1 \times 10^{-3}}\right]$$

$$\therefore P_r(10\text{ km})(\text{dBm}) = -81 \text{ dBm} \quad \text{...Ans.}$$

Ex. 3.3.7 : A unit gain antenna with a maximum dimension of 1 m produces 50 W power at 900 MHz. Find (i) the transmit power in dBm and dBW, (ii) the received power at a free space distance of 5 m and 100 m using free space distance formula. **S-17, 7 Marks**

Soln. :

Given :

P_t = 50 W, f_C = 900 MHz, $G_t = G_r = 1$,

d_1 = 5 m, d_2 = 100 m, Assume L = 1

To Find :

1. P_t in dBm 2. P_t in dBW
3. P_r (5 m) 4. P_r (100 m)

- Refer Ex. 3.3.5 for the transmit power in dBm and dBW and the received Power at a free space distance of 100 m.

Find P_r (5 m) :

- Received Power at a free space distance of 5 m is given by,

$$P_r(5\text{ m}) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$\text{But } \lambda = \frac{C}{f_C} = \frac{3 \times 10^8}{900 \times 10^6} = 0.33 \text{ m}$$

$$\therefore P_r(5\text{ m}) = \frac{50 \times 1 \times 1 \times (0.33)^2}{(4\pi)^2 \times (5)^2 \times 1}$$

$$= 1.38 \text{ mW} \quad \text{...Ans.}$$

$$\therefore P_r(5\text{ m})(\text{dBm}) = 10 \log_{10}\left[\frac{1.38 \times 10^{-3}}{1 \times 10^{-3}}\right]$$

$$= 1.4 \text{ dBm} \quad \text{...Ans.}$$

Ex. 3.3.8 : Assume a receiver located10 km from a 50 W transmitter The carrier frequency is 1900 MHz. Free space propagation is assumed.

$G_t = 1$ and $G_r = 2$.

Find:

1. The power at the receiver.
2. The magnitude of E field at the receiver antenna.
3. The rms voltage applied to the receiver input assuming that the receiver antenna has a purely real impedance of 50 Ω and is matched to the receiver. **W-15, 7 Marks**

Soln. :

Given : $P_t = 50W$, $f_C = 1900$ MHz, $G_t = 1$, $G_r = 2$, $d = 10$ km

To Find :

1. The power at the receiver.
2. The magnitude of E field at the receiver antenna.
3. The rms voltage applied to the receiver input

1. The power at the receiver :

– The power received at the receiver is given by,

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

$$\text{But } \lambda = \frac{C}{f_C} = \frac{3 \times 10^8}{1900 \times 10^6} = 0.\ m$$

$$\therefore P_r(d) = \frac{50 \times 1 \times 2 \times (0.157)^2}{(4\pi)^2 \times (10000)^2 \times 1}$$

$$= 1.56 \times 10^{-10}\ W \quad \text{...Ans.}$$

$$\therefore P_r(\text{dBm}) = 10 \log_{10}\left[\frac{1.56 \times 10^{-10}}{1 \times 10^{-3}}\right]$$

$$= -68.06\ \text{dBm} \quad \text{...Ans.}$$

2. The magnitude of E field at the receiver antenna :

– For a receiving antenna, the effective area is given by,

$$A_e = G_r \frac{\lambda^2}{4\pi}$$

– And the received power in terms of the effective area and the magnitude of E field is given by,

$$P_r(d) = \frac{|E^2|}{120\,\pi} A_e$$

$$\therefore |E| = \sqrt{\frac{P_r(d) \times 120\,\pi}{G_r \lambda^2 / 4\pi}}$$

$$= \sqrt{\frac{1.56 \times 10^{-10} \times 120\pi}{2 \times (0.157)^2 / 4\pi}}$$

$$= \sqrt{\frac{1.56 \times 10^{-10} \times 120 \times \pi}{3.92 \times 10^{-3}}}$$

$$\therefore |E| = 3.871 \times 10^{-3}\ V/m \quad \text{...Ans.}$$

3. Rms voltage at receiver input :

– With antenna impedance of 50 Ω and matched to receiver, the rms voltage at the receiver input is ,

$$V_{rms} = \frac{(P_r(d)\,.\,R)^{1/2}}{2} = \frac{(1.56 \times 10^{-10}\ .\ 50)^{1/2}}{2}$$

$$\therefore V_{rms} = 8.83 \times 10^{-5}\ V \quad \text{...Ans.}$$

Ex. 3.3.9 : Calculate the change in received signal power in a free-space propagation environment at two different points such that the distance of the second point is ten times the distance of the first point. Express your answer in dB. **S-20, W-20, 3 Marks**

Soln. :

Given : $d_2 = 10\ d_1$

To Find : change in received signal power

– The power received at a distance d_1 is given by,

$$P_{r1} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_1^2 L} = \frac{k}{d_1^2} \quad \text{...(1)}$$

– The power received at a distance d_2 is given by,

$$P_{r2} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_2^2 L} = \frac{k}{d_2^2} \quad \text{...(2)}$$

– But $d_2 = 10\ d_1$. Substituting this into Equation(2) we get,

$$P_{r2} = \frac{k}{100\ d_1^2}$$

$$\therefore P_{r2} = (k / d_1^2)/ 100 \quad \text{...(3)}$$

– Substituting Equation (1) into Equation (3) we get,

$$P_{r2} = \frac{(P_{r1})}{100} \quad \text{...(4)}$$

– Thus with 10 fold increase in the distance, the received power reduces by 100 times.

3.4 Basic Propagation Mechanisms :

GTU : W-13

University Questions

Q. 1 Explain the three basic propagation mechanisms which impact the propagation of signal in a mobile environment. **(W-13, 7 Marks)**

- The basic propagation mechanisms that have an impact on a mobile communication system are as follows :
  1. Reflection.
  2. Diffraction and
  3. Scattering.
- The large scale propagation models predict the received power and the path loss, based on the physics of these propagation mechanisms.
- It is also possible to explain the small scale fading and multipath propagation by the physics of the three basic propagation mechanisms.
- We have already defined these terms earlier in this chapter.

3.5 Reflection : GTU : W-13, S-19

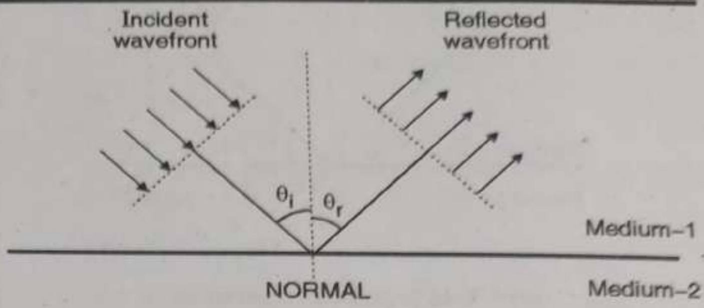
University Questions

Q. 1 Explain the three basic propagation mechanisms which impact the propagation of signal in a mobile environment. **(W-13, 7 Marks)**

Q. 2 Explain three basic propagation mechanisms. **(S-19, 3 Marks)**

Definition :

- The meaning of word "Reflect" is to turn back, and reflection is the process or act of reflecting.
- Reflection of EM waves will take place when it strikes a boundary of two media and some or all the incident power does not enter the second material.
- The EM waves which do not enter the second medium are reflected.
- The concept of reflection will be clear if you refer to Fig. 3.5.1.
- E_i is the incident voltage intensity and E_r is the reflected voltage intensity. θ_i and θ_r are the incident and reflected angles in degrees.
- All the transmitted energy is returned as reflected energy in this case because no energy penetrates through medium-2 as shown in Fig. 3.5.1.



(D-713)Fig. 3.5.1 : Illustration of EM reflection

- The velocity of incident and reflected waves will be equal, hence the **angle of reflection** is equal to **angle of incidence** ($\theta_i = \theta_r$).
- However eventhough the angles are equal, the incident and reflected voltage intensities are not equal.

Reflection from a perfect dielectric :

- When a plane wave is incident on a perfect dielectric, a part of energy is transmitted into the second medium and the remaining energy is reflected.
- Thus no energy is lost due to absorption.

Reflection from a perfect conductor :

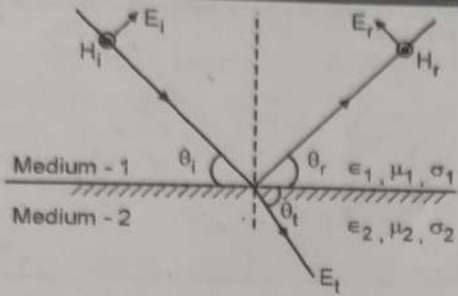
- If the second medium is a perfect conductor, then the entire incident energy is reflected back. No energy is lost due to absorption.

Fresnel reflection coefficient :

- Fresnel reflection coefficient (Γ) is used to relate the electric field intensities of transmitted and reflected waves with that of the incident waves.
- Its value is a function of following parameters :
  1. Material properties.
  2. Wave polarization
  3. Angle of incidence
  4. Frequency of waves.

3.5.1 Reflection from Dielectrics :

- Refer Fig. 3.5.2(a), which shows that an EM wave is incident on the boundary of two dielectric media.
- The angle of incidence with the plane is θ_i. A part of incident energy is reflected back into medium-1 at an angle θ_r.
- And the remaining energy is transmitted (refracted) through to medium-2 at an angle θ_t.



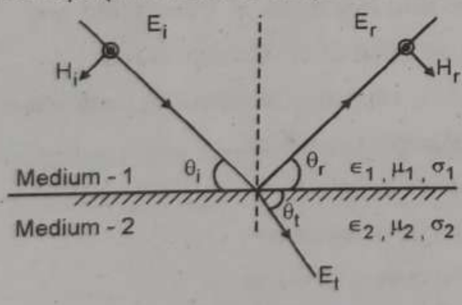
(a) E-field in plane of incidence

(G-2679) **Fig. 3.5.2 : Calculation of reflection coefficient between two dielectrics**

- The nature of reflection is dependent on the polarization of E field in the incident wave.
- We will take help of Fig. 3.5.2(a) and (b) to explain this point.
- The plane containing the incident, reflected and transmitted rays is called as the **Plane of Incidence (POI)**.

E-field polarization parallel perpendicular perpendicular with POI :

- Refer Fig. 3.5.2(a) in which the polarization of E-field is parallel with the plane of incidence.
- That means the E-field is vertically polarized and has a normal component with respect to the reflecting surface.
- Now refer Fig. 3.5.2(b) in which the polarization of E-field is perpendicular to the plane of incidence.



(b) E-field normal to plane of incidence

(G-2680) **Fig. 3.5.2 : Calculation of reflection coefficient between two dielectrics**

- That means the E-field in the incident wave is pointing out of the page towards the reader. It is perpendicular to the plane of paper but parallel to the reflecting surface.
- The permittivity, permeability and conductance of the two dielectric materials are $(\epsilon_1, \mu_1, \sigma_1)$ and $(\epsilon_2, \mu_2, \sigma_2)$ respectively.
- For a perfect (lossless) dielectric,

$$\epsilon = \epsilon_0 \epsilon_r$$

- However for a lossy dielectric, that absorbs power, the dielectric constant ϵ is expressed as follows :

$$\epsilon = \epsilon_0 \epsilon_r - j\epsilon' \qquad ...(3.5.1)$$

$$\text{Where } \epsilon' = \frac{\sigma}{2\pi f} \qquad ...(3.5.2)$$

and σ = Conductivity of the material

- For a good conductor, ϵ_r and σ are not dependent on the frequency. However for lossy dielectric, ϵ_r is constant and σ is dependent on frequency.
- Generally, the conductivity of a dielectric material increases with increase in frequency.

Reflection coefficient :

- The expressions for the reflection coefficients for the two cases of E-field polarization being parallel and perpendicular at the boundary of two dielectrics are as follows :

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_i}$$

...E-field in plane of incidence ...(3.5.3)

$$\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_2 \sin\theta_i + \eta_1 \sin\theta_t}$$

...E-field normal to the plane of incidence ...(3.5.4)

- Where η_1 and η_2 are the intrinsic impedances of the two dielectric mediums. In general it is denoted by η_i (i = 1, 2) and given by,

$$\eta_i = \sqrt{\frac{\mu_i}{\epsilon_i}} \qquad ...(3.5.5)$$

Definition of Intrinsic impedance:

- The intrinsic impedance of a dielectric medium (η_i) is defined as the ratio of electric to magnetic field for a uniform plane wave.
- The **velocity** of an E.M. wave is given by,

$$v = \frac{1}{\sqrt{\mu\epsilon}} \qquad ...(3.5.6)$$

- The boundary conditions at the surface of incidence obey the Snell's law, which is given by the following expression, after referring to Fig. 3.5.1.

$$\sqrt{\mu_1 \epsilon_1} \sin(90-\theta_i) = \sqrt{\mu_2 \epsilon_2} \sin(90-\theta_t) \quad ...(3.5.7)$$

- Note that, the Equations (3.5.3) and (3.5.4) have been derived by using the boundary conditions from Maxwell's equations.
- We can also derive the following expressions by using the boundary conditions from Maxwell's equations.

$$\theta_i = \theta_r \quad ...(3.5.8)$$

$$E_r = \Gamma E_i \quad ...(3.5.9(a))$$

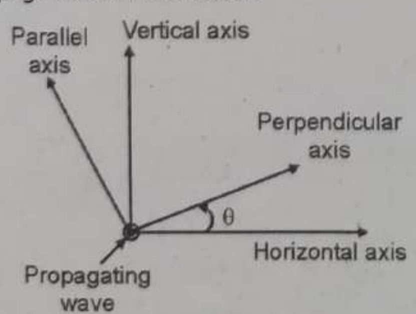
$$\text{and } E_t = (1+\Gamma) E_i \quad ...(3.5.9(b))$$

- Where Γ can be either $\Gamma_{\parallel}$ or $\Gamma_{\perp}$, depending on the polarization of E-field.
- If the first medium is free space with $\mu_1 = \mu_2$, the two reflection coefficients are given by,

$$\Gamma_{\parallel} = \frac{-\epsilon_r \sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}}{\epsilon_r \sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}} \quad ...(3.5.10)$$

$$\text{and } \Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\epsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}} \quad ...(3.5.11)$$

- If the waves are elliptically polarized, then the wave may be depolarized into its vertical and horizontal E-field components.
- Then we can find out the reflected and transmitted waves by applying superposition theorem.
- In the general case, of reflection or transmission, the horizontal and vertical axes of the spatial coordinates may or may not coincide with the perpendicular and parallel axes of the propagating waves, instead would make an angle of θ° as shown in Fig. 3.5.3, for a propagating wave coming out of the page towards the reader.



(G-2681) Fig. 3.5.3

- In such a case, the following expression would relate the V and H field components at a boundary of dielectrics.

$$\begin{bmatrix} E_H^d \\ E_V^d \end{bmatrix} = R^T D_C R \begin{bmatrix} E_H^i \\ E_V^i \end{bmatrix} \quad ...(3.5.12)$$

- Where,

  E_H^d and E_V^d = Depolarized field components in the H and V directions

  E_H^i and E_V^i = H and V polarized varying components of incident wave.

- All these are the time varying components of E-field which can be represented by phasors.
- R is a transformation matrix and R^T is its transpose.

$$R = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \quad ...(3.5.13)$$

- D_C in Equation (3.5.12) is a depolarization matrix which is given by,

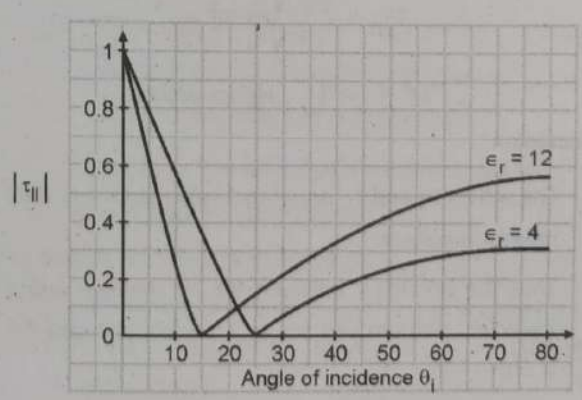
$$D_C = \begin{bmatrix} D_{\perp\perp} & 0 \\ 0 & D_{\parallel\parallel} \end{bmatrix} \quad ...(3.5.14)$$

Where $D_{xx} = \Gamma_x$ for reflection and

$D_{xx} = T_x = 1 + \Gamma_x$ for transmission

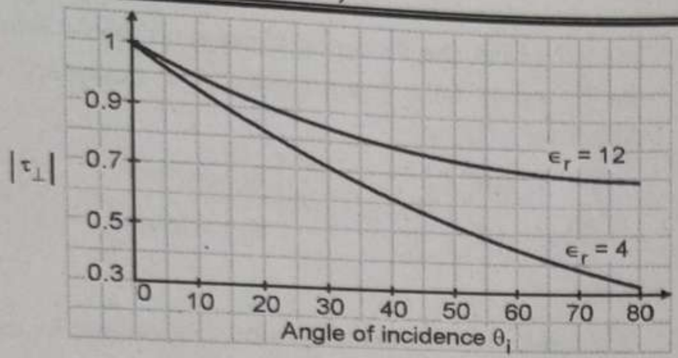
3.5.2 Plots of Reflection Coefficients :

- Fig. 3.5.4(a) and (b) show the plots of reflection coefficients versus incident angle θ_i for both types of polarizations.
- Another variable in this plot is the value of dielectric constant ϵ_r.



(G-2682) (a) Plot for parallel polarization

Fig. 3.5.4(Contd...)



(G-2629) (b) Plot for perpendicular polarization

Fig. 3.5.4

Ex. 3.5.1 : If medium-1, is free space and medium-2 is a dielectric, then prove that at $\theta_i = 0°$ both $|\Gamma_{||}|$ and $|\Gamma_\perp|$ approach 1 irrespective of the value of ϵ_r. Write your conclusion from the result.

Soln. :

1. **Find value of $|\Gamma_{||}|$:**

– Refer Equation (3.5.10) to write,

$$\Gamma_{||} = \frac{-\epsilon_r \sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}}{\epsilon_r \sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}}$$

– Substitute $\theta_i = 0$ to get,

$$\Gamma_{||} = \frac{0 + \sqrt{\epsilon_r - 1}}{0 + \sqrt{\epsilon_r - 1}} = 1 \qquad \text{...Hence proved}$$

2. **Find value of $|\Gamma_\perp|$:**

– Refer Equation (3.5.11) to write,

$$\Gamma_\perp = \frac{\sin\theta_i - \sqrt{\epsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\epsilon_r - \cos^2\theta_i}}$$

– Substitute $\theta_i = 0$ to get,

$$\Gamma_\perp = \frac{0 - \sqrt{\epsilon_r - 1}}{0 + \sqrt{\epsilon_r - 1}} = -1$$

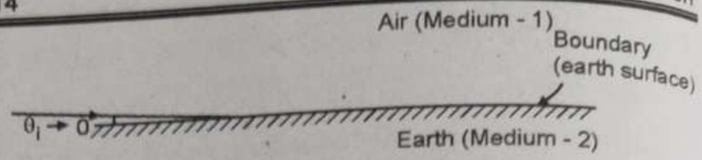
$$\therefore \; |\Gamma_\perp| = 1 \qquad \text{...Hence proved}$$

Conclusion :

– The values $\Gamma_{||}$ and $\Gamma_\perp$ equal to 1 represents a perfect reflecting surface.

– Thus the boundary between the air medium and a dielectric medium can act as a perfect reflector for $\theta_i = 0°$.

– This situation in real life is observed for the earth air boundary as shown in Fig. 3.5.5.



(G-2630) Fig. 3.5.5

– Therefore the ground can be modelled as a perfect reflector when the angle of incidence $\theta_i = 0°$, irrespective of the polarization of wave or dielectric constant ϵ_r of the ground.

3.5.3 Brewster Angle :

Definition :

– The Brewster angle is defined as the angle of incidence at which there is no reflection occurring in the medium of origin.

– It is defined as the angle of incidence θ_B at which the reflection coefficient $\Gamma_{||}$ is equal to zero, as shown in Fig. 3.5.5.

– Note that the Brewster angle (θ_B) occus only for the vertical (or parallel) polarization.

Mathematical expression :

– The value of θ_B can be obtained from the following expression,

$$\sin(\theta_B) = \sqrt{\frac{\epsilon_1}{\epsilon_1 + \epsilon_2}} \qquad \text{...(3.5.15)}$$

– If the first medium is space, the second medium is dielectric with dielectric constant ϵ_r, then the above expression gets modified as follows :

$$\sin(\theta_B) = \frac{\sqrt{\epsilon_r - 1}}{\sqrt{\epsilon_r^2 - 1}} \qquad \text{...(3.5.16)}$$

Ex. 3.5.2 : If a wave is impinging upon ground with $\epsilon_r = 5$, then find the value of Brewster angle θ_B.

Soln. :

Given : $\epsilon_r = 5$

Find : θ_B

$$\sin\theta_B = \frac{\sqrt{\epsilon_r - 1}}{\sqrt{\epsilon_r^2 - 1}} = \frac{\sqrt{5-1}}{\sqrt{25-1}}$$

$$\therefore \sin\theta_B = 0.4082$$

$$\therefore \theta_B = 24.09° \qquad \text{...Ans.}$$

Ex. 3.5.3 : Calculate the Brewster angle for a wave impinging on a ground having a permittivity of $\epsilon_r = 4$. **S-19, 3 Marks**

Soln. :

Given : $\epsilon_r = 4$

To Find : Brewster angle θ_B

$$\sin\theta_B = \frac{\sqrt{\epsilon_r - 1}}{\sqrt{\epsilon_r^2 - 1}} = \frac{\sqrt{4-1}}{\sqrt{16-1}}$$

$$\therefore \sin\theta_B = 0.4472$$

$$\therefore \theta_B = 26.56° \quad \text{...Ans.}$$

3.5.4 Reflection from Perfect Conductors :

- EM energy, cannot pass through a perfect conductor.
- Therefore if a plane wave is incident on a perfect conductor, then all the incident energy gets reflected.
- In order to obey they Maxwell's equations, the electric field at the surface of the conductor should always be equal to zero.
- This implies that, the magnitude of the reflected wave must be equal to that of the incident wave.
- If the E-field polarization is in the plane of incidence, then the boundary conditions require the following :

$$\left.\begin{array}{ll} 1. & \theta_i = \theta_r \\ \text{and } 2. & E_i = E_r \end{array}\right\} \text{E-field in to the plane of incidence} \quad ...(3.5.17)$$

- However if the E-field polarization is horizontal, then the boundary conditions require the following :

$$\left.\begin{array}{ll} 1. & \theta_i = \theta_r \\ 2. & E_i = -E_r \end{array}\right\} \text{E-field normal to the plane of incidence} \quad ...(3.5.18)$$

Conclusions :

- The reflection coefficients for a perfect conductor are $\Gamma_{\parallel} = 1$ and $\Gamma_{\perp} = -1$ irrespective of the value of angle of incidence (θ_i).

3.6 Ground Reflection (Two Ray) Model :

GTU : S-12, S-14, S-16, W-17, S-19

University Questions

Q. 1 Derive an expression for the received power for a two-ray reflection point to point mobile communication propagation model. Assume path loss exponent n = 4. **(S-12, 6 Marks)**

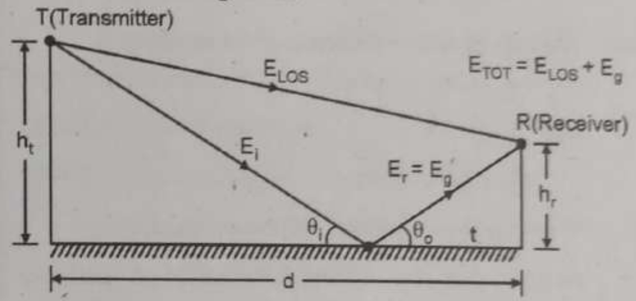
Q. 2 Derive an expression for a ground reflection model assuming distance between transmitter and receiver antenna is very large compare to heights of the antennas. **(S-14, 9 Marks)**

Q. 3 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 4 Derive the equation of two-my reflection point to point mobile communication propagation model. **(W-17, 7 Marks)**

Q. 5 Explain ground reflection(Two-ray) Model with figure and derive the equation for Electric Field ETotal. **(S-19, 7 Marks)**

- The two ray model is also called as ground reflection model or two ray ground reflection model and it is as shown in Fig. 3.6.1.



(G-2824) Fig. 3.6.1 : 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,

$$E(d, t) = \frac{E_0 d_0}{d} \cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) \text{......}(d > d_0) \quad ...(3.6.1)$$

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,

$$E_{LOS}(d', t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) \quad ...(3.6.2)$$

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

$$E_g(d'', t) = \frac{\tau E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right) \quad ...(3.6.3)$$

- The laws of reflection in dielectrics states that,

$$\theta_i = \theta_0 \quad ...(3.6.4)$$

and $$E_g = \tau E_i \quad ...(3.6.5)$$

$$E_t = (1 + \tau) E_i \quad ...(3.6.6)$$

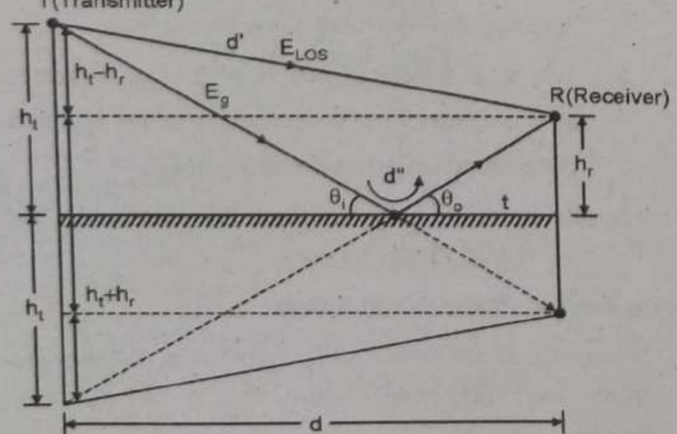
Where τ is the reflection coefficient for ground.

- Assume that the E-field polarization is perfectly horizontal and a perfect ground reflection ($\tau_1 = -1$, $E_t = 0$), to obtain the total E- field $E_{TOT}(d, t)$ at the receiver as follows,

$$|E_{TOT}| = |E_{LOS} + E_g| \quad ...(3.6.7)$$

- Substituting values of E_{LOS} and E_g from Equations (3.6.2) and (3.6.3) we get,

$$E_{TOT}(d, t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right) \quad ...(3.6.8)$$



(G-2813) Fig. 3.6.2 : Method of images to find the path difference between the line-of sight and ground reflected paths

- The geometry of Fig. 3.6.2 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,

$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2} \quad ...(3.6.9)$$

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

$$\Delta = d'' - d' = \frac{2h_t h_r}{d} \quad ...(3.6.10)$$

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

$$\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta\omega_c}{c} \quad ...(3.6.11)$$

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

$$\tau_d = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c} \quad ...(3.6.12)$$

- 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,

$$\left|\frac{E_0 d_0}{d}\right| \approx \left|\frac{E_0 d_0}{d'}\right| \approx \left|\frac{E_0 d_0}{d''}\right| \quad ...(3.6.13)$$

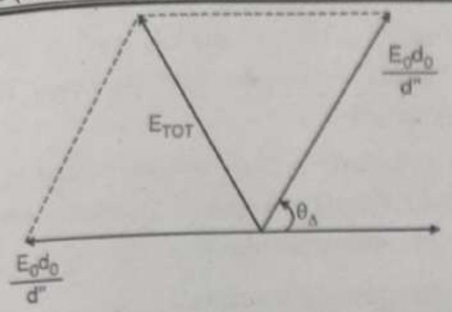
- The value of received electric field at time $t = \frac{d''}{c}$, can be evaluated as,

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_0 d}{d'} \cos\left(\omega_c\left(\frac{d'' - d'}{c}\right)\right) - \frac{E_0 d_0}{d''} \cos 0° \quad ...(3.6.14)$$

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

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

- Fig. 3.6.3 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. 3.6.3 : Phasor diagram**

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

$$|E_{TOT}(d) = \sqrt{\left(\frac{E_0\, d_0}{d}\right)^2 (\cos\theta_\Delta - 1)^2 + \left(\frac{E_0\, d_0}{d}\right)^2 \sin^2\theta_\Delta} \quad ...(3.6.15)$$

$$|E_{TOT}(d)| = \frac{E_0\, d_0}{d}\sqrt{2 - 2\cos\theta_\Delta} \quad ...(3.6.16)$$

- Solving using trigonometric identities we get,

$$|E_{TOT}(d)| = \frac{2\,E_0\, d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right) \quad ...(3.6.17)$$

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

Approximate expression for E_{TOT} (d) :

- For the sufficiently large values of distance d, the phase difference θ_Δ will be $\leq \pi$ and the E field received E_{TOT} (d) will decrease asymptotically with increase in the distance.
- We can simplify Equation (3.6.17) when $\sin\left(\frac{\theta_\Delta}{2}\right) \approx \frac{\theta_\Delta}{2}$, which happens when $\frac{\theta_\Delta}{2} < 0.3$ radians.
- Use Equations (3.6.10) and (3.6.11) to write,

$$\frac{\theta_\Delta}{2} \approx \frac{2\pi\, h_t\, h_r}{\lambda d} < 0.3 \text{ rad} \quad ...(3.6.18)$$

- This implies that, Equation (3.6.17) will get simplified if,

$$d > \frac{20\,\pi\, h_t\, h_r}{3\,\lambda} \approx \frac{20\, h_t\, h_r}{\lambda} \quad ...(3.6.19)$$

- Thus, if the value of d is such that it satisfies Equation (3.6.19), we can approximate the received E-Field as,

$$E_{TOT}(d) \approx \frac{2\,E_0\, d_0}{d} \cdot \frac{2\,\pi\, h_t\, h_r}{\lambda d} \approx \frac{k}{d^2} \text{ V/m}$$

Where k : constant ...(3.6.20)

Received power :

- The expression for the received power at a distance d from the transmitter for a two ray ground reflection model is given by,

$$P_r = P_t\, G_t\, G_r \frac{h_t^2\, h_r^2}{d^4} \quad ...(3.6.21)$$

Conclusion :

- We conclude from Equation (3.6.21), that at large distances d >> $\sqrt{h_t\, h_r}$, the received power is inversely proportional to d^4 and reduced at a rate of 40 dB/decade.
- This path loss is much more rapid than path loss in free space.
- For large values of d, the received power and path loss are independent of frequency.

Path loss for two ray model :

- The pass loss for two ray model is given by,

$$PL(dB) = 40 \log d - (10 \log G_t + 10 \log G_r + 20 \log h_t + 20 \log h_r) \quad ...(3.6.22)$$

3.6.1 Advantages of Two Ray Model :

- 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.

3.6.2 Disadvantage of Two Ray Model :

- The major disadvantages of the two ray model are as 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.

Ex. 3.6.1 : In the following cases, tell whether the two-ray model could be applied, and explain why or why not:

Case 1: $h_t = 35$ m, $h_r = 3$ m, $d = 250$ m.

Case 2: $h_t = 30$ m, $h_r = 1.5$ m, $d = 450$ m.

S-20, W-20, 4 Marks

Soln. :

- We can apply the two ray model only if the following condition is satisfied.

$$d > 10(h_t + h_r)$$

Case-1 :

$$h_t = 35 \text{ m}, h_r = 3 \text{ m}, d = 250 \text{ m}.$$

$$\text{Here, } 10(h_t + h_r) = 10(35+3) = 380 \text{ m}.$$

- Thus the condition is not satisfied. Hence, we cannot apply the two ray model.

Case-2 :

$$h_t = 30 \text{ m}, h_r = 1.5 \text{ m}, d = 450 \text{ m}.$$

$$\text{Here, } 10(h_t + h_r) = 10(30+1.5) = 315 \text{ m}.$$

- Thus, the condition is satisfied. Hence, we can apply the two ray model.

3.7 Diffraction : GTU : W-13, S-17, S-19, W-19

University Questions

Q. 1 Explain the three basic propagation mechanisms which impact the propagation of signal in a mobile environment. **(W-13, 7 Marks)**

Q. 2 What is diffraction? Briefly explain knife-edge diffraction model with figure. **(S-17, 7 Marks)**

Q. 3 Explain three basic propagation mechanisms. **(S-19, 3 Marks)**

Q. 4 What is diffraction? Explain. **(W-19, 3 Marks)**

- A propagating wave gets diffracted when it hits an object or surface which cannot be penetrated and has sharp irregularities i.e. edges.
- 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 diffracted field has enough strength to produce a useful signal for a receiver that has moved deeper into the obstructed region,

3.7.1 Huygen's Principle :

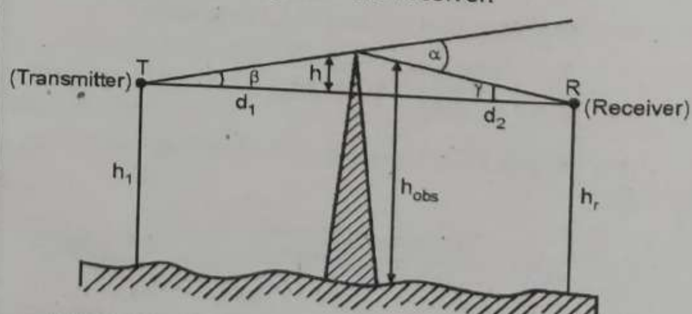
- **Huygen's principle** can be used to explain the phenomenon of diffraction.
- It states that all points on a particular wavefront can be considered as a secondary point sources that produce secondary waveslets.
- Propagation of these wavelets is responsible for the diffraction in the shadow zone.
- The field strength of diffracted wave in the shadow region is equal to the vector sum of the electric field components of all the secondary wavelets.

3.7.2 Fresnel Zone Geometry : GTU : W-17

University Questions

Q. 1 Explain Fresnel Zone. **(W-17, 3 Marks)**

- Refer Fig. 3.7.1(a) that shows a transmitter and receiver separated in free space.
- Imagine that there is an obstructing screen of effective height h and infinite has been placed between them.
- Let this screen be at a distance d_1 from the transmitter and d_2 from the receiver.



(G-2820) **Fig. 3.7.1(a) : Knife edge diffraction geometry**

- As seen in this figure the wave propagating from the transmitter to the receiver via the top of the screen needs to travels a longer distance than a direct line-of-sight LOS path if it existed.

- The difference between the direct path and the diffracted path is called as **excess path length (Δ).**
- We may find the expression for the excess path length (Δ) from Fig. 3.7.1(a) as,

$$\Delta = \sqrt{d_1^2 + h^2} + \sqrt{d_2^2 + h^2} - (d_1 + d_2) \quad ...(3.7.1)$$

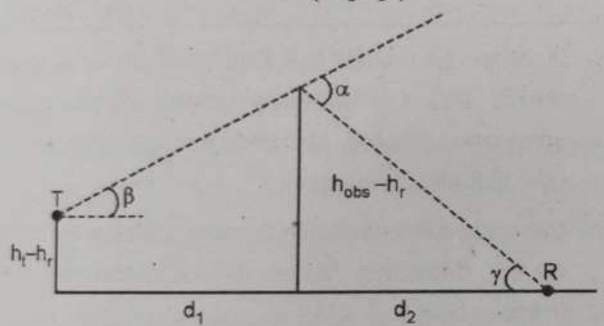
- If $h << d_1, d_2$ and $h >> \lambda$, then

$$\Delta = d_1\left(1 + \frac{1}{2}\frac{h^2}{d_1^2}\right) + d_2\left(1 + \frac{1}{2}\frac{h^2}{d_2^2}\right) - (d_1 + d_2) \quad ...(3.7.2)$$

$$\Delta = \frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2} \quad ...(3.7.3)$$

- The phase difference associated with this path difference is given by,

$$\phi = \frac{2\pi\Delta}{\lambda} = \frac{2\pi h^2}{\lambda\, 2}\left(\frac{d_1 + d_2}{d_1 d_2}\right) \quad ...(3.7.4)$$



(G-2826) **Fig. 3.7.1(b) : Equivalent knife edge geometry where the smallest height (h_r) is subtracted from all other heights**

- Refer Fig. 3.7.1(b). For small values of θ, when tan θ ≈ θ, then $\alpha = \beta + \gamma$ and

$$\alpha \approx h\left(\frac{d_1 + d_2}{d_1 d_2}\right)$$

Where α has unit of radians.

- The expression for ϕ given in Equation (3.7.4) is normalized using the dimensionless Fresnel-Kirchoff diffraction parameter ν that is given by,

$$\nu = 2\sqrt{\frac{\Delta}{\lambda}} \quad ...(3.7.5)$$

$$\nu = 2\sqrt{\frac{2\,(d_1 + d_2)}{\lambda\, d_1 d_2}}$$

$$= \alpha\sqrt{\frac{2\, d_1 d_2}{\lambda\,(d_1 + d_2)}} \quad ...(3.7.6)$$

Where α has unit of radians.

- We can express ϕ in terms of the parameter ν as,

$$\phi = \frac{\pi}{2}\nu^2 \quad ...(3.7.7)$$

Note : This expression indicates that the phase difference between the direct and diffracted paths is dependent on the height and position of the obstruction and the locations of transmitter and receiver.

Fresnel zones :

- The Fresnel zones are used to express the diffraction loss as a function of the path difference around an obstacle.
- These zones represent the successive regions in which the path lengths of secondary wavelets from transmitter to receiver are $n\lambda/2$ greater than the path length of direct LOS path.
- These zones appear as concentric circles as shown in Fig. 3.7.2 and are called as **Fresnel zones**.
- The successive Fresnel zones alternately provide a constructive and destructive interference to the total received signal.
- The radius of the n^{th} Fresnel zone circle is given by,

$$r_n = \sqrt{\frac{n\lambda\, d_1 d_2}{d_1 + d_2}} \quad ...(3.7.8)$$

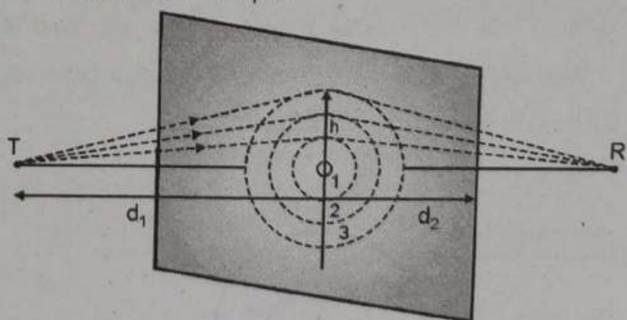
Where,

d_1 = Distance between the obstacle and the transmitter.

d_2 = Distance between the obstacle and the receiver.

λ = Wavelength

- Fig. 3.7.2 shows Fresnel zones with three concentric circles as an example.



(G-2827) **Fig. 3.7.2 : Fresnel zones**

- The excess total path length traversed by a ray passing through each circle is $n\lambda/2$, where n is an integer.
- That means the excess path length corresponding to the smallest circle with n = 1 in Fig. 3.7.2 will be equal to $\lambda/2$ as compared to a line-of-sight path.

– Similarly the excess path lengths corresponding to the outer circles with n = 2, 3, etc. will be equal to λ, 3λ /2, etc respectively.

Ex. 3.7.2 : What is a Fresnel Zone? A general design rule for microwave links is to have 55% clearance of the first Fresnel zone. For a 1 km link at 2.5 GHz, what is the maximum first Fresnel zone radius? What clearance is required for this system? **W-14, 7 Marks**

Soln. :

– Refer Section 3.7.2 for Fresnel Zone.

Given : $n = 1, d_1 = d_2 = 500$ m, $f = 2.5$ GHz $= 2.5 \times 10^9$

To Find : 1. Maximum first Fresnel zone radius

2. Required Clearance

1. Calculate Maximum first Fresnel zone radius (n = 1) :

– The wavelength of the RF signal is given by,

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.5 \times 10^9} = 0.12 \text{ m}$$

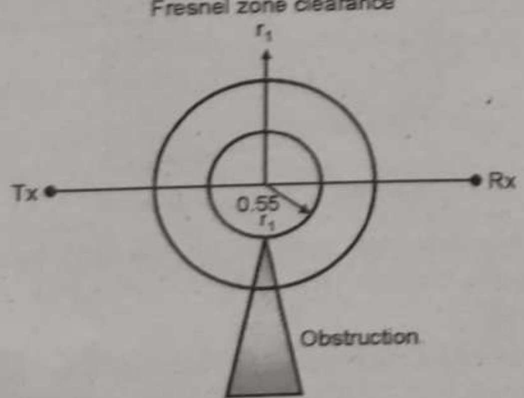
– The radius of the n^{th} Fresnel zone circle is given by,

$$r_n = \sqrt{\frac{n\lambda\, d_1 d_2}{d_1 + d_2}} = \sqrt{\frac{1 \times 0.12 \times 500 \times 500}{500 + 500}}$$

$$\therefore \quad r_n = 5.48 \text{ m}$$

2. Required Clearance:

– Thus, 55% first Fresnel zone clearance will need at least 5.477 × 55% = 3.01 m above the obstruction to the LOS path as shown in Fig. P. 3.7.2.



(G-2805) **Fig. P. 3.7.2**

3.7.3 Knife-edge Diffraction Model :

GTU : W-15, S-16, S-17, W-17, W-19

University Questions

Q. 1 With figure explain Knife-edge diffraction model in detail. Write the Equation for diffraction gain. **(W-15, 7 Marks)**

Q. 2 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 3 What is diffraction? Briefly explain knife-edge diffraction model with figure. **(S-17, 7 Marks)**

Q. 4 Explain Knife edge diffraction model. **(W-17, 7 Marks)**

Q. 5 Briefly explain knife-edge diffraction model. **(W-19, 7 Marks)**

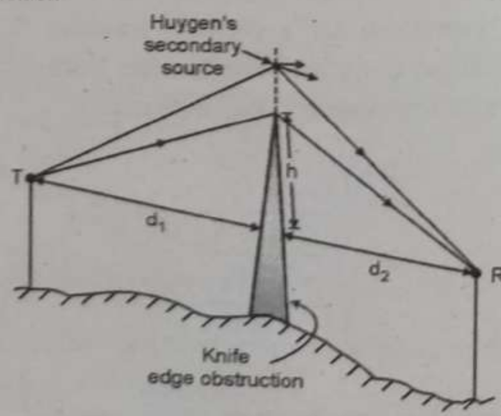
– In order to predict the field strength in a given service area it is necessary to estimate the signal attenuation caused by diffraction of radio waves over hills and buildings.

– Generally, it is impossible to make a precise estimate of the diffraction losses over the complex and irregular terrain.

– However the knife edge model can be used as a starting point for calculating the diffraction loss.

– It is one of the simplest propagation models to calculate the diffraction loss using Fresnel solution for the field behind the knife edge.

– Fig. 3.7.3 shows the simple Knife edge diffraction model.



(G-2665) **Fig. 3.7.3 : Knife edge diffraction model**

– In this model an obstructing screen is present between transmitter and a receiver.

- The effective height of the obstructing screen is h and it has an infinite width and it is placed at a distance d_1 from the transmitter and d_2 from the receiver.
- In Fig. 3.7.3 a receiver at a point R is located in the shadowed region or **diffraction zone.**
- The field strength at point R is equal to the vector sum of fields due to all the secondary Huygen's sources that are located above the knife edge.
- The electric field strength E_d of the knife edge diffracted wave is given by,

$$\frac{E_d}{E_0} = F(v) = \frac{(1+j)}{2} \int_v^{\infty} \exp((-j\pi t^2)/2)\, dt \quad ...(3.7.9)$$

Where E_d = Electric field strength of knife edge diffracted wave

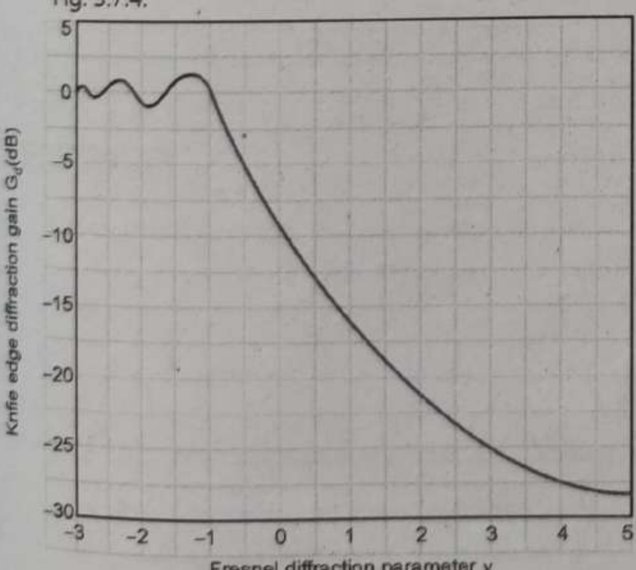
E_0 = Free space field strength

$F(v)$ = Complex Fresnel integral

- The Fresnel integral F(v) is a function of Fresnel-Kirchoff diffraction parameter v which we have defined earlier and is found using tables or graphs for given values of v.
- The **diffraction gain** because of the presence of a knife edge as compared to the free space electric field is given by,

$$G_d(\text{dB}) = 20 \log |F(v)| \quad ...(3.7.10)$$

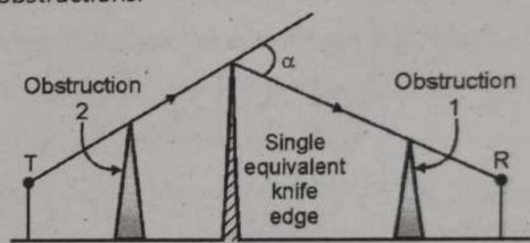
- A graph of G_d (dB) as a function of v is shown in Fig. 3.7.4.



(G-2808) **Fig. 3.7.4 : Graphical representation of G_d (dB) as a function of Fresnel diffraction parameter v**

3.7.4 Multiple Knife-Edge Diffraction :

- In the hilly terrains the propagation path may consist of more than one obstacles and we need to compute the total diffraction loss due to all the obstacles.
- Bullington showed that it is possible to replace the series of obstacles by a single equivalent obstacle as shown in Fig. 3.7.5 and then the path loss can be obtained using single knife edge diffraction model.
- Later Millington provided a wave theory solution for the field behind two knife edges in series.
- It is useful for predicting diffraction losses due to two knife edges.
- However, extending concept to more than two knife edges becomes problematic.
- Many less complicated models have been developed to estimate the diffraction losses due to multiple obstructions.



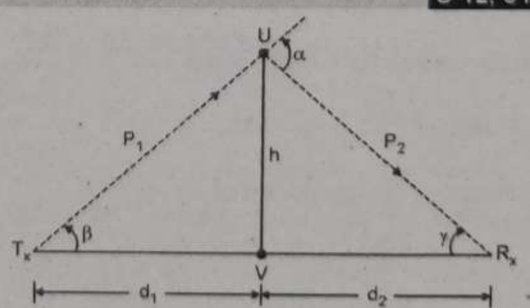
(G-2666) **Fig. 3.7.5 : Multiple knife edge model by Bullington**

Ex. 3.7.3 : For the knife edge geometry in Fig. P. 3.7.3, show that :

(a) $\phi = \frac{2\pi\Delta}{\lambda} = \frac{2\pi}{\lambda}\left[\frac{h^2}{2}\frac{(d_1+d_2)}{d_1 d_2}\right]$ and (b) $v = \alpha\sqrt{\frac{2 d_1 d_2}{\lambda(d_1+d_2)}}$

Where $\frac{v^2\pi}{2} = \phi$, $d_1 d_2 >> h >>> \lambda$ and $\Delta = P_1 + P_2 - (d_1 + d_2)$.

S-12, 6 Marks



(G-2806) **Fig. P. 3.7.3 : Knife edge geometry**

Soln. :

Given : $d_1\, d_2 >> h >>> \lambda$, $\Delta = P_1 + P_2 - (d_1 + d_2)$

Part-a : Expression for ϕ:

- Refer Fig. P. 3.7.3. T_x and R_x are the transmitter and receiver respectively.
- The single equivalent knife edge is located at a distance d_1 from the T_x and at distance d_2 from the R_x.
- The height of this knife edge is "h".
- For the right angle triangle T_x UV we can write,

$$P_1 = \sqrt{d_1^2 + h^2} = d_1\sqrt{1 + \left(\frac{h}{d_1}\right)^2} \quad ...(1)$$

- Similarly for the right angle triangle UV R_x,

$$P_2 = \sqrt{d_2^2 + h^2} = d_2\sqrt{1 + \left(\frac{h}{d_2}\right)^2} \quad ...(2)$$

- Assume $d_1, d_2 >> h >> \lambda$,

$$\therefore \frac{h}{d_1}, \frac{h}{d_2} << 1.$$

- Using Taylor series approximation the expressions for P_1 and P_2 get modified as follows,

$$P_1 = d_1\left[1 + \frac{1}{2}\left(\frac{h}{d_1}\right)^2\right] = d_1 + \frac{1}{2}\frac{h^2}{d_1}$$

$$P_2 = d_2\left[1 + \frac{1}{2}\left(\frac{h}{d_2}\right)^2\right] = d_2 + \frac{1}{2}\frac{h^2}{d_2}$$

- It is given that,

$$\Delta = P_1 + P_2 - (d_1 + d_2)$$

$$\therefore \Delta = \left[d_1 + \frac{1}{2}\frac{h^2}{d_1}\right] + \left[d_2 + \frac{1}{2}\frac{h^2}{d_2}\right] - (d_1 + d_2)$$

$$\therefore \Delta = \frac{h^2}{2}\left[\frac{1}{d_1} + \frac{1}{d_2}\right]$$

$$\therefore \Delta = \frac{h^2}{2}\left(\frac{d_1 + d_2}{d_1\, d_2}\right) \quad ...(3)$$

- The expression for ϕ is as follows :

$$\phi = \frac{2\pi\,\Delta}{\lambda}$$

- Substituting the expression of Δ in ϕ,

$$\phi = \frac{2\pi\,\Delta}{\lambda}$$

$$= \frac{2\pi}{\lambda}\left[\frac{h^2}{2}\left(\frac{d_1 + d_2}{d_1\, d_2}\right)\right] \quad \text{...Proved.}$$

Part-b : Expression for v :

- It is given that,

$$\frac{v^2\pi}{2} = \phi$$

$$\therefore v^2 = \phi \cdot \frac{2}{\pi}$$

$$\therefore v = \sqrt{\phi \cdot \frac{2}{\pi}}$$

- Substituting the expression for ϕ we get,

$$v = \sqrt{\frac{2\pi}{\lambda}\left[\frac{h^2}{2}\left(\frac{d_1 + d_2}{d_1\, d_2}\right)\right]\frac{2}{\pi}}$$

$$= h\sqrt{\frac{2}{\lambda}\left(\frac{d_1 + d_2}{d_1\, d_2}\right)} \quad ...(4)$$

- From Fig. P. 3.7.3 we can write,

$$\tan\beta = \frac{h}{d_1} << 1, \quad \text{and } \tan\gamma = \frac{h}{d_2} << 1$$

$$\therefore \beta \approx \tan\beta = \frac{h}{d_1}, \quad \text{and } \gamma \approx \tan\gamma = \frac{h}{d_2}$$

$$\text{Also, } \alpha = \beta + \gamma = \frac{h}{d_1} + \frac{h}{d_2} = h\left(\frac{d_1 + d_2}{d_1\, d_2}\right)$$

$$\therefore h = \alpha \cdot \left(\frac{d_1\, d_2}{d_1 + d_2}\right) \quad ...(5)$$

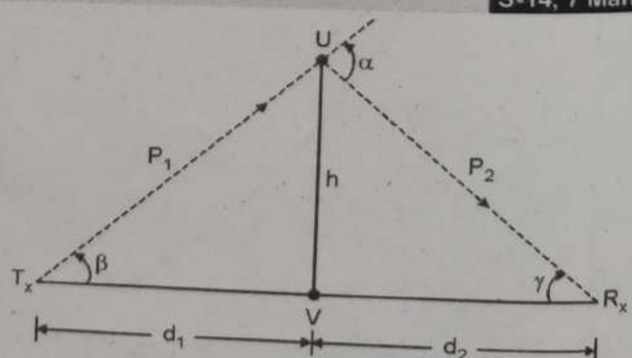
- Substituting Equation (5) into Equation (4) we get,

$$v = \alpha \cdot \left(\frac{d_1\, d_2}{d_1 + d_2}\right) \times \sqrt{\frac{2}{\lambda}\frac{(d_1 + d_2)}{d_1\, d_2}}$$

$$\therefore v = \alpha \cdot \sqrt{\frac{2}{\lambda}\frac{d_1\, d_2}{(d_1 + d_2)}} \quad \text{... Proved.}$$

Ex. 3.7.4 : For the Knife-edge geometry of Fig. P. 3.7.4 show that $\upsilon = \alpha\left(\frac{2d_1\, d_2}{\lambda\,(d_1 + d_2)}\right)^{1/2}$, approximately. Assume $d_1, d_2 >> h$.

S-14, 7 Marks



(G-2806) **Fig. P. 3.7.4 : Knife edge geometry**

Soln. :

- Refer the previous example.

3.8 Scattering :

GTU : W-13, S-19

University Questions

Q. 1 Explain the three basic propagation mechanisms which impact the propagation of signal in a mobile environment. **(W-13, 7 Marks)**

Q. 2 Explain three basic propagation mechanisms. **(S-19, 3 Marks)**

- We know that a radio wave impinging on a rough surface gets scattered in all directions.
- The objects like trees, lamp posts can scatter the incident RF energy in all directions.
- Due to scattering the received signal strength is generally higher than the predicted signal strength by only the reflection and diffraction models.
- We can model the flat surfaces having much larger dimensions as compared to the wavelength as the reflective surfaces.
- However due to their roughness these flat surfaces induce some propagation effects that are different from the specular reflection.
- We can test the surface roughness by using **Rayleigh's criterion** which defines a critical height (h_c) of surface protuberances for a given angle of incidence θ_i as follows :

$$h_c = \frac{\lambda}{8 \sin \theta_i} \quad ...(3.8.1)$$

- A given surface is considered as rough if its protuberance h is greater than h_c and the surface is smooth if its protuberance h is less than h_c.
- We can account for the diminished reflected field for the rough surfaces, by multiplying the flat surface reflection coefficient by the scattering loss factor "ρ_s".
- Assuming surface height "h" to be a Gaussian distributed random variable with local mean, the value of ρ_s can be obtained from the following expression,

$$\rho_s = \exp\left[-8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right] \quad ...(3.8.2)$$

where ρ_s = Scattering loss factor

θ_i = Angle of incidence

λ = Wavelength

σ_h = Standard deviation of the surface height.

- The above expression was modified as follows to obtain better results.

$$\rho_s = \exp\left[-8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right] I_0\left[8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right] \quad ...(3.8.3)$$

where I_0 = Bessel function of first kind and zero order

- We can compute the reflected fields for $h > h_c$ for rough surfaces using a modified reflection coefficient that is given by,

$$\tau_{rough} = \rho_s \tau \quad ...(3.8.4)$$

- This phenomenon of scattering is significant only if receiver or transmitter is located in highly cluttered environment.
- Scattering also plays an important role in the IR propagations inside rooms having rough walls.
- In the radio channels where scattering is induced by large objects, the scattered signal strengths can be predicted accurately by using the knowledge of their physical location.

The Radar Cross Section (RCS) :

- The Radar Cross Section (RCS) of a scattering object is defined as the ratio of power density of the signal scattered in the direction of the receiver to the power density of the radio wave incident upon the scattering object. It's unit is square meters.

3.9 Link Budget Design :

- We can use a combination of analytical and empirical methods to derive most of the radio propagation models that are used in practice.
- The empirical approach is based on the actually measured verifiable data rather than theory or pure logic.

- The advantage of this approach is that it takes into account all propagation factors, both known and unknown through actual field measurements.
- But many times the transmission frequencies and/or the environments that are being actually used can be different than those used to derive the empirical model.
- In such cases the necessary validation of these transmission frequencies or environments can be established only by additional measured data in the new environment at the required transmission frequency.
- Recently some classical propagation models have emerged and we may use them to predict large scale coverage for mobile communication systems design.
- If we use the **path loss models** to estimate the received signal level as a function of distance, then it becomes possible for us to predict the SNR for a mobile communication system.
- We can determine the noise floor, required for SNR estimation by using noise analysis technique.
- For example the two Ray model that we described earlier in this chapter can be used to estimate capacity in a spread spectrum cellular system, before such systems were deployed.
- Some of the practical path loss estimation techniques are as follows :
  1. Log-distance path loss model
  2. Log-normal shadowing
  3. Determination of percentage of coverage area.

3.9.1 Log-Distance Path Loss Model :

GTU : S-16

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

- There are two types of propagation models :
  1. Theoretical based propagation models and
  2. Measurement based propagation models
- And both these models indicate the same fact that, the average received signal power decreases logarithmically with distance in outdoor as well as indoor radio channels.
- We can use the following expression in terms of a path loss exponent n, to express the average large scale path loss for any arbitrary distance between a transmitter and a receiver.

$$\overline{PL}\ (d) \propto \left(\frac{d}{d_0}\right)^n \text{ or} \quad ...(3.9.1)$$

$$\overline{PL}\ (dB) = \overline{PL}\ (d_0) + 10\, n \log\left(\frac{d}{d_0}\right) \quad ...(3.9.2)$$

- Where the path loss exponent(n) indicates the rate at which the path loss increases with distance, d_0 is the closed in reference distance which is determined from measurements close to the transmitter and d is distance between the transmitter and receiver.
- The bars in Equations (3.9.1) and (3.9.2) denote the ensemble average of the of all possible path loss values for a given value of d.
- If we plot the modeled path loss on a log- log scale, then it is a straight line with slope equal to **10n dB** per decade.
- The value of path loss exponent(n), is dependent on the specific propagation environment.
- For example the value of n in free space is equal to 2 and n will have a larger value when obstructions are present.
- Table 3.9.1 lists typical path loss exponents obtained in various mobile radio environments.

(G-2814) Table 3.9.1 : Path loss exponent (n) for different environments

Sr. No.	Type of environments	Value of n
1.	Free space	2
2.	Cellular radio in urban area	2.7 to 3.5
3.	Shadowed urban cellular radio	3 to 5
4.	In building line of sight	1.6 to 1.8
5.	Building with obstruction	4 to 6
6.	Factories with obstruction	2 to 3

- We must select the free space reference distance that is appropriate for the propagation environment.

- In large coverage cellular systems, they commonly use 1-km as reference distance whereas in micro cellular systems the commonly used reference distances are 100-m or 1-m.
- Note that the reference distance should always be in the far field of the antenna.
- This is necessary to avoid the reference path loss being altered by the near field effects.
- The reference path loss is calculated using the free space path loss formula given by the following expression or through the field measurements at distance d_0.

$$PL\ (dB) = 10 \log \frac{P_t}{P_r} = -10 \log \left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \quad ...(3.9.3)$$

3.9.2 Log-normal Shadowing :

- The log-distance path loss model, does not consider the surrounding environmental clutter, which can be different at two different locations that have the same Tx - Rx separation.
- Due to this the measured signals are different than the average predicted value.
- The path loss is given by,

$$PL\ (d)\ [dB] = \overline{PL}\ (d) + X_\sigma$$

- Where X_σ = zero-mean Gaussian distributed random variable with standard deviation σ

$$PL\ (d)\ [dB] = \overline{PL}\ (d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \quad ...(3.9.4)$$

and $P_r\ (d)\ [dBm] = P_t\ [dBm] - PL\ (d)\ [dB]$

(with antenna gains included) ...(3.9.5)

- The log-normal distribution is used to describe the random **shadowing** effects that are observed over a large number of measurement locations which have same Tx-Rx separation, but different levels of clutter on the propagation path.
- This process is called **log-normal shadowing.**
- The log-normal shadowing shows that the signal levels measured at specific Tx-Rx separation have Gaussian distribution.
- We can express the standard deviation of Gaussian distribution that describes shadowing in dBs.
- We can use this model in computer simulation which can predict the received power levels at random locations in the analysis and design of communication systems.
- Note that the path loss PL (d) is a random variable that has normal distribution in dB about the distance dependent mean.
- We can use $P_r(d)$ and Q-function or the error function (erf) to determine the probability of the received signal level exceeding a particular level.
- The Q-function is given by,

$$Q\ (z) = \frac{1}{\sqrt{2\pi}} \int_z^\infty \exp\left(\frac{-x^2}{2}\right) dx$$

$$= \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{z}{\sqrt{2}}\right)\right] \quad ...(3.9.6)$$

- Where

$$Q\ (z) = 1 - Q\ (-z)$$

- We can compute the probability that the received signal level will exceed a value γ, from the cumulative density function (CDF) as follows,

$$P_r\ [P_r\ (d) > \gamma] = Q\left(\frac{\gamma - \overline{P_r\ (d)}}{\sigma}\right) \quad ...(3.9.7)$$

- And, the probability that the received signal level is below γ is given by,

$$P_r\ [P_r\ (d) < \gamma] = Q\left(\frac{\overline{P_r\ (d)} - \gamma}{\sigma}\right) \quad ...(3.9.8)$$

3.10 Maximum Distance Coverage Formula :

- For a good quality of communication, the signal level at the receiver should be higher than a specific signal threshold.
- Ideally a signal level higher than the threshold value should be present at any point in the coverage area of a transmitter.
- However, in practice, due to the random effects of shadowing, the signal level in some parts within a coverage area is below the specific signal threshold.
- Let the coverage area be circular with radius R from the base station, and let the desired received signal threshold be γ.

- Then we will find U (γ) i.e. the percentage of total coverage area which receives signal with strength equal or greater than γ.
- Let d = r be the radial distance of a receiver from a transmitter and let P_r (P_r (r) > γ) be the probability that the level of a randomly received signal at d = r is higher than the threshold γ within as incremental area dA.
- Then the expression for U (γ) can be written as follows:

$$U(\gamma) = \frac{1}{\pi R^2} \int P_r [P_r (r) > \gamma] \, dA$$

$$= \frac{1}{\pi R^2} \int_0^{2\pi} \int_0^R P_r [P_r (r) > \gamma] \, r \, dr \, d\theta \quad ...(3.10.1)$$

- Using Equation (3.9.7),we get,

$$P_r [P_r (r) > \gamma] = Q\left(\frac{\gamma - \overline{P_r (r)}}{\sigma}\right) = \frac{1}{2} - \frac{1}{2} \text{erf}\left(\frac{\gamma - \overline{P_r (r)}}{\sigma\sqrt{2}}\right) \quad ...(3.10.2)$$

$$P_r [P_r (r) > \gamma] = \frac{1}{2} - \frac{1}{2} \text{erf}\left(\frac{\gamma - [P_t - \overline{PL} (d_0) + 10n \log (r / d_0)]}{\sigma\sqrt{2}}\right) \quad ...(3.10.3)$$

- The path loss at r = R is given by,

$$\overline{PL} (r) = 10 \, n \log \left(\frac{R}{d_0}\right) + 10n \log \left(\frac{r}{R}\right) + \overline{PL} (d_0) \quad ...(3.10.4)$$

- Then we can express Equation (3.9.4) as,

$$P_r [P_r (r) > \gamma] = \frac{1}{2} - \frac{1}{2} \text{erf} \left(\frac{\gamma - [P_t - (\overline{PL} (d_0) + 10n \log (R/d_0) + 10n \log (r/R))]}{\sigma\sqrt{2}}\right)$$

- In the above equation, let,

$$a = \frac{\gamma - P_t + \overline{PL} (d_0) + 10n \log \left(\frac{R}{d_0}\right)}{\sigma\sqrt{2}} \quad \text{and} \quad b = \frac{10n \log e}{\sigma\sqrt{2}}$$

- Then,

$$U(\gamma) = \frac{1}{2} - \frac{1}{R^2} \int_0^R r \, \text{erf}\left(a + b \ln \frac{r}{R}\right) dr \quad ...(3.10.5)$$

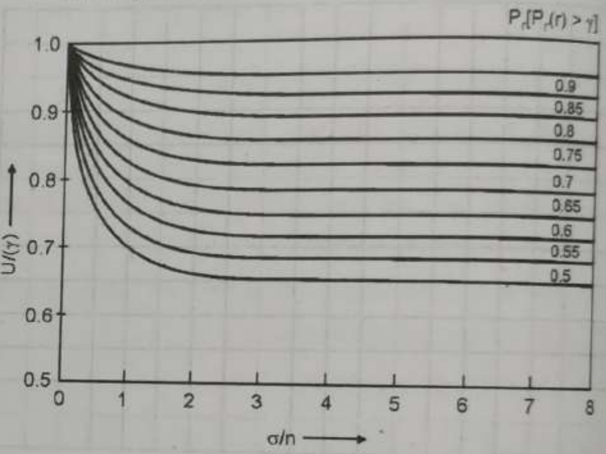
- Substitute $t = a + b \ln \left(\frac{r}{R}\right)$ in Equation (3.10.5), to get,

$$U(\gamma) = \frac{1}{2}\left(1 - \text{erf}(a) + \exp\left(\frac{1-2ab}{b^2}\right)\left[1 - \text{erf}\left(\frac{1-ab}{b}\right)\right]\right) \quad ...(3.10.6)$$

- If we select the signal level such that $\overline{P_r}$ (R) = γ (i.e. a = 0), then,

$$U(\gamma) = \frac{1}{2}\left[1 + \exp\left(\frac{1}{b^2}\right)\left(1 - \text{erf}\left(\frac{1}{b}\right)\right)\right] \quad ...(3.10.7)$$

- This expression is known as the maximum distance coverage formula.
- We can evaluate Equation (3.10.7) for different values of σ and n to plot the graph of Fig. 3.10.1.
- If n = 4, σ = 8 dB and if boundary has 75% boundary coverage then the area is equal to 90%.



(G-2809) Fig. 3.10.1 : U (γ) as a function of probability of signal above threshold on the cell boundary

3.11 Empirical Formula for Path Loss :

GTU : S-16, S-17

University Questions

Q. 1 Describe empirical formula for path loss in mobile networks **(S-16, S-17, 7 Marks)**

- Hata model is used for empirical formulation of the path loss provided by Okumura model.
- It is valid from 150 - 1500 MHz.
- The median path loss in urban areas is given by,

$$L \text{ (urban) (dB)} = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a (h_{re}) + (44.9 - 6.55 \log h_{te}) \log d \quad ...(5.11.1)$$

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 for small city is given by,

$$a(h_{re}) = (1.1 \log f_c - 0.7)\, h_{re} - (1.56 \log f_c - 0.8) \text{ dB} \quad ...(3.11.2)$$

Whereas, a (h_{re}) for large city is, a (h_{re})

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

$$a(h_{re}) = 3.2 (\log 11.75\, h_{re})^2 - 4.97 \text{ dB for } f_c \geq 300 \text{ MHz} \quad ...(3.11.3)$$

- In suburban area, the path loss is given by,

$$L(\text{dB}) = L(\text{urban}) - 2 \log \left(\frac{f_c}{28}\right)^2 - 5.4 \quad ...(3.11.4)$$

- The path loss in open rural areas is,

$$L(\text{dB}) = L(\text{urban}) - 4.78 \log f_c^2 + 18.33 \log f_c - 40.94 \quad ...(3.11.5)$$

3.12 Outdoor Propagation Models :

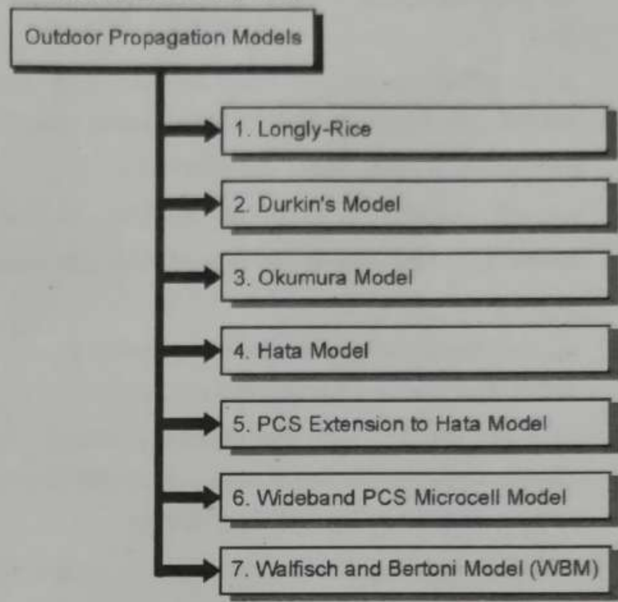
GTU : S-16, S-18

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 2 Describe the various outdoor propagation models. **(S-18, 7 Marks)**

- The transmission of radio waves in mobile communication generally takes place over irregular terrain.
- Hence we need to take in to consideration the terrain profile of a particular area to calculate the path loss.
- The outdoor terrain profile can vary to a great extent.
- Therefore a number of outdoor propagation models have been developed to predict path loss over irregular terrain.
- The aim of all these models is to predict signal strength at a particular receiving point or in a specific local area (called a sector).
- However they use different methods that vary widely in their approach, complexity and accuracy to achieve their goal.
- Some of the commonly used outdoor propagation models are as follows :



(G-2830) Fig. 3.12.1 : Outdoor propagation models

- Radio propagation models are empirical in nature, that is, they are developed based on large collections of measured data for the specific wireless communication environment.
- It is necessary to have sufficiently large collection of data to provide enough likeliness to all kinds of situations that can happen in that specific environment.

3.12.1 Okumura Propagation Model :

GTU : W-12, W-14, S-16, S-18

University Questions

Q. 1 Discuss the Okumura's prediction method with necessary equations. **(W-12, W-14, 4 Marks)**

Q. 2 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 3 Describe the various outdoor propagation models. **(S-18, 7 Marks)**

- 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.

- We can 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 :

$$L_{PO}\,(dB) = L_f\,(dB) + \alpha_m\,(f_c, r) - \alpha_t - \alpha_r - \sum \alpha_c \quad ...(3.12.1)$$

- 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:

$$\alpha_t = 20 \log (0.005 \times h_t) \quad ...(3.12.2)$$

- 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 :

$$\alpha_r = 20 \log (0.33 \times h_r) \text{ for } 10 \text{ m} > h_r > 3 \text{ m} \quad ...(3.12.3)$$

And $$\alpha_r = 10 \log (0.33 \times h_r) \quad \text{for } h_r \le 3 \text{ m} \quad ...(3.12.4)$$

- 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 base on the Okumara model .

Features of Okumura model :

- Some of the important features of this model are as follows:
  1. It is suitable for large cell coverage up to 100 km.
  2. It is suitable for urban areas
  3. This model can be used for effective base-station antenna heights from 30 m to 1000 m, and effective mobile receiver antenna height of 3 m.
  4. The standard deviation for this model is 10-14 dB.
  5. The Okumura propagation model is very accurate.

Ex. 3.12.1 : Find median path loss using Okumura's model for d = 50 km h_{te} = 100 m, h_{re} = 10 m. If EIRP from base station is 1kW at 900 MHz, find received power. Take A_{mu}(900 Mhz (50 km)) = 43 dB and G_{AREA} = 9 dB.

S-12, 8 Marks

Soln. :

Given : Okumura's model, d=50 km h_{te}=100 m, h_{re}=10 m, EIRP= 1kW, f = 900 MHz

To find : Received power

- The path loss is given by,

$$L_{50}\,(dB) = L_F + A_{mu}\,(f, d) - G\,(h_{te}) - G(h_{re}) - G_{Area}$$

- Where,

L_F : free space propagation loss

L_{50} : 50th percentile (median) value of propagation path loss

A_{mu} : median attenuation relative to free space

$G\,(h_{te})$: base station antenna height gain factor

$G\,(h_{re})$: mobile antenna height gain factor.

G_{Area} : gain because of type of environment.

1. **The free space path loss :**

- The free space path loss is given by,

$$L_F = 10 \log \left[\frac{\lambda^2}{(4\pi)^2 d^2} \right]$$

- But $\lambda = c/f$ and d = 50 km.

$$\therefore L_F = 10 \log \left[\frac{\left(\frac{3 \times 10^8}{900 \times 10^6}\right)^2}{(4\pi)^2 \times (50 \times 10^3)^2} \right]$$

$$\therefore L_F = 125.5 \text{ dB} \quad ...(1)$$

2. Find G (h_{te}) and G (h_{re}) :

A_{mu} (900 MHz (50 Km)) = 43 dB, h_{te} = 10 m

G_{AREA} = 9 dB and h_{te} = 100 m

- We know that,

$$G(h_{te}) = 20 \log \left(\frac{h_{te}}{200}\right) = 20 \log \left(\frac{100}{200}\right)$$

$$\therefore G(h_{te}) = -6 \text{ dB} \quad ...(2)$$

- And,

$$G(h_{re}) = 20 \log \left(\frac{h_{re}}{3}\right) = 20 \log \left(\frac{10}{3}\right)$$

$$\therefore G(h_{re}) = 10.46 \text{ dB} \quad ...(3)$$

3. The total path loss :

- For Okumura model the total path loss is given by,

$$L_{50} (\text{dB}) = L_F + A_{mu} (f, d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

$$L_{50} (\text{dB}) = 125.5 + 43 - (-6) - 10.46 - 9$$

$$\therefore L_{50} (\text{dB}) = 155.04 \text{ dB} \quad ...(4)$$

4. The median received power :

- The median received power is given by,

$$P_r (d) = \text{EIRP} (\text{dB}_m) - L_{50} (\text{dB}) + G_r (\text{dB})$$

$$\text{EIRP} = 1 \text{ KW} = 20 \log (1 \times 10^3) = 60 \text{ dBm}$$

$$\therefore P_r (d) = 60 \text{ dBm} - 155.04 \text{ dB} + 0 \text{ dB}$$

$$\therefore P_r (d) = -95.04 \text{ dBm}$$ **...Ans.**

3.12.2 Hata Model : GTU : S-16, S-18

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 2 Describe the various outdoor propagation models. **(S-18, 7 Marks)**

- 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.

$$L (\text{urban}) (\text{dB}) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d \quad ...(3.12.1)$$

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,

$$a(h_{re}) = (1.1 \log f_c - 0.7) h_{re} - (1.56 \log f_c - 0.8) \text{ dB} \quad ...(3.12.2)$$

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

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

$$a(h_{re}) = 3.2 (\log 11.75 h_{re})^2 - 4.97 \text{ dB} \quad \text{for } f_c \geq 300 \text{ MHz} \quad ...(3.12.3)$$

- We can modify the standard Hata formula of Equation (3.12.1) as follows to calculate the path loss in suburban area.

$$L (\text{dB}) = L (\text{urban}) - 2 \log \left(\frac{f_c}{28}\right)^2 - 5.4 \quad ...(3.12.4)$$

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

$$L (\text{dB}) = L (\text{urban}) - 4.78 \log f_c^2 + 18.33 \log f_c - 40.94 \quad ...(3.12.5)$$

Features :

- The important features of this model are :
  1. In Hata model there are no path specific corrections.
  2. The data loss predicted by this model is very close to that predicted by the Okumura model provided d is greater than 1 km.
  3. This model works well for the mobile systems with large sized cells.

4. It is not suitable for the personal communication systems (PCS) which have smaller cell size.

3.12.3 Longley-Rice Propagation Model :

GTU : S-16, S-18

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 2 Describe the various outdoor propagation models. **(S-18, 7 Marks)**

- The Longley-Rice propagation model is also known as the Irregular Terrain Model (ITM).
- It is used to calculate the large-scale median propagation loss relative to free-space propagation loss over irregular terrain.
- We can apply this model for point-to-point wireless communication systems operating over different terrain conditions.
- This model can operate in the frequency range from 40 MHz up to 100 GHz.
- The frequency planning in television broadcasting and preparation of the tables of channel allocations for VHF/UHF broadcasting has been done using this model.
- We can use the modified model for radio propagation in urban areas for mobile radio application.
- For this we need to add the urban factor which considers urban clutter near the mobile receiving antenna.
- The Longley-Rice propagation model is made of the following two parts :
  1. A model for predictions over an area and
  2. A model for point-to-point link predictions.
- We can use the first part i.e. area-to-area prediction model when the terrain path profile is not available.
- We can also use this part to estimate many path-specific parameters such as :
  1. Terrain irregularity,
  2. Horizon distance and angular trans-horizon distance between transmitting and receiving antennas,
  3. Horizon elevation angle, etc.
- We can use the second part i.e. point-to-point wireless link prediction model when a detailed path profile is available, and path-specific parameters can be easily determined.

Drawback :

- The main drawback of this propagation model is that it does not consider the effects of various factors such as multipath, buildings, foliage, and other environmental factors.

3.12.4 Durkin's Propagation Model :

GTU : S-16, S-18

University Questions

Q. 1 Enumerate various radio propagation model and explain any two of them **(S-16, 7 Marks)**

Q. 2 Describe the various outdoor propagation models. **(S-18, 7 Marks)**

Purpose :

- In order to predict field strength contours over irregular terrain, Durkin proposed a computer simulator.
- The two parts of Durkin's path loss simulator are :
  1. To access the topographic database of a proposed service area.
  2. To use quantized maps of service area heights, and to reconstruct the ground profile information which includes diffraction from obstacles, along the radial line-of-sight path between the transmitter with the receiver.
- The important assumption in this model is that the receiving antenna receives all of its energy along that radial path joining the transmitter to the receiver.
- That means, this model does not take the multipath propagation into account.
- The working of this model is as follows:

- On the radial LOS path between a transmitter and a receiver, the model identifies isolated weak signal spots.
- Then simulation algorithm is used for calculating the estimated path loss between the fixed locations of the transmitter and receiver.
- After this, we can move the simulated location of the receiver iteratively to different locations in the given service area, around the fixed transmitter location.
- Finally we can use the combined results of all these iterations to deduce the contour of the received signal strength and the propagation path loss.

Loss estimation in LOS condition :

- The first step in the operation of this algorithm is to decide whether a line-of-sight path exists between the transmitter and the receiver.
- The next step is that it checks the clearance of the first Fresnel zone.
- This step may be two outcomes :
  1. We can apply the free space path loss formula if the first Fresnel zone of the radio path is cleared without any obstruction from the ground profile.
  2. The received signal strength is 6 dB less than the value computed from free-space condition if the first Fresnel zone of the radio path is not cleared i.e. there is an obstruction that just meets the radial path between the transmitter and the receiver.
- This loss of signal strength is due to the diffraction loss occurring at the edge of the obstruction is lost.
- This is called as the line-of-sight propagation but with inadequate first Fresnel-zone clearance.
- The simulator program will calculate both the free-space path loss and the mobile point-to-point path loss.
- Then it takes the least value out of these two to determine the received signal strength for the given terrain profile.
- Finally it calculates and adds the loss due to inadequate first Fresnel-zone clearance to it.

Loss estimation in Non-LOS condition :

- For the non line-of-sight condition, the simulator program calculates the loss due to single diffraction edge, two diffraction edges, three diffraction edges, etc., and adds them together.
- Then this total loss due to diffraction is added to the free- space path loss.

Application :

- Durkin's propagation model is used by the Joint Radio Committee in the UK.

3.13 Indoor Propagation Models :

- With the advent of Personal Communication Systems (PCS), a need to characterizing radio propagation inside buildings has arisen.
- The indoor radio channel are different from the traditional mobile radio channel in the following two aspects :
  1. The distances involved are much smaller, and
  2. For a much smaller separation between Tx and Rx there is a great variability of the environment.
- This is because, propagation within buildings is influenced greatly by the features like, the layout of the building, the construction materials, and the building type.
- In this section we will discuss models for path loss within buildings i.e. the indoor models.
- The mechanisms that dominate the indoor radio propagation are same as outdoor : reflection, diffraction, and scattering.
- However, the operating conditions are much more variable.

- For example, the received signal levels vary greatly depending on whether interior doors are open or closed..
- The locations at which the antennas are mounted also impacts large-scale propagation.
- We can classify the indoor channels as :
  1. Line-of-sight (LOS) channels or
  2. obstructed (OBS) channels with varying degrees of clutter.
- Some of the important indoor models are as given below :
  1. Partition losses same floor
  2. Partition losses between floors
  3. Log-distance path loss model
  4. Ericsson Multiple Breakpoint Model
  5. Attenuation Factor Model

3.13.1 Partition Losses (Same Floor of a Building) :

- Closed aces like buildings have different types of partitions and obstacles which are parts of the internal and external structure.
- They include wood frame partitions,internal walls and wood or non-reinforced concrete between floors.
- The office buildings, have large open areas which contain moveable office partitions in order to reorganize the space easily and use metal reinforced concrete between floors.
- Partitions are of two types : hard and soft.
- **Hard partitions** are those which form a part of the building structure, and the movable which do not span to the ceiling are called **soft partitions**.
- As these partitions have different physical and electrical characteristics, it is difficult to apply general models to specific indoor installations.
- Therefore researchers have collected ANextensive data on losses for different types of partitions.

Table 3.13.1 : Materials used in building and corresponding

Sr. No.	Type of material used	Loss in dB
1.	All metals	26
2.	Metal stairs	5
3.	Foil insulation	3.9
4.	Concrete block wall	13
5.	Light textile inventory	3 - 5
6.	Metal blanket - 12 sq ft	4 - 7
7.	Aluminium sliding	20.4
8.	Heavy textile inventory	8 - 11
9.	Empty cardboard inventory boxes	3 - 6
10.	Ceiling duct	1 - 8
11.	5 m storage rack with large paper products (tightly packed)	6
12.	Semi-automated assembly line	5 - 7
13.	0.6 m square reinforced concrete pillar	12 - 14
14.	Stainless steel piping for cook - cool process	15
15.	Concrete wall	8 - 15
16.	Concrete floor	10
17.	Dry plywood (3/4 in) - 1 sheet	1 - 8

3.13.2 Partition Losses between Floors :

- The losses between floors of a building are dependent on the external dimensions and materials used for the building, and the type of construction used.
- In addition to this, the other factors such as number of windows in a building and the presence of tinting can affect the loss between floors.
- Table 3.13.2 shows the values for floor attenuation factors (FAF) in three buildings.

(G-2815) **Table 3.13.2 : Total Floor Attenuation Factor and Standard Deviation σ (dB) for Three Buildings**

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut creek						
One floor	33.6	3.2	25	31.3	4.6	110
Two floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One floor	13.2	9.2	16	26.2	10.5	21
Two floors	18.1	8.0	10	33.4	9.9	21
Three floors	24.0	5.6	10	35.2	5.9	20
Four floors	27.0	6.8	10	38.4	3.4	20
Five floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One floor	29.1	5.8	93	35.4	6.4	74
Two floors	36.6	6.0	81	35.6	5.9	41
Three floors	39.6	6.0	70	35.2	3.9	27

- It shows that for all three buildings, the attenuation between one floor of the building is greater than the incremental attenuation caused by each additional floor.
- Table 3.13.3 illustrates very similar observations. It shows that the additional path loss after about five or six floor separations, is negligible.

(G-2816) **Table 3.13.3 : Average Floor Attenuation Factor in dB for One, Two, Three, and Four Floors in Two Office Buildings**

Building	FAF (dB)	σ (dB)	Number of locations
Office Building 1 :			
Through one Floor	12.9	7.0	52
Through two Floors	18.7	2.8	9
Through three Floors	24.4	1.7	9
Through four Floors	27.0	1.5	9
Office Building 2 :			
Through one floor	16.2	2.9	21
Through two Floors	27.5	5.4	21
Through three Floors	31.6	7.2	21

3.13.3 Log-distance Path Loss Model :

- Indoor path loss obeys the distance power law given in the following Equation.

$$PL\ (dB) = PL(d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (3.13.1)$$

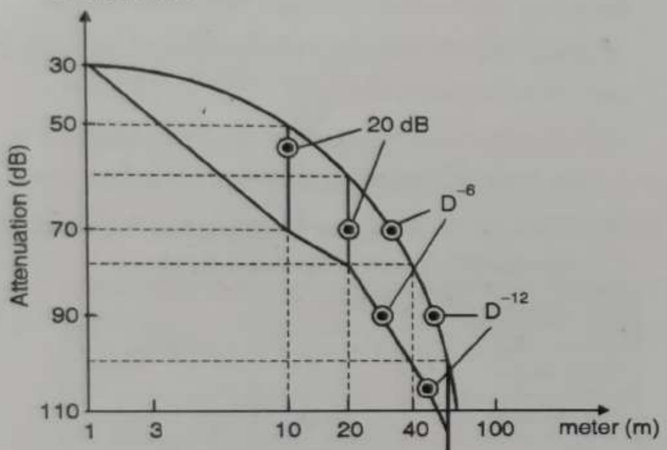
- In this equation, X_σ represents a normal random variable in dB having a standard deviation of σ dB.
- Whereas, the surroundings and building type would determine the value of n.
- Note that the form of Equation (3.13.1) is identical to the log-normal shadowing model of Equation (3.9.4).

(G-2817) **Table 3.13.4 : Path Loss Exponent and Standard Deviation Measured in Different Buildings**

Building	Frequency (MHz)	n	σ (dB)
Retail stores	914	2.2	8.7
Grocery store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metal working	1300	1.6	5.8
Suburban Home			
Indoor street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metal working	1300	3.3	6.8

3.13.4 Ericsson Multiple Breakpoint Model :

- The Ericsson radio system model was obtained based on measurements taken in a multiple floor office building.
- This model has four breakpoints and it considers an upper and as well as lower bound on the path loss.
- In this model it is assumed that the attenuation at d_0 = 1 m is 30 dB.
- It can be shown that the above mentioned value is accurate for f = 900 MHz and unity gain antennas.
- This model does not assume a log-normal shadowing component.
- Instead, it provides a deterministic limit on the range of path loss at a particular distance.
- Refer Fig. 3.13.1, which shows a plot of in-building path loss based on the Ericsson model as a function of distance.



(G-2789) Fig. 3.13.1 : Ericsson model in-building path loss

3.13.5 Attenuation Factor Model :

- This is an in-building site-specific propagation model that includes the effects of building type and different obstacles.
- It was described by Seidel and we can use it to deploy the indoor and campus networks accurately.
- The advantage of this model is that it is flexible and reduces the standard deviation between measured and predicted path loss to around 4 dB.
- This is much lower than 13 dB when only a log-distance model was used in two different buildings.
- The following expression gives the attenuation factor model.

$$\overline{PL}(d)\ [dB] = \overline{PL}(d_0)\ [dB] + 10\ n_{SF} \log\left(\frac{d}{d_0}\right) + FAF\ [dB] + \sum PAF\ [dB] \quad ...(3.13.2)$$

- Where,

n_{SF} = the exponent value for the "same floor" measurement,

FAF = floor attenuation factor for a specified number of building floors, and

PAF = the partition attenuation factor for a specific obstruction experienced by a ray travelling from the transmitter and receiver in 3-D.

- The technique in which a single ray is drawn between the transmitter and receiver is called **primary ray tracing.**
- The cumulative partition losses along the primary ray are added together.
- This technique has to advantages of excellent accuracy and very high computational efficiency.
- Thus, if we have a good estimate for n (e.g., selected from Table 3.13.4 or Table 3.13.5) on the same floor, then it is possible to predict the path loss on a different floor.
- The path loss can be predicted by adding an appropriate value of FAF selected from Table 3.13.4, and then summing the partition losses selected from Table 3.13.3.
- Alternatively, we may replace FAF, in Equation (3.13.2), by an exponent which has already considered the effects of multiple floor separation, to obtain the following equation.

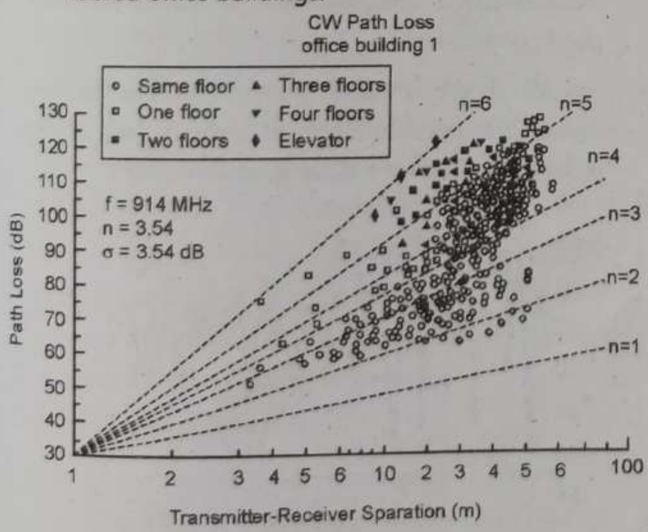
$$\overline{PL}(d)\ [dB] = \overline{PL}(d_0) + 10 n_{MF} \log\left(\frac{d}{d_0}\right) + \sum PAF\ [dB] \quad ...(3.13.3)$$

- Where n_{MF} represents a path loss exponent based on measurements through multiple floors.
- Refer Table 3.13.5 which contains typical values of n for a various types of locations in many buildings.

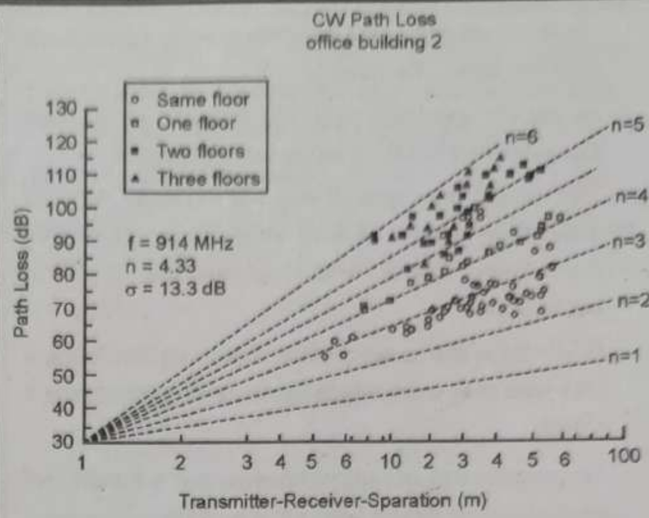
Table 3.13.5 : Path loss exponent and standard deviation for various types of buildings

Sr. No	Type of building	Number of locations	n	σ (dB)
1.	Office building 1 same floor	238	3.27	11.2
2.	Complete building	320	3.54	12.8
3.	Office building 2			
4.	Same floor	37	3.25	5.2
5.	Compute building	100	4.33	13.3
6.	All buildings same floor	501	2.76	12.9
7.	Building with one floor	73	4.19	5.1
8	Building with two floors	30	5.04	6.5
9.	Building with three floors	30	5.22	6.7
10.	All locations	634	3.14	16.3
11.	Grocery store	89	1.81	5.2
12.	Retail store	137	2.18	8.7

- It also demonstrates that the standard deviation decreases as the average region becomes smaller and more site specific.
- Fig. 3.13.2 and Fig. 3.13.3 show the scatter plots showing actual measured path loss in two multi-floored office buildings.



(G-2822) **Fig. 3.13.2**



(G-2823) **Fig. 3.13.3**

- It was found that in-building path loss obeys free space loss plus an additional loss factor.
- As shown in Table 3.13.6. this additional loss factor increases exponentially with distance.
- Based on this work, we can modify Equation (3.13.2) as follows,

$$\overline{PL}(d)\,[dB] = \overline{PL}(d_0)\,[dB] + 20\log\left(\frac{d}{d_0}\right) + \alpha d + FAF\,[dB] + \sum PAF\,[dB]$$

- where α is the attenuation constant for the channel expressed in dB per meter (dB/m) and its typical values as a function of frequency in Table 3.13.6

(G-2818) **Table 3.13.6 : Free space plus**

Location	Frequency	α–Attenuation (dB/m)
Building 1 : 4 story	850 MHz	0.62
	1.7 Ghz	0.57
	4.0 Ghz	0.47
Building 2 : 2 story	850 MHz	0.48
	1.7 Ghz	0.35
	4.0 Ghz	0.23

3.14 Signal Penetration into Buildings :

- Some wireless systems share frequencies with neighboring buildings or with outdoor systems.
- For such systems, the strength of received signal inside a building due to an external transmitter is important.
- In such situations, it is difficult to determine exact models for penetration of the signal.

- However, we can come to some general conclusions from the ability literature.
- As per the available data, the strength of received signal inside a building increases with height.
- That means, the signal strength at the lower floors of a building, reduces due to attenuation induced by the urban clutter and reduces the level of penetration.
- However at the exterior wall of the higher floors, a LOS path may exist, which causes a stronger incident signal.
- The penetration of radio frequencies is a function of frequency and height within the building.
- How much signal penetrates a building from the outside, also depends on the antenna pattern in the elevation plane.
- In most measurements the antenna heights of outdoor transmitters are assumed to be far less than the maximum height of the building under test.
- Some measurements have shown that penetration loss decreases with increase in frequency.
- The following table demonstrates this observation.

Table 3.14.1

Sr. No.	Frequency MHz	Penetration attenuation
1.	441 MHz	16.4 dB
2.	896.5 MHz	11.6 dB
3.	1400 MHz	7.6 dB

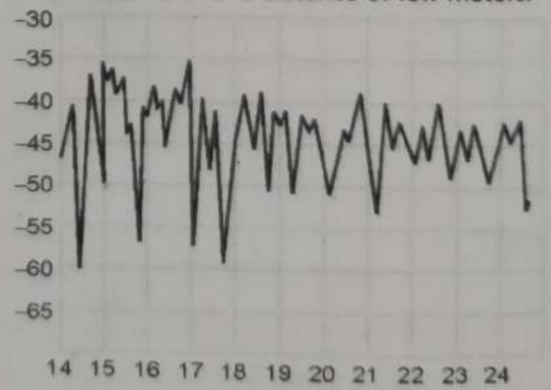
- The penetration loss in front of windows is about 6 dB less than that in the buildings without windows.

3.15 Small Scale Multipath Propagation :

- Small scale fading or simply fading describes the rapid fluctuations of signal amplitude over a short period of time or travel distance.
- Small scale fading is caused by the multipath reception of radio waves.

3.15.1 Effects of Small Scale Fading :

- The three small scale fading effects created by multipath are :
  1. Time dispersion or echoes due to multipath propagation delays.
  2. Rapid fluctuations in the signal strength over a small travel distance or time interval.
  3. Random frequency modulation because of varying Doppler shifts on different multipath signals.
- In built up urban areas, fading occurs due to small heights of mobile antennas as compared to height of surrounding structures which results in no direct line of sight path to the base station.
- Even when line of sight exists, the multipath signals are present because of reflections from the ground and surrounding structure.
- The received signal at the mobile station may consist of a number of waves with different amplitudes, phases and angles of arrivals.
- The vector sum of such signals will causes received signal to distort or fade. This effect is more severe if the receiver is moving but is also present when the receiver is stationary.
- If the objects in the radio channel are static and the movement is only because of the mobile, then fading is purely a **spatial** phenomenon.
- At the receiver the signal undergoes variations in strength because of constructive and destructive effects of multipath waves at different points in space.
- If the received signal is in deep fade, which is a serious case, the receiver may stop at that particular location and it becomes very difficult to maintain good communication.
- Fig. 3.15.1 shows rapid variations in the received signal level because of small scale fading, as the receiver moves over a distance of few meters.



(O-1459) Fig. 3.15.1 : Small-scale fading

Doppler shift :

- As the mobile moves, each multipath signal experiences an apparent shift in frequency due to the relative motion between the mobile and the base station.
- Such a shift in the received signal frequency because of relative motion is known as **Doppler shift**.
- The Doppler shift is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of the received multipath wave.

3.15.2 Factors Affecting Small-Scale Fading :

GTU : W-15, S-19

University Questions

Q. 1 Describe the factors influencing small scale fading. **(W-15, 7 Marks)**

Q. 2 Explain the factors influencing small scale fading. **(S-19, 4 Marks)**

- Small scale fading is influenced by the following factors :
  1. Multipath propagation.
  2. Speed of mobile.
  3. Speed of surrounding objects.
  4. Transmission bandwidth of the channel.

1. Multipath propagation :

- The presence of reflecting and scattering objects in the channel creates a constantly changing environment that dissipates the signal energy in amplitude, phase and time.
- Such random phase and amplitude variations of different multipath components can cause fluctuations in the signal strength which results in signal distortion, small scale fading or both.
- Due to multipath propagation the time required for the baseband signal to reach the receiver is increased which can result in signal smearing because of intersymbol interference.

2. Speed of the mobile :

- Due to the relative motion between the base station and the mobile station there occurs a random frequency modulation because of different Doppler shifts on each multipath component.
- The Doppler shift will be positive or negative depending on the direction of mobile receiver either towards or away from the base station.

3. Speed of the surrounding objects :

- If the objects in the radio channel are in motion they will induce a time varying Doppler shift on the multipath components.
- If the surrounding objects move at a higher rate than the mobile, then this effect dominates the small-scale fading.
- Otherwise, the motion of surrounding objects is to be ignored and only the speed of the mobile is to be considered.

4. Transmission bandwidth of the channel :

- If the bandwidth of the transmitted radio signal band is greater than the bandwidth of the multipath channel, then the received signal is distorted but the signal does not fade much.
- The bandwidth of the channel can be quantified by coherence bandwidth which is related to the specific multipath structure of the channel.

3.15.3 Coherence Bandwidth :

GTU : W-17

University Questions

Q. 1 Define Coherence Bandwidth and Doppler Spread. **(W-17, 3 Marks)**

- **Coherence bandwidth** is a measure of the maximum frequency difference for which signals are strongly correlated with each other in amplitude.
- If the transmitted signal has a smaller bandwidth as compared to that of the channel, then the signal amplitude will vary rapidly but there will be no signal distortion in time

3.15.4 Doppler Shift :

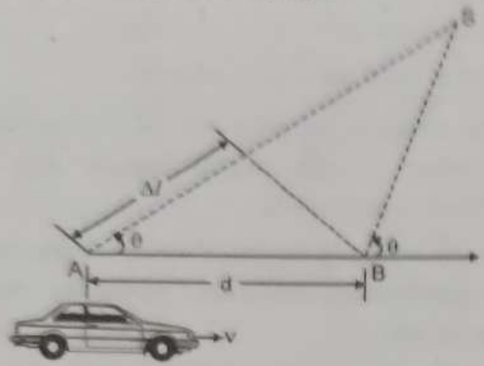
GTU : S-14, S-19

University Questions

Q. 1 Describe the concept of Doppler effect with relevant mathematical expressions. **(S-14, 7 Marks)**

Q. 2 Explain Doppler Shift with equation. **(S-19, 3 Marks)**

- Refer Fig. 3.15.2. Let a mobile be moving at a constant velocity v, along a path segment AB with a distance d separating points A and B and it receives signals from a remote source S.



(G-2821) **Fig. 3.15.2 : Doppler effect**

- The path lengths SA and SB are different from each other as shown and the difference in path lengths travelled by the signal from source S to mobile at points A and B is given by,

$$\Delta l = SA - SB = d \cos\theta = v\,\Delta t \cos\theta$$

Where Δt = Time taken by mobile to reach B from A

- The phase change in received signal corresponding to the difference in path length is given by,

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi\, v\, \Delta t}{\lambda} \cos\theta \quad ...(3.15.1)$$

- Therefore the apparent change in signal frequency due to Doppler shift is given by f_d as follows,

$$f_d = \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

$$f_d = \frac{v\cos\theta}{\lambda} \quad ...(3.15.2)$$

- Equation (3.15.2) expresses the relation between Doppler shift and the mobile velocity and spatial angle between the direction of motion of the mobile and direction of arrival of the wave.
- The Doppler shift is positive if the mobile is moving towards the direction of arrival of the signal and Doppler shift is negative if the mobile is moving away from the direction of the arrival of the signal.

Ex. 3.15.1 : Consider a transmitter that radiates a sinusoidal carrier frequency of 1850 MHz. For a vehicle moving 60 mph, compute the received carrier frequency if the mobile is moving (a) directly towards the transmitter (b) directly away from the transmitter (c) in a direction that is perpendicular to the direction of arrival of the transmitted signal.

W-12, W-17, 4 Marks

Soln. :

Given : f_c (carrier frequency) = 1850 MHz

Hence wavelength $\lambda = \frac{c}{f_c} = \frac{3 \times 10^8}{1850 \times 10^6} = 0.162$ m

Vehicle speed v = 60 mph = 60 × 1.609

$$= 96.56 \text{ k m/h} = \frac{96.56 \times 10^3}{60 \times 60}$$

$$\therefore \quad v = 26.82 \text{ m/s}$$

To find : Received carrier frequency

(a) Mobile moving towards the transmitter :

- When mobile is moving directly towards transmitter, the Doppler shift is positive and the received frequency is given by,

$$\theta = 0°$$

$$f = f_c + f_d = f_c + \frac{v}{\lambda}\cos 0°$$

$$= 1850 \times 10^6 + \left(\frac{26.82}{0.162}\right)$$

$$\therefore f = 1850 \times 10^6 + 165.55$$

$$\therefore f = 1850.000166 \text{ MHz}$$ ...Ans.

(b) Mobile moving away from the transmitter :

- When the mobile is moving away from the transmitter, the Doppler shift will be negative.
- The received frequency is given by,

$$\theta = 0°$$

$$f = f_c - f_d = f_c - \frac{v}{\lambda}\cos 0°$$

$$= 1850 \times 10^6 - \frac{26.82}{0.162}$$

$$\therefore f = 1849.999834 \text{ MHz}$$ ...Ans.

(c) Mobile moving in the direction perpendicular to the direction of arrival of the transmitted signal :

- When the mobile is moving in a direction perpendicular to the direction of arrival of the transmitted signal,

$$\theta = 90° \quad \therefore \cos 90° = 0$$

There will be no Doppler shift.

- Hence the received signal frequency will be same as the transmitted signal frequency of 1850 MHz.

$$\therefore f = 1850 \text{ MHz}$$ ...Ans.

x. 3.15.2 : A base station has a 900 MHz transmitter and a hicle is moving at the speed of 50 kmph. Compute the ceived carrier frequency if the vehicle is moving :

Directly towards the BS,

Directly away from the BS.

In a direction that is 60° to the direction of arrival of the transmitted signal?

Soln. :

Given :

f_c (carrier frequency) = 900 MHz

Hence wavelength $\lambda = \frac{c}{f_c} = \frac{3 \times 10^3}{900 \times 10^6} = 0.33$ m

Vehicle speed $v = 50$ km/h $= \frac{50 \times 10^3}{60 \times 60}$

$\therefore v = 13.88$ m/s

To find : Received carrier frequency

1. **Mobile moving towards the B.S. :**

- When mobile is moving directly towards the B.S., the Doppler shift is positive and the received frequency is given by,

$$\theta = 0°$$

$$f = f_c + f_d = f_c + \frac{v}{\lambda} \cos 0°$$

$$= 900 \times 10^6 + (\frac{13.88}{0.33})$$

$\therefore f = 900.0000421$ MHz ...**Ans.**

2. **Mobile moving away from the B.S. :**

- When vehicle is moving directly away from the base station, the Doppler shift will be negative.
- The received frequency is given by,

$$\theta = 0°$$

$$f = f_c - f_d = f_c - \frac{v}{\lambda} \cos 0° = 900 \times 10^6 - (\frac{13.88}{0.33})$$

$\therefore f = 899.9999579$ MHz ...**Ans.**

3. **Mobile moving in the direction that is 60° to the direction of arrival of the transmitted signal :**

- When the mobile is moving in a direction that is at 60° to the direction of arrival of the transmitted signal,

$$\theta = 60°$$

$\therefore \cos\theta = 0.5$ That means Doppler shift is positive

$$\therefore f = f_c + f_d = 900 \times 10^6 + (\frac{13.88}{0.33} \times 0.5)$$

$\therefore f = 900.000021$ MHz ...**Ans.**

Ex. 3.15.3 : In a cellular system, if carrier frequency $f_c = 900$ MHz and mobile velocity is 70 km/hr. Compute the received carrier frequency if the mobile is moving.

1. directly towards the transmitter
2. directly away from the transmitter
3. In a direction which is perpendicular to the direction of arrival of the transmitted signal

Soln. :

Given : f_c (carrier frequency) = 900 MHz

Hence wavelength $\lambda = \frac{c}{f_c} = \frac{3 \times 10^8}{900 \times 10^6} = 0.33$ m

Vehicle speed $v = 70$ km/hr $= \frac{70 \times 10^3}{60 \times 60}$

$\therefore v = 19.44$ m/s

To find : Received carrier frequency

1. **Mobile moving towards the transmitter :**

- When mobile is moving directly towards transmitter, the Doppler shift is positive and the received frequency is given by,

$$\theta = 0°$$

$$f = f_c + f_d = f_c + \frac{v}{\lambda} \cos 0°$$

$$= 900 \times 10^6 + \frac{19.44}{0.333} = 900 \times 10^6 + 58.392$$

$\therefore f = 900.00005839$ MHz ...**Ans.**

2. **Mobile moving away from the transmitter :**

- When the mobile is moving away from the transmitter, the Doppler shift will be negative.
- The received frequency is given by,

$$\theta = 0°$$

$$f = f_c - f_d = f_c - \frac{v}{\lambda} \cos 0°$$

$$= 900 \times 10^6 - (\frac{19.44}{0.333})$$

$\therefore f = 899.9999416$ MHz ...**Ans.**

(c) **Mobile moving in the direction perpendicular to the direction of arrival of the transmitted signal :**

- When the mobile is moving in a direction perpendicular to the direction of arrival of the transmitted signal,

$\theta = 90°$ $\therefore$ $\cos 90° = 0$

There will be no Doppler shift.

- Hence the received signal frequency will be same as the transmitted signal frequency of 900 MHz.

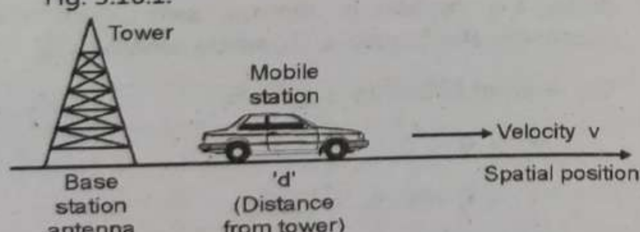
$\therefore$ $f = 900$ MHz. ......Ans.

3.16 Impulse Response Model of a Multipath Channel : GTU : S-19

University Questions

Q. 1 Explain direct RF channel impulse response measurement system with diagram. **(S-19, 7 Marks)**

- The impulse response of a radio channel is directly related to the small scale variations of the mobile radio channel.
- The impulse response is a wideband channel characterization.
- It consists of all the information that is essential to simulate and analyze any kind of radio transmission through that channel.
- The impulse response is useful to predict and compare the performance of different mobile communication systems and transmission bandwidths for a specific mobile channel condition.
- We can model a mobile radio channel as a linear filter with a time varying impulse response.
- To do so, consider the case where time variation is only due to the receiver motion in space as shown in Fig. 3.16.1.



(G-2668) **Fig. 3.16.1 : Mobile radio channel as a function of time and space**

- The mobile moves along the ground at a constant velocity v in the opposite direction to the base station antenna.
- The distance between the base station transmitting antenna and mobile is "d".
- We can model the channel between the transmitter and the mobile (receiver) as a linear time invariant system.
- The impulse response of the linear time invariant channel must be a function of the position of the mobile (receiver).
- This is because of the different multipath waves that have propagation delays varying over spatial locations of the receiver.
- If the impulse response of the channel is expressed as h (d, t) and if x (t) is the transmitted signal then the received signal y (d, t) at position d can be expressed as a convolution of x (t) with h (d, t).

$$y(d, t) = x(t) \otimes h(d, t) \quad ...(3.16.1)$$

- For a causal system,

$$h(d, t) = 0 \text{ for } t < 0$$

- Thus Equation (3.16.1) becomes,

$$y(d, t) = \int_{-\infty}^{t} x(\tau) \cdot h(d, t-\tau)\, d\tau \quad ...(3.16.2)$$

- Thus, the output signal y (d, t) is a convolution of two signals $x(\tau)$ and $h(d, t-\tau)$.
- For a stable system

$$\int_{-\infty}^{\infty} [h(d, t)]\, dt < \infty$$

- Applying causality condition in the above equation $h(d, t-\tau) = 0$ for $t - \tau < 0$ i.e. $\tau > t$ the integration limits change to

$$y(d, t) = \int_{-\infty}^{t} x(\tau) \cdot h(d, t-\tau)\, d\tau \quad ...(3.16.3)$$

- Thus, the output signal y (d, t) is a convolution of two signals $x(\tau)$ and $h(d, t-\tau)$.
- The receiver moves along the ground with a constant velocity v.
- Hence, we can express the position of the receiver as,

$$d = vt \quad ...(3.16.4)$$

- Substitute Equation (3.16.4) in Equation (3.16.3) to get,

$$y(vt, t) = \int_{-\infty}^{t} x(\tau)\, h(vt, t-\tau)\, d\tau \quad ...(3.16.5)$$

- However, v is a constant. Therefore, y (vt, t) is a function of only t.
- Hence, we can express the above expression as,

$$y(t) = \int_{-\infty}^{t} x(\tau)\, h(vt, t-\tau)\, d\tau \quad ...(3.16.6)$$

$$y(t) = x(t) \otimes h(vt, t) \quad ...(3.16.6(a))$$

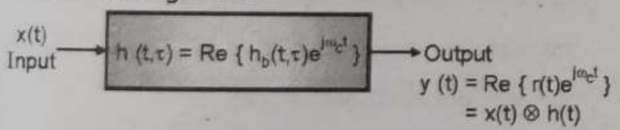
$$y(t) = x(t) \otimes h(d, t) \quad ...(3.16.6(b))$$

where vt = d

- As the mobile radio channel is time varying, we can model it as linear time varying channel, where the channel varies with distance (d) and time period (t).

Impulse response :

- As v is constant, let the transmitted band pass waveform be x (t), the received waveform be y(t) is and the impulse response of the time varying radio channel be h (t, τ).
- The radio channel is completely characterized by the impulse response h (t, τ) which is a function of the time periods t and τ.
- Here, "t" represents the time variations due to motion and τ represents the channel multipath delay for a fixed value of t.
- The band pass channel impulse response model is as shown in Fig. 3.16.2.



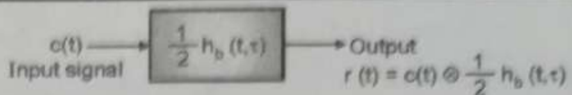
(G-2810) Fig. 3.16.2 : Bandpass channel impulse response model

- Then the received output signal y (t) is equal to the convolution of the transmitted signal x (t) and the channel impulse response.

$$y(t) = \int_{-\infty}^{\infty} x(\tau) \cdot h(t, \tau)\, d\tau \quad ...(3.16.7)$$

$$\therefore y(t) = x(t) \otimes h(t, \tau) \quad ...(3.16.8)$$

- If we assume the multipath channel to be a band limited band pass channel then we can describe the impulse response h (t, τ) as a complex baseband impulse response h_b (t, τ) as shown in Fig. 3.16.3.



(G-2811) Fig. 3.16.3 : Baseband equivalent channel impulse response model

- The output signal is given by,

$$r(t) = c(t) \otimes \frac{1}{2} h_b(t, \tau) \quad ...(3.16.9)$$

- where c (t), r (t) : complex envelopes of x (t) and y (t) such that,

$$x(t) = \mathrm{Re}\{ c(t) \exp(j2\pi f_c t) \} \quad ...(3.16.10)$$

$$y(t) = \mathrm{Re}\{ r(t) \exp(j2\pi f_c t) \} \quad ...(3.16.11)$$

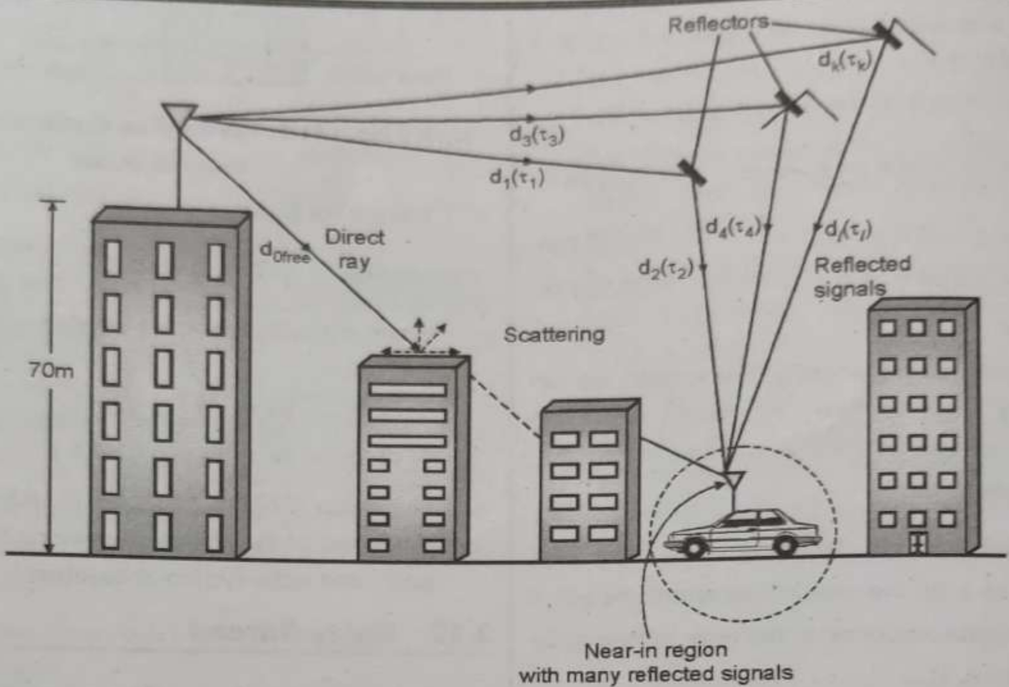
- The factor (1/2) in Equation (3.16.9) is due to the properties of the complex envelope to represent the pass band radio system at baseband.

3.17 Delay Spread :

- Fig. 3.17.1 (a) shows the propagation of a land-mobile line of sight (LOS) and non-line of sight (NLOS) radio system which is obstructed by several buildings.
- The height of the base station antenna is 70 m and it is at the top of the tallest building.
- The direct line of sight (LOS) free space path "d_{0free}" exists between the base station antenna and first building after which the direct path d_0 is attenuated.
- The mountains reflect and delay the signals from base station and the receiver can receive these reflected delayed signals at a comparable power level to the attenuated direct path signals.
- Let a short RF burst at 150 MHz is transmitted at t = 0 from the base station antenna.
- Let the direct LOS signal has the path length of d_0 and propagation delay of τ_0.
- Let the attenuation caused by the obstruction be 96 dB. If d_0 = 1 km then the free space LOS loss at 150 MHz is 65 dB.
- Therefore, the total loss for the direct path is,

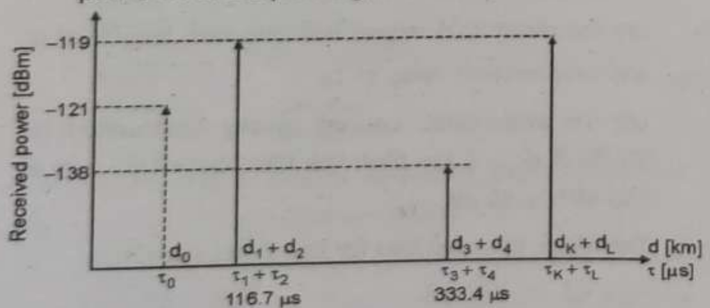
$$96 + 65 = 161 \text{ dB}$$

- The reflected multipath RF signals travel along different path lengths such as ($d_1 + d_2$), ($d_3 + d_4$), ... ($d_K + d_L$) as shown in Fig. 3.17.1(a).



(G-2812) **Fig. 3.17.1(a) : Propagation environment of land-mobile line of sight (LOS) and non line of sight (NLOS) radio system obstructed by several buildings**

- If the attenuation due to diffraction is small, then the received reflected signals will have almost the same strength but longer propagation delays than the direct LOS signal.
- The propagation delay of the signal received by the mobile along the path (d_1+d_2) is $\tau_1 + \tau_2$.
- Therefore, the delay of this reflected signal relative to the direct LOS signal is $\tau_A = \tau_1 + \tau_2 - \tau_0$ and it is called as the **first arrival delay**.
- This received power for this signal is of – 119 dBm as shown in Fig. 3.17.1(b) which is 2 dB higher than the power of direct path signal.



(G-2819) **Fig. 3.17.1(b) : Delays and signal strengths of direct and reflected signals**

- The propagation delay for the reflected signal received by the mobile via the second reflected path ($d_3 + d_4$) is of ($\tau_3 + \tau_4$).
- Therefore, the delay relative to the direct LOS signal is equal to ($\tau_B = \tau_3 + \tau_4 - \tau_0$).
- As shown in Fig. 3.17.1(b), the received power with this signal is of –138 which is 17 dB less than the power of the direct path signal.

Delay spread :

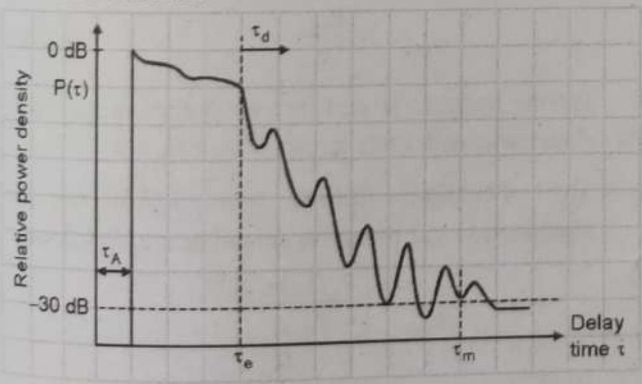
- Practically, along with a direct LOS component a large number of delayed components are also present.
- These components create a **power delay profile**.
- The extent of the power delay profile is called as **delay spread**.
- Table 3.17.1 gives the delay spread and propagation loss values for 150 MHz radio system shown in Fig. 3.17.1(a).

Table 3.17.1 : Delay spread "τ" and propagation loss values for 150 MHz radio system of Fig. 3.17.1(a)

Sr. No.	Parameter	Direct LOS path "d_0"	First reflected path "$d_1 + d_2$"	Second reflected path "$d_3 + d_4$"
1.	Total propagation distance	d_0 = 1 km	$d_1 + d_2$ = 36 km	$d_3 + d_4$ = 101 km
2.	Total propagation delay	$\tau_0 = 3.3\ \mu s$	$\tau_1 + \tau_2 = \frac{d_1 + d_2}{c} = \frac{36 \times 10^3}{3 \times 10^8}$ $\tau_1 + \tau_2 = 120\ \mu s$	$\tau_3 + \tau_4 = \frac{d_3 + d_4}{c} = \frac{101 \times 10^3}{3 \times 10^8}$ $\tau_3 + \tau_4 = 336.7\ \mu s$.
3.	Transmit power P_T = 10 W.	40 dBm	40 dBm	40 dBm
4.	Propagation path loss	65 dB	152 dB	168 dB
5.	Path loss due to buildings and obstructions	96 dB	7 dB	10 dB
6.	Total path loss (L_T)	(65 + 96) = 161 dB	(152 + 7) = 159 dB	(168 + 10) = 178 dB.
7.	Received power $P_R = P_T - L_T$	40 – 161 = – 121 dBm	40 – 159 = – 119 dBm	40 – 178 = – 138 dBm
8.	Delay spread "τ" of reflected signal. $\tau = (\tau_N + \tau_m) - \tau_0$	0 μs.	$(\tau_1 + \tau_2) - \tau_0$ = 120 – 3.3 = 116.7 μs.	$(\tau_3 + \tau_4) - \tau_0$ = 336.7 – 3.3 = 333.4 μs.

3.17.1 Power Delay Profile

- Due to the multipath propagation a severe dispersion of the transmitted signal takes place.
- We need to measure the power delay profile to find the expected degree of dispersion.
- The dispersion or the distribution of transmitted power over the multipath structure is indicated by the power delay profile.
- Fig. 3.17.2 shows the power delay profile of a mobile radio channel.



(G-2832) **Fig. 3.17.2 : Typical power delay profile P (τ)**

- Where,

  τ_A : first arrival delay

  τ_e : mean excess delay

  τ_d : root mean square (rms) delay

  τ_m : maximum excess delay with respect to some power level.

First Arrival Delay (τ_A)

- First arrival delay of the first arriving signal which acts as a reference is measured at the receiver.
- It is denoted by (τ_A) and all the other delays are measured with respect to it.
- First arrival delay is defined as the minimum possible propagation path delay from the transmitter to the receiver.
- An **excess delay** is defined as the delay that is measured at the right of the first arrival delay.

Mean Excess Delay (τ_e) :

- Mean excess delay is defined as the average delay measured with respect to the first arrival delay. It is expressed as,

$$\tau_e = \int (\tau - \tau_A)\, P(\tau)\, d\tau \quad ...(3.17.1)$$

- The power delay profile of a mobile radio channel is a density function which is given by,

$$P(\tau) = \frac{s(\tau)}{\int s(\tau)\, d\tau} \quad ...(3.17.2)$$

- Where,

  s (τ) : measured power delay profile.

RMS Delay (τ_d)

- RMS delay is defined as the standard deviation about the mean excess delay. It is given by,

$$\tau_d = [\int (\tau - \tau_e - \tau_A)^2 P(\tau)\, d\tau]^{1/2} \quad ...(3.17.3)$$

- It is generally used to measure the delay spread.

Maximum Excess Delay (τ_M)

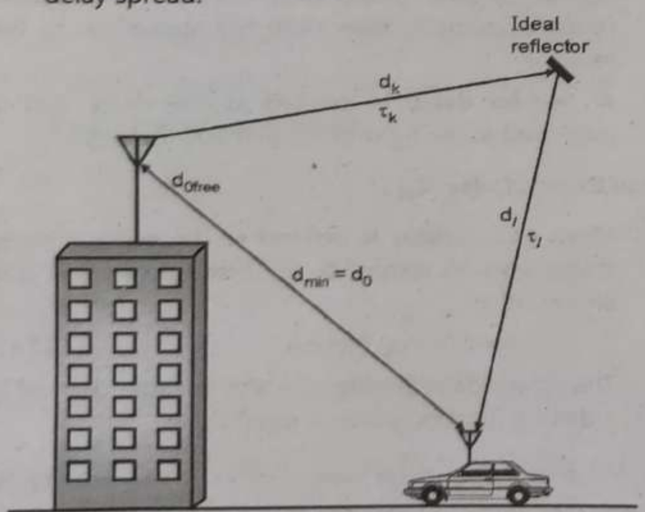
- Maximum excess delay (τ_M) is measured with respect to some specific power level. Refer Fig. 3.17.2 which shows that the maximum excess delay spread is specified as the excess delay (τ) for which P (τ) falls to – 30 dB .

3.18 Feher's Delay Spread - Upper Bound :

- Feher introduced a bound of worst case delay spread that is the maximum value of delay spread which is denoted by τ_{max}.
- It is difficult to measure and compute the maximum delay spread.
- If the BER is increased it can have undesirable effect.
- We can compute the maximum delay spread if we know the system parameters like transmit power (P_T), receiver power at threshold (P_{Rmin}), radio frequency (f_c).
- We can apply this delay spread bound to all wireless radio systems.

Expression for Feher's delay spread :

- Refer Fig. 3.18.1 to derive the upper bound Feher's delay spread.



(G-2831) Fig. 3.18.1 : Model for worst case Feher's upper bound delay spread

- Let d_k and d_l signal paths be the longest line-of-sight (LOS) signal paths with propagation delays τ_k and τ_l.
- Assume that the entire signal energy is reflected for the signal travelling this path from an ideal reflector.
- Also let the direct path is LOS for the shortest distance d_{0free}.
- Signal scattering and attenuation takes place in the direct path.
- The delayed signal energy can affect the system performance if the power of the received signal on delayed path is at threshold level given by,

$$P_{R\,min} = P_{rthreshold} \quad ...(3.18.1)$$

- The distance of maximum delay path is given by,

$$d_{max} = r_{max} = d_k + d_l \quad ...(3.18.2)$$

- For LOS propagation the path loss is given by ratio,

$$\frac{P_{Rmin}}{P_T} = G_T\, G_R \left(\frac{\lambda}{4\,\pi d_{max}}\right)^2 \quad ...(3.18.3)$$

- From this expression we can obtain **Feher's bound**.

$$d_{max} = \left[\frac{P_T\, G_T\, G_R\, (\lambda / 4\pi)^2}{P_{Rmin}}\right]^{1/2} \quad ...(3.18.4)$$

- Where
  - P_T : transmit power
  - G_T : transmit antenna gain
  - G_R : receive antenna gain
  - λ : wavelength
  - c : velocity of light
  - f : radio carrier frequency.
- Feher's bound on round trip propagation delay is given by the following expression.

$$\tau_{max} = \frac{d_{max}}{c} \quad ...(3.18.5)$$

- Let the transmitter and receiver antennas are omni-directional with unity gains i.e. $G_T = G_R = 1$.
- Then Equations (3.18.4) and (3.18.5) can be simplified to get the delay spread bound as follows :

$$\tau_{max} = \frac{d_{max}}{c} = \frac{\left[\frac{P_T\,(\lambda/4\pi)^2}{P_{Rmin}}\right]^{1/2}}{f\lambda}$$

$$\therefore \tau_{max} = \left[\frac{P_T}{P_{Rmin}}\right]^{1/2} \cdot \frac{\lambda}{4\pi} \times \frac{1}{f\lambda}$$

$$\therefore \tau_{max} = \frac{1}{4\,\pi f}\sqrt{\frac{P_T}{P_{Rmin}}} \text{ Seconds} \quad ...(3.18.6)$$

- This is the required expression for the delay spread bound.

Ex. 3.18.1 : What is the delay spread bound τ_{max} of a 220 MHz radio system if P_T = 1 watt (+ 30 dBm) and P_{Rmin} = – 90 dBm ? How much is τ_{max} if sensitivity of the receiver is improved to P_{Rmin} = – 100 dBm ? Why does increased sensitivity or increased system gain, $G_S = P_T / P_{Rmin}$, lead to a higher delay spread bound ?

W-12, 5 Marks

Soln. :

1. **Delay spread bound with omnidirectional antennas :**

Given : f = 220 MHz, P_T = 1 W, P_{Rmin} = – 90 dBm

- With unity gain omnidirectional antennas, the Feher's bound is given by,

$$\tau_{max} = \frac{1}{4\pi}\frac{1}{f}\sqrt{\frac{P_T}{P_{Rmin}}}$$

$$P_{Rmin} = -90 \text{ dBm} = 10^{-9} \text{ mW and}$$

$$P_T = 1 \text{ W} = 10^3 \text{ mW}$$

$$\therefore \frac{P_T}{P_{Rmin}} = 10^{12}$$

$$\therefore \tau_{max} = \frac{1}{4\pi}\cdot\frac{1}{220\times10^6}\sqrt{10^{12}}$$

$$\therefore \tau_{max} = 361.7 \ \mu s \quad \text{...Ans.}$$

2. **Delay spread bound with a sensitive receiver :**

Given : f = 220 MHz, P_T = 1 W, P_{Rmin} = – 100 dBm

$$P_{Rmin} = -100 \text{ dBm} = 10^{-10} \text{ mW}$$

$$\therefore \frac{P_T}{P_{Rmin}} = 10^{13}$$

$$\therefore \tau_{max} = \frac{1}{4\pi}\cdot\frac{1}{220\times10^6}\sqrt{10^{13}}$$

$$\therefore \tau_{max} = 1143.8 \ \mu s \quad \text{...Ans.}$$

- Thus for a more sensitive receiver, the delay spread bound increases as compared to that for a less sensitive receiver.
- The increased receiver sensitivity or increased system gain leads to an increased delay spread because the weaker reflected signals from larger distances also have a considerable effect on the overall measured delay spread profile.

3.19 Small-Scale Multipath Measurements : **GTU : S-15, S-19**

University Questions

Q. 1 Explain any one technique of small-scale multipath measurements. **(S-15, 7 Marks)**

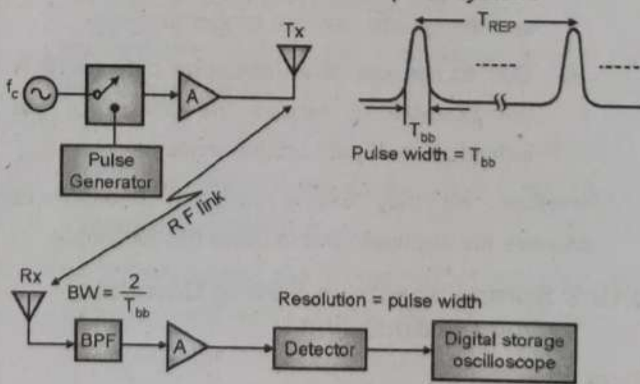
Q. 2 Explain direct RF channel impulse response measurement system with diagram. **(S-19, 7 Marks)**

- We know that the multipath structure is important in determining the small-scale fading effects.
- Therefore a number of wideband channel sounding techniques are developed to determine the fading effects.
- These techniques are classified as follows :
  1. Direct pulse measurements,
  2. Spread spectrum sliding correlator measurements and
  3. Swept frequency measurements.
- A number of wideband channel sounding techniques have been developed due to the importance of the multipath structure in determining the small-scale fading effects.
- These techniques may be classified as direct pulse measurements, spread spectrum sliding correlator measurements, and swept frequency measurements.

3.19.1 Direct RF Pulse System :

Block diagram :

- Fig. 3.19.1 shows a simple channel sounding approach that is the direct RF pulse system.



(G-2790) **Fig. 3.19.1 : Direct RF channel impulse response measurement system**

- This technique allows us to determine the power delay profile of any channel quickly.
- It is basically a wideband pulsed bistatic radar.
- As shown in Fig. 3.19.1, this system transmits a repetitive pulse of width T_{bb}. These pulses are repeatedly transmitted after a time period of T_{REP}.
- At the receiver a wide band pass filter with a bandwidth of $2/T_{bb}$Hz is used.
- The received signal is passed through an amplifier, detected with an envelope detector, and finally displayed and stored on a high speed oscilloscope.
- This method measures the square of the channel impulse response convolved with the probing pulse.
- This system can provide a local average power delay profile, if we set the oscilloscope on averaging mode.
- The minimum resolvable delay between multipath components is equal to the probing pulse width T_{bb}.

Advantages :

1. This system is less complex.
2. This system has a high accuracy of measurement.

Disadvantages :

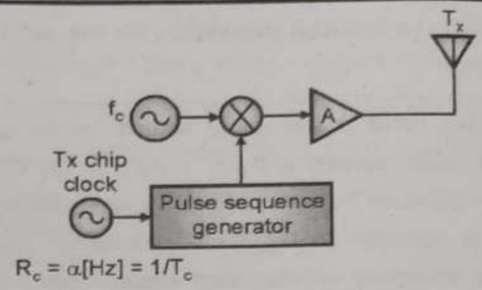
1. The main disadvantage of this system is that it is subject to interference and noise, due to the use of the wide pass-band filter.
2. Another disadvantage is that, the pulse system depends on the ability to trigger the oscilloscope on the first arriving signal.
3. In the event that the first arriving signal gets blocked or faded, severe fading takes place, and the system may not trigger properly.
4. Due to the use of an envelope detector, it is not possible to receive the phases of the individual multipath components.

- However, we may use a coherent detector to measure the multipath phase using this technique.

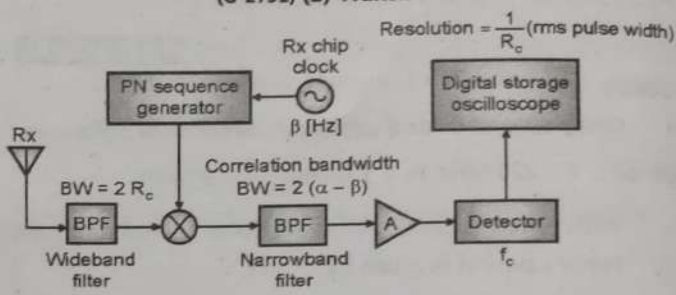
3.19.2 Spread Spectrum Sliding Correlator Channel Sounding :

Block diagram :

- Fig. 3.19.2 shows the block diagram of a spread spectrum channel sounding system



(G-2791) **(a) Transmitter**



(b) Receiver

(G-2791(a)) **Fig. 3.19.2 : Spread spectrum channel impulse response measurement system**

- The spread spectrum system has an advantage over the previous system.
- Even though the probing signal is wideband, we can detect the transmitted signal using a narrowband receiver preceded by a wideband mixer.
- This improves the dynamic range of the system as compared to the direct RF pulse system.
- The spread spectrum channel impulse response measurement system of Fig. 3.19.2 consists of two parts: transmitter and receiver.

Transmitter :

- At the transmitter of this system, we spread a carrier signal f_c over a large bandwidth by mixing it with a binary pseudo-noise (PN) sequence having a chip duration T_c and a chip rate R_c equal to $1/T_c$ Hz.
- At the output of the mixer, we obtain the spread spectrum signal, which is amplified and transmitted by the transmitting antenna.
- The power spectrum of the transmitted spread spectrum signal is expressed as follows :

$$S(f) = \left[\frac{\sin \pi (f-f_c) T_c}{\pi (f-f_c) T_c}\right]^2$$

$$= S_a^2 (\pi(f-f_c) T_c) \quad (3.19.1)$$

- From this expression we can obtain the null-to-null RF bandwidth as,

$$BW = 2 R_c \qquad (3.19.2)$$

- Where Rc is the chip rate.

Receiver :

- The spread spectrum signal received by the receiving antenna is passed through a band-pass filter.
- The filter output is applied to mixer along with a PN sequence generator identical to that used at the transmitter.
- At the output of the mixer we get a despread signal.
- Although the PN sequence at the receiver and that at the transmitter are identical, the transmitter chip clock is slightly faster than the receiver chip clock.
- When the chip sequences are mixed in this fashion the implementation a called as **sliding correlator.**
- The correlator output is passed through a narrow band filter which can reject almost all of the incoming signal power.
- This is known as realizing the processing in a spread spectrum receiver which enables it to reject pass-band interference, unlike the direct RF pulse sounding system.
- Processing gain (PG) of the receiver is given by,

$$PG = \frac{2 R_c}{R_{bb}} = \frac{2 T_{bb}}{T_c} = \frac{(S/N)_{out}}{(S/N)_{in}} \qquad (3.19.3)$$

- Where $T_{bb} = 1/R_{bb}$, is the period of the baseband information.
- If the incoming signal is correlated with the receiver sequence, it is despread to its original bandwidth, envelope detected, and displayed on an oscilloscope.
- Different incoming multipath signals will have different time delays.
- Therefore, they will maximally correlate with the receiver PN sequence at different times.
- Depending on the time delay, the energy of these individual paths will pass through the correlator.
- Therefore, after envelope detection, the oscilloscope displays the channel impulse response convolved with the pulse shape of a single chip.

Time resolution :

- The expression for the time resolution ($\Delta\tau$) of multipath components using a spread spectrum system with sliding correlation is as follows :

$$\Delta\tau = 2 T_c = \frac{2}{R_c} \qquad (3.19.4)$$

- This expression indicates that this system can resolve two multipath components as long as they are equal to or greater than two chip durations, or 2 T_c seconds apart.
- The process of sliding correlation gives equivalent time measurements which get updated every time the two sequences are maximally correlated.
- The time between maximal correlations is given by,

$$\Delta T = T_c \gamma l = \frac{\gamma l}{R_c} \qquad (3.19.5)$$

where T_c = chip period (s)

R_c = chip rate (Hz)

γ = slide factor (dimensionless)

l = sequence length (chips)

The slide factor (γ) :

- We may define the slide factor as the ratio of the transmitter chip clock rate and the difference between the transmitter and receiver chip clock rates.
- It is a dimensionless quantity.
- The slide factor is expressed as follows,

$$\gamma = \frac{\alpha}{\alpha - \beta} \qquad (3.19.6)$$

where α = transmitter chip clock rate (Hz)

β = receiver chip clock rate (Hz)

- The sequence length for a maximal length PN sequence is ,

$$l = 2^n - 1 \qquad (3.19.7)$$

- where n represents is the number of shift registers in the sequence generator.
- As stated earlier, the incoming spread spectrum signal is mixed with a receiver PN sequence which is slower than the transmitter sequence.
- This means that the signal is down-converted or "collapsed*' to a low-frequency narrowband signal.

- Therefore we can say that, the rate of information transferred to the oscilloscope is equal to the relative rate of the two codes slipping past each other.
- As this signal is a narrowband signal, we can carry out narrowband processing, which eliminates much of the pass-band noise and interference.
- It is possible to realize the processing gain of Equation (3.19.3) with a narrowband filter having BW = $2(\alpha - \beta)$).
- The equivalent time measured on the oscilloscope corresponds to the relative times of multipath components displayed on the oscilloscope.
- There is a relation between the observed time scale on the oscilloscope and the actual propagation time scale as follows :

$$\text{Actual Propagation Time} = \frac{\text{Observed Time}}{\gamma} \tag{3.19.8}$$

- This effect is due to the relative rate of information transfer in the sliding correlator.
- For example, ΔT of Equation (3.19.5) gives the observed time measured on an oscilloscope and it is not the actual propagation time.
- This effect is known as **time dilation** and it takes place in the sliding correlator system because the propagation delays actually get expanded in time by the sliding correlator.
- We must take care that the sequence length period is greater than the longest multipath propagation delay.
- The PN sequence period is given by,

$$\tau_{PNseq} = T_c \, l \tag{3.19.9}$$

Advantages:

- Some of the major advantages of the spread spectrum channel sounding system are as follows :
  1. It rejects the pass-band noise, and improves the coverage range for a given transmitter power.
  2. The need of synchronization between the transmitter and receiver PN sequences is eliminated by the sliding correlator.
  3. It is possible to adjust the by changing the sliding factor and the post-correlator filter bandwidth.
  4. This system requires less transmitter powers than comparable direct pulse systems due to its "processing gain".

Disadvantages :

- Some of the major disadvantages of the spread spectrum channel sounding system are as follows :
  1. The measurements in this system are not made in real time.
  2. This system may need excessive time to make power delay profile measurements.
  3. It is not possible to measure phases of individual multipath components due to the use of a non-coherent detector.

Applications :

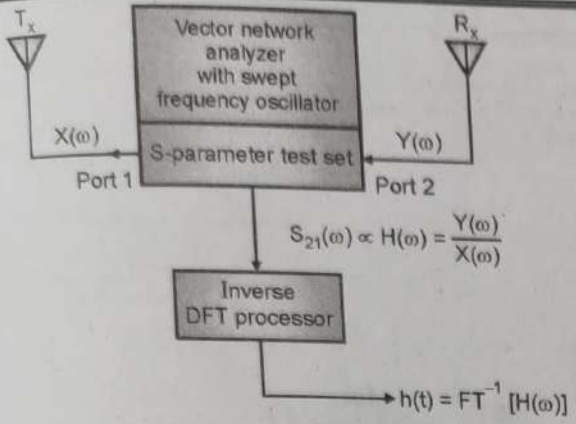
- Some of the important applications of this system are as follows :
  1. In the measurement of channel impulse responses in outdoor suburban environments at 910 MHz.
  2. To measure the time delay spread of multi-path components and signal level measurements in office and residential buildings at 850 MHz.

3.19.3 Frequency Domain Channel Sounding :

- There is a dual relationship between time domain and frequency domain techniques.
- Therefore, we can measure the channel impulse response in the frequency domain.

Block diagram :

- A frequency domain channel sounder used for measuring channel impulse responses is as shown in Fig. 3.19.3.
- As shown in Fig. 3.19.3, a vector network analyzer is used for controlling a synthesized frequency sweeper, and an S-parameter test set is used for monitoring the frequency response of the channel.



(G-2792) **Fig. 3.19.3 : Frequency domain channel impulse response measurement system.**

- The sweeper scans a particular frequency band with the carrier at the center of the band by changing the frequency in discrete steps.
- The time resolution of the impulse response measurement depends on the number of these frequency steps and the spacing between them.
- For each frequency step, the S-parameter test set would transmit a known signal level at port 1 and monitors the corresponding received signal level at port 2.
- Base on the signal levels at the two ports, the analyzer determines the complex response that is the **transmissivity** $S_{21}(\omega)$ of the channel over the measured frequency range.
- This transmissivity response is a frequency domain representation of the channel impulse response.
- The inverse discrete Fourier transform (IDFT) processing is used to convert this response to the time domain, giving a band-limited version of the impulse response.

Drawbacks :

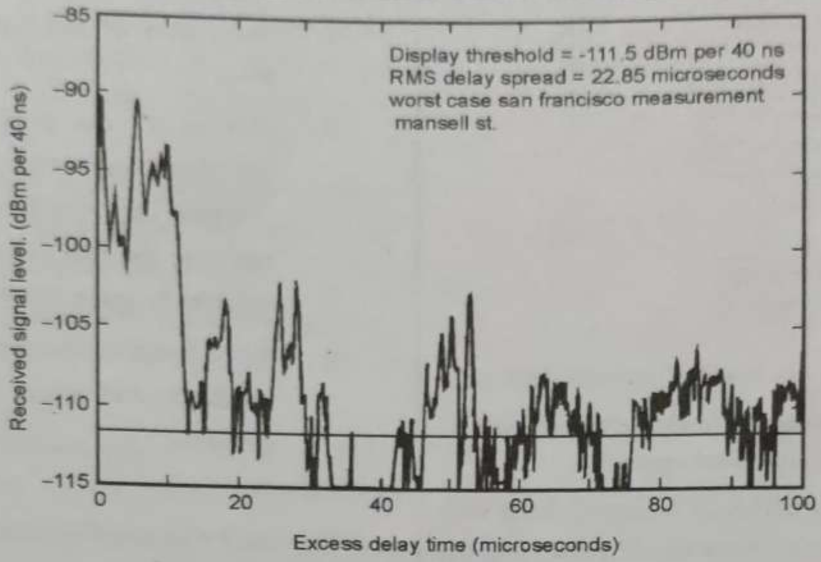
- Some of the major drawbacks of this system are as given below :
  1. In theory, this technique works well. However, in practice a careful calibration and hardwired synchronization between the transmitter and receiver is required to make it work. Therefore, this system is useful only for very close measurements such as indoor channel sounding.
  2. The nature of the measurement is non-real-time.
  3. This system can produce erroneous impulse response measurement for the time varying channels, for which the channel frequency response can change rapidly. This effect can be reduced by using fast sweep times.
  4. But a faster sweep time can reduce the time resolution and excess delay range in the time domain.

Applications :

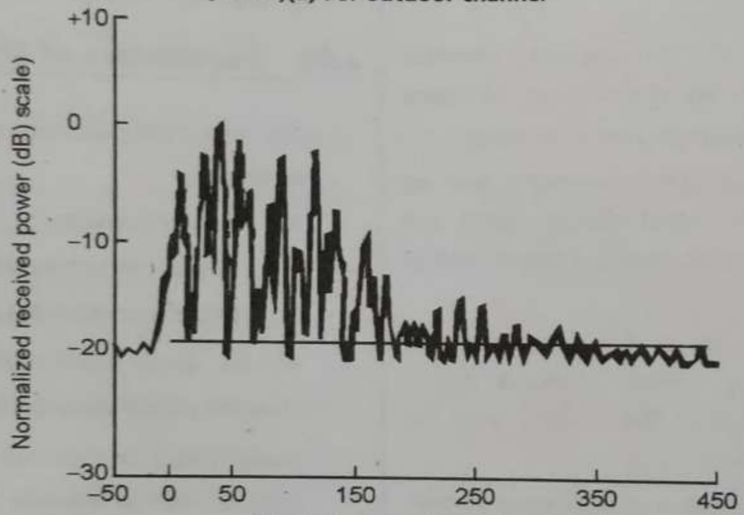
- The swept frequency system can be used for indoor propagation studies.

3.20 Parameters of Multipath Channels :

- The important parameters of multipath channels are as follows :
  1. Time dispersion
  2. Coherence bandwidth
  3. Doppler spread and coherence time.
- We can derive many multipath channel parameters from the power delay profile.
- Power delay profiles are generally represented as plots of relative received power versus excess delay with respect to a fixed time delay reference.
- In order to determine an average small-scale power delay profile, we can obtain the power delay profiles by averaging instantaneous power delay profile measurements over a local area.
- Depending on the time resolution of the probing pulse and the type of multipath channels being studied, observers take sample at spatial separations of a λ/4 and over receiver movements less than 6 m in outdoor channels and less than 2 m in indoor channels in the frequency range of 450 MHz-6 GHz.
- Typical power delay profile plots from outdoor and indoor channels have been shown in Fig. 3.20.1.



(G-2833)**(a) For outdoor channel**



(b) For indoor channel

(G-2834)**(Fig. 3.20.1 : Measured multipath power delay**

3.20.1 Time Dispersion Parameters :

- We can compare different multipath channels and develop some general design guidelines for wireless systems, base on the time dispersion parameters.
- The multipath parameters that can be determined from the power delay profile are as follows :
  1. Mean excess delay
  2. Rms delay spread
  3. Excess delay spread

1. The mean excess delay ($\bar{\tau}$) :

- The mean excess delay is the first moment of the power delay profile and is defined as follows :

$$\bar{\tau} = \frac{\sum_k \alpha_k^2 \tau_k}{\sum_k \alpha_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \qquad ...(3.20.1)$$

2. The Rms delay spread :

- The rms delay spread is defined as the square root of the second central moment of the power delay profile and it is given by,

$$\sigma_\tau = \left[(\overline{\tau^2}) - (\bar{\tau})^2\right]^{1/2} \qquad ...(3.20.2)$$

- Where

$$\overline{\tau^2} = \frac{\sum_k \alpha_k^2 \tau_k^2}{\sum_k \alpha_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)} \qquad ...(3.20.3)$$

- These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$.
- The typical measured values of rms delay spread are as shown in Table 3.20.1.

Table 3.20.1 : Measured values of RMS delay spread

Environment	Frequency	RMS Delay Spread (σ_τ)
Urban	910 MHz	1300 ns average 600 ns standard deviation 3500 ns maximum
Urban	892 MHz	10 – 25 μs
Suburban	910 MHz	200 – 310 ns
Suburban	910 MHz	1960 – 2110 ns
Indoor	850 MHz	270 ns
Indoor	1500 MHz	10 – 50 ns
Indoor	1900 MHz	70 – 94 ns average 1470 ns maximum

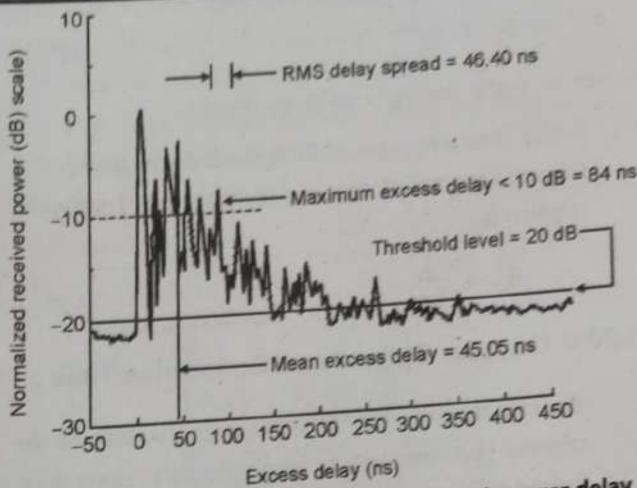
- Note that the rms delay spread and mean excess delay are defined by using a single power delay profile.
- In order to determine a statistical range of multipath channel parameters for a mobile communication system over a large-scale area, researches make multiple measurements at many local areas.

3. **The maximum excess delay :**

- We may define the maximum excess delay (X dB) of the power delay profile as the time delay during which multipath energy falls to X dB below the maximum.
- That means, the maximum excess delay is given by,

$$\text{Maximum excess delay} = (\tau_x - \tau_0)$$

- Where τ_0 is the first arriving signal and and τ_x is the maximum delay at which a multipath component is within X dB of the strongest multipath signal.
- The maximum excess delay for multipath components within 10 dB of the maximum can be calculated as shown in Fig. 3.20.2.



(G-2835) **Fig. 3.20.2 : Excess delay for multipath power delay profile**

4. **The excess delay spread :**

- The value of τ_x is called as the excess delay spread of a power delay profile.
- In order to characterize the channel in the frequency domain we use **coherence bandwidth** which is analogous to the delay spread parameters in the time domain.
- The coherence bandwidth and rms delay spread are inversely proportional to each another.

3.20.2 Coherence Bandwidth (B_c) :

- The delay spread occurs naturally due to reflected and scattered propagation paths in the radio channel.
- However, the coherence bandwidth, B_C, is a defined relation which is derived from the rms delay spread.
- **Coherence bandwidth** is a statistical measure of the frequency range over which the channel can be considered as a "flat" channel.
- A **flat channel** is defined as the one which passes all frequencies with approximately equal gain and linear phase.
- Alternatively, we may define the coherence bandwidth as the range of frequencies over which two frequency components have a high possibility of amplitude correlation.
- If we define the coherence bandwidth as the range of frequencies over which the frequency correlation function is above 0.9, then the coherence bandwidth is mathematically expressed as,

$$B_c = \frac{1}{50\, \sigma_\tau} \quad (3.20.4)$$

where σ_τ is the average rms delay spread.

- If the frequency correlation function is above 0.5, then the approximate value of coherence bandwidth is given by,

$$B_c \approx \frac{1}{5\, \sigma_\tau} \quad (3.20.5)$$

3.20.3 Doppler Spread and Coherence Time :

- We can describe the time dispersive nature of the channel in a local area by using the parameters delay spread and coherence bandwidth.
- However, they cannot provide any information about the time varying nature of the channel which results due to either relative motion between the mobile and base station, or by movement of objects in the channel.
- In order to describe the time varying nature of the channel in a small-scale region we need to use the parameters called Doppler spread and coherence time.

Doppler spread :

- Doppler spread is defined as the range of frequencies over which the received Doppler spectrum is non-zero.
- It is denoted by B_D and it is a measure of the broadening in frequency domain which is caused by the time rate of change of the mobile radio channel.
- When we transmit a pure sinusoidal tone of frequency f_c, the spectrum of received signal is called as the **Doppler spectrum**.
- It consists of the frequency components in the range $(f_c - f_d)$ to $(f_c + f_d)$ where f_d is the Doppler shift.
- Thus when a single frequency is transmitted, the spectrum of received signal consists of additional frequency components.
- This is called as pulse broadening in the frequency domain.
- The amount of such spectral broadening depends on the Doppler shift f_d.
- The Doppler shift depends on the relative velocity of the mobile, and the angle θ between the direction of motion of the mobile and direction of arrival of the scattered waves.
- the effects of Doppler spread are negligible at the receiver.
- The effects of Doppler spread are negligible at the receiver if the bandwidth of the baseband signal is much higher than the Doppler spread B_D.
- Such a channel is known as a **slow fading channel**.

Coherence time T_C :

- Coherence time T_c is the time domain dual of Doppler spread.
- It is used for characterizing the time varying nature of the frequency dispersiveness of the channel in the time domain.
- The relation between Doppler spread and coherence time is as given below.

$$T_C = \frac{1}{f_m} \quad (3.20.6)$$

- where

  T_c: coherence time and

  f_m: maximum Doppler shift.

- It shows that these two parameters are are inversely proportional to each other.
- The coherence time gives a statistical measure of the time duration over which the channel impulse response is essentially invariant.
- We may also define the coherence time as the time duration over which two received signals have a strong potential for amplitude correlation.

Significance of coherence time :

- A signal distortion occurs at the receiver if the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, because then the channel will change during the transmission time of the baseband signal.

Expression for T_C :

- If we define the coherence time as the time over which the time correlation function is above 0.5, then the coherence time is approximately given by,

$$T_C \approx \frac{9}{16\, \pi f_m} \quad (3.20.7)$$

where f_m is the maximum Doppler shift given by $f_m = v/\lambda$.

- In practice, the coherence time is defined as the geometric mean of its expressions given in Equations (3.20.6) and (3.20.7).
- That is,

$$T_C = \sqrt{\frac{9}{16 \pi f_m^2}} = \frac{0.423}{f_m} \qquad ...(3.20.8)$$

- The importance of coherence time is that, if two signals are arriving at a receiver with a time separation greater than T_c, then they are affected differently by the channel.

3.21 Types of Small Scale Fading :

GTU : S-12, W-14, W-15, S-16, W-17, S-18, S-19

University Questions

Q. 1 Give complete classification of types of small-scale fading. **(S-12, 6 Marks)**

Q. 2 Give complete classification of small scale fading and summarize the conditions for each type of small scale fading. **(W-14, 7 Marks)**

Q. 3 Describe briefly the types of small scale fading (based on multipath time delay spread). **(W-15, 7 Marks)**

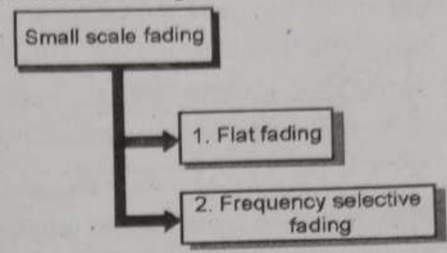
Q. 4 What is fading? List and explain various types of small scale fading. **(S-16, 7 Marks)**

Q. 5 Give complete classification of types of small scale fading. **(W-17, 7 Marks)**

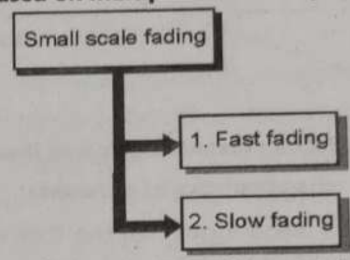
Q. 6 Explain different types of small-scale fading. **(S-18, 7 Marks)**

Q. 7 Explain small scale fading (based on time delay spread) **(S-19, 4 Marks)**

- The type of signal fading over a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel.
- The relation between the signal parameters (such as bandwidth, symbol period, etc.) and the channel parameters (such as delay spread and Doppler spread), decides the type of fading experienced by different transmitted signals.
- The time dispersion and frequency dispersion mechanisms in a mobile radio channel lead to four types of fading.
- The multipath delay spread is responsible for the time dispersion and frequency selective fading.
- The Doppler spread is responsible for frequency dispersion and time selective fading.
- Fig. 3.21.1 shows the classification of different types of small scale fading.



(a) Based on multipath time delay spread



(b) Based on Doppler spread

(G-2667) Fig. 3.21.1 : Classification of small scale fading

3.21.1 Small-Scale Fading Effects Due to Multipath Time Delay Spread :

- As stated earlier the transmitted signal undergoes either flat fading or frequency selective fading due to the time dispersion generated because of multipath.

3.21.1.1 Flat Fading :

GTU : S-12, W-14, W-15, S-16, W-17, S-18, S-19

University Questions

Q. 1 Give complete classification of types of small-scale fading. **(S-12, 6 Marks)**

Q. 2 Give complete classification of small scale fading and summarize the conditions for each type of small scale fading. **(W-14, 7 Marks)**

Q. 3 Describe briefly the types of small scale fading (based on multipath time delay spread). **(W-15, 7 Marks)**

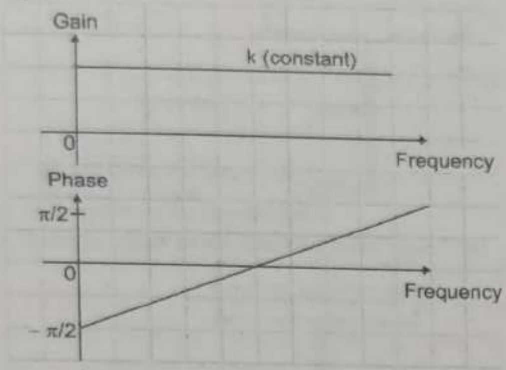
Q. 4 What is fading? List and explain various types of small scale fading. **(S-16, 7 Marks)**

Q. 5 Give complete classification of types of small scale fading. **(W-17, 7 Marks)**

Q. 6 Explain different types of small-scale fading. **(S-18, 7 Marks)**

Q. 7 Explain small scale fading (based on time delay spread) (S-19, 4 Marks)

- The received signal undergoes the **flat fading** if the channel has a constant gain and linear phase response over a bandwidth that is greater than the bandwidth of the transmitted signal. This is as shown in Fig. 3.21.2.



(GT-16)**Fig. 3.21.2 : Constant gain and linear phase characteristics of a channel**

- Due to the constant gain, all the transmitted signals will be amplified equally and due to linear phase response the channel introduces a phase shift that is proportional to frequency of the signal.
- This ensures that no phase distortion is introduced by the channel.
- Hence the spectral characteristics of the channel are preserved at the receiver end in flat fading.
- However, due to flat fading, the strength of the received signal varies with time.
- Actually, the gain of the channel will also vary because of multipath as shown in Fig. 3.21.3.

Flat fading channel characteristics :

- Fig. 3.21.3 shows the characteristics of a flat fading channel in both time as well as frequency domain.

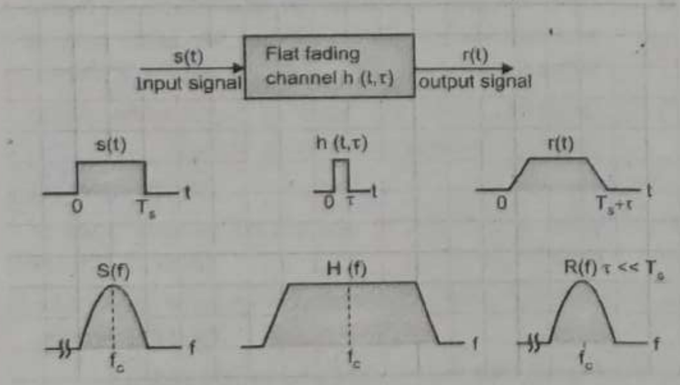


Fig. 3.21.3 : Flat fading channel characteristics

- A signal s(t) of small bandwidth as compared to that of the channel is applied at the input of the flat fading channel with an impulse response of h(t, τ).
- We get the output or received signal r(t) at the output of the channel which is equal to the convolution of the input signal and the impulse response of the channel in the time domain.
- Fig. 3.21.3 also shows the frequency domain characteristics.
- S(f) is the spectrum of the input signal, H(f) is the spectrum of the channel and R(f) is the spectrum of the output signal which is equal to the product of S(f) and H(f).
- Due to the variation in both signal strength and gain with time in a random manner, the amplitude of the received signal also changes with time.
- In this way, with passage of time the gain of the received signal r(t) would vary in its value.
- However, the spectrum of the transmitted signal is preserved.
- This means that the frequency spectrum and the shape of the transmitted signal will be preserved.
- In channel with flat fading, the reciprocal bandwidth of the transmitted signal is much larger than the multipath time delay spread of the channel.
- Therefore we can approximate its impulse response $h_b(t, \tau)$ as having no excess delay.
- The flat fading channels are also called as **amplitude varying channels** or **narrowband channels,** as the bandwidth of the applied signal is much less(narrow) as compared to the flat fading bandwidth of the channel.
- The effect of flat fading channels is that they can cause **deep fades,** due to which they might need a 20 to 30 dB higher transmitted power during the period of deep fades to achieve an acceptably low bit error rate.
- While designing the radio links, the distribution of gain of the flat fading channel plays an important role and the most common amplitude distribution is **Rayleigh distribution.**

- The Rayleigh flat fading channel model assumes that the channel induces an amplitude that varies in time according to the Rayleigh distribution.
- We will summarize the discussion on flat fading as follows.
- A signal undergoes flat fading if

$$B_s << B_c \quad ...(3.21.1)$$

and

$$T_s >> \sigma_\tau \quad ...(3.21.2)$$

Where B_s : Transmitted signal bandwidth

B_c : Bandwidth of the channel

T_s : Reciprocal bandwidth or symbol period of the transmitted signal

σ_τ : rms delay spread of the channel.

Disadvantages of flat fading channels :

1. The flat fading channels cause deep fades.
2. They need a 20 to 30 dB higher transmitter power during the period of deep fades to achieve an acceptably low bit error rate.

3.21.1.2 Frequency Selective Fading :

GTU : S-12, W-14, W-15, S-16, W-17, S-18, S-19

University Questions

Q. 1 Give complete classification of types of small-scale fading. **(S-12, 6 Marks)**

Q. 2 Give complete classification of small scale fading and summarize the conditions for each type of small scale fading. **(W-14, 7 Marks)**

Q. 3 Describe briefly the types of small scale fading (based on multipath time delay spread). **(W-15, 7 Marks)**

Q. 4 What is fading? List and explain various types of small scale fading. **(S-16, 7 Marks)**

Q. 5 Give complete classification of types of small scale fading. **(W-17, 7 Marks)**

Q. 6 Explain different types of small-scale fading. **(S-18, 7 Marks)**

Q. 7 Explain small scale fading (based on time delay spread) **(S-19, 4 Marks)**

- In frequency selective fading, only a few selected frequency components present in the spectrum of the input signal, undergo fading rather than all of them.
- The received signal undergoes the **frequency selective** fading if the channel has a linear phase response and constant gain over a bandwidth that is smaller than the bandwidth of the transmitted signal.
- Thus here the two characteristics of the channel (constant gain and linear phase response) are same as those of the flat fading channels.
- But here the bandwidth of the channel is less than that of the transmitted signal. That means,

$$B_C < B_S$$

Characteristics of Frequency Selective Fading Channel :

- Fig. 3.21.4 shows the characteristics of a frequency selective fading channel.
- A signal s(t) of bandwidth B_S is applied at the input of the frequency selective fading channel with an impulse response of $h(t, \tau)$ and bandwidth B_C which is less than that of the input signal.
- We get the output or received signal r(t) at the output of the channel which is equal to the convolution of the input signal and the impulse response of the channel in the time domain.
- Fig. 3.21.4 also shows the frequency domain characteristics.

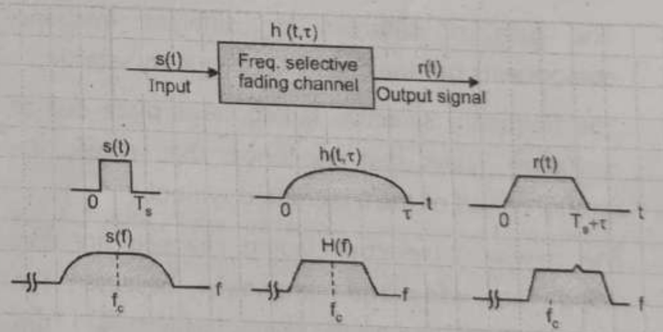


Fig. 3.21.4 : Frequency selective fading channel characteristics

- S(f) is the spectrum of the input signal, which is much wider than H(f) i.e. the spectrum of the channel.
- R(f) is the spectrum of the output signal which is equal to the product of S(f) and H(f).
- In frequency selective fading the impulse response of the channel has multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform.

- Due to frequency selective fading, the received signal will consist of multiple versions of the transmitted signal that are attenuated and delayed in time.
- This results in distortion in the received signal.
- Frequency selective fading takes place due to time dispersion of the transmitted symbols within the channel.
- The spreading of the signal on frequency selective channel will cause **Inter symbol Interference (ISI).**
- It is difficult to model a frequency selective fading channel as compared to the flat fading channel because of the following reasons :
  1. Each multipath signal needs to be modelled.
  2. The channel should be considered as a linear filter.
- For analyzing frequency selective small scale fading statistical impulse response models such as either the two-ray **Rayleigh fading model** is used or computer generated models are used analysis for frequency selective small scale fading.
- The spectrum S(f) of the transmitted signal has a bandwidth greater than the coherence bandwidth B_c of the channel.
- The gain is different for different frequency components but the channel is frequency selective.
- The frequency selective fading takes place due to multipath delays that are longer than exceed the symbol period of the transmitted symbol.
- The frequency selective fading channels are also called as **wideband channels** because the bandwidth of spectrum s(t) is wider than the bandwidth of channel impulse response $h(t, \tau)$.
- Due to this the gain of the channel varies with variation in time.
- The phase across the spectrum will also vary which results in distortion in the received signal r(t).
- We will summarize the discussion on frequency selective fading as follows.
- A signal will undergo frequency selective fading if the following conditions are satisfied.

$$B_s > B_c \quad ...(3.21.3)$$

- And $T_s < \sigma_\tau$ ...(3.21.4)
- Where

  T_s : Reciprocal bandwidth of transmitted signal

  σ_τ : Rms delay spread of channel

  B_s : Bandwidth of transmitted signal

  B_c : Coherence bandwidth of channel
- Thus we conclude that If $T_s \geq 10\ \sigma_\tau$ then the channel undergoes flat fading and if $T_s < 10\ \sigma_T$ then the channel undergoes frequency selective fading.

3.21.2 Fading Effects Due to Doppler Spread :

- The multipath is responsible for the generation of frequency dispersion, which causes the transmitted signal to undergo either fast or slow fading.
- Let us discuss them one by one.

1. Fast fading :

Fast fading channel :

- We can classify a channel as either a fast fading channel or a slow fading channel, based on how rapidly the transmitted baseband signal changes as compared to the rate of change of the channel.
- A channel is called as the fast fading channel if the impulse response of the channel changes rapidly within the symbol duration of the transmitted signal.
- In other words, for a fast fading channel, the coherence time of the channel is smaller than the symbol time period of the transmitted signal.
- This would lead to the **frequency dispersion** or **time selective fading** due to the Doppler spreading, which in turn results in the distortion of the received signal.
- Talking in terms of the frequency domain, the signal distortion due to fast fading increases with increase in the Doppler frequency spread as compared with the bandwidth of the transmitted signal.

Condition for fast fading :

- The condition for fast fading can be stated as follows: A signal undergoes fast fading if,

$$T_s > T_c \quad ...(3.21.5)$$

and $B_s < B_D$ ...(3.21.6)

Flat fading or Frequency selective fading :

- We have talked about whether a radio channel is slow or fast fading channel but we have not talked about whether the channel is flat fading or frequency selective fading type.
- The fast fading deals only with the rate of change of channel due to motion.
- For a flat fading channel, the impulse response can be approximated to a single delta function without any time delay.

A flat fading, fast fading channel :

- We can define a flat fading, fast fading channel as the one in which the amplitude of delta function varies faster than the rate of change of transmitted baseband signal.

A fast fading, frequency selective fading channel :

- In case of a fast fading, frequency selective fading, the rate of change of amplitudes, phases and time delays of any one multipath component, is faster than the rate of change of transmitted signal.

> **Note :** Fast fading occurs only for the transmitted signals having very low data rates.

2. **Slow fading :**

A slow fading channel :

- A slow fading channel can be defined as the channel for which the impulse response of the channel changes at a much slower rate than the transmitted baseband signal s(t).
- We can assume the slow fading channel to be static over one or more reciprocal bandwidth intervals.
- The meaning of this in the frequency domain is as follows: in frequency domain the Doppler spread of the channel is much less as compared to the bandwidth of baseband signal.
- Hence, we conclude that the slow fading of a signal occurs if,

$$T_s << T_c \quad ...(3.21.7)$$

and $$B_s >> B_D \quad ...(3.21.8)$$

> **Note :** Whether the transmitted signal undergoes slow fading or fast fading, is determined by the velocity of the mobile(velocity of moving objects in a channel) and the baseband signalling.

Relation between multipath parameters and type of fading :

- Fig. 3.21.5(a) and (b) summarize the relation between different multipath parameters and the type of fading experienced by the transmitted signal.

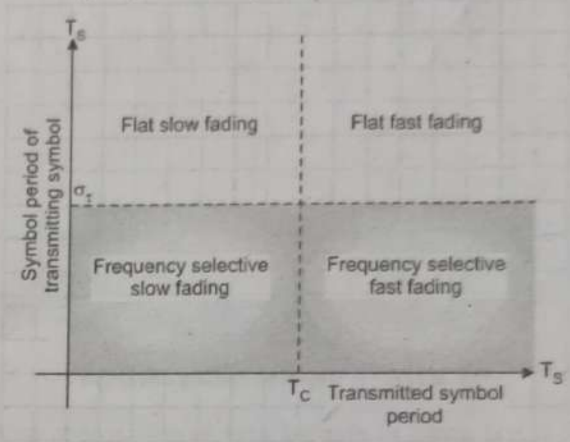


Fig. 3.21.5(a) : Types of fading experienced by a signal as a function of symbol period

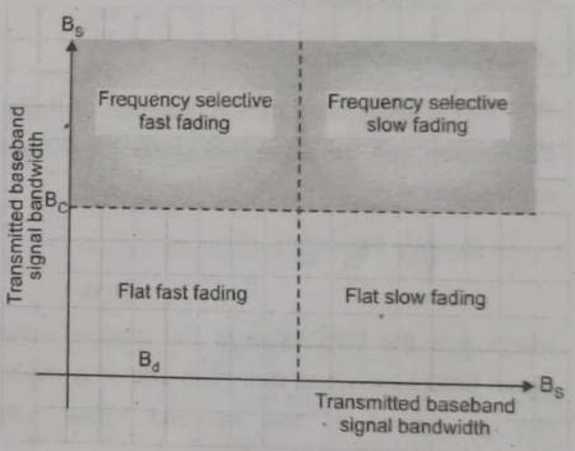


Fig. 3.21.5(b) : Types of fading experienced by a signal as a function of baseband signal bandwidth

3.22 Rayleigh and Rician Distributions :

- In this section we will discuss two different types of distributions that are used in mobile radio channels.
- They are as follows :
  1. Rayleigh distribution and
  2. Rician distribution

3.22.1 Rayleigh Distribution :

- In mobile radio communication the Rayleigh distribution is popularly used for explaining the statistical time varying nature received envelope of a flat fading signal.

– Fig. 3.22.1 illustrates the Rayleigh distribution of signal strength with respect to time.

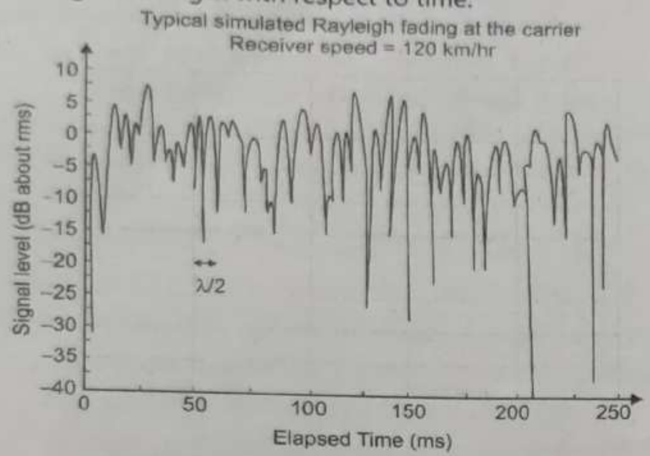


Fig. 3.22.1 : A Rayleigh fading envelope

– It is a graph of elapsed time in milliseconds on the x-axis versus the received signal strength in decibels on the y-axis as shown.

PDF of Rayleigh distribution :

– PDF that is probability density function of Rayleigh distribution can be expressed using the following expression.

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} \exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases} \quad \textbf{(OT-11)}$$

– where σ is the RMS value of the received voltage signal before envelope detection and σ^2 is the time average power of the received signal before envelope detection.

– Rayleigh PDF and CDF are as shown in Fig. 3.22.2(a) and (b) respectively.

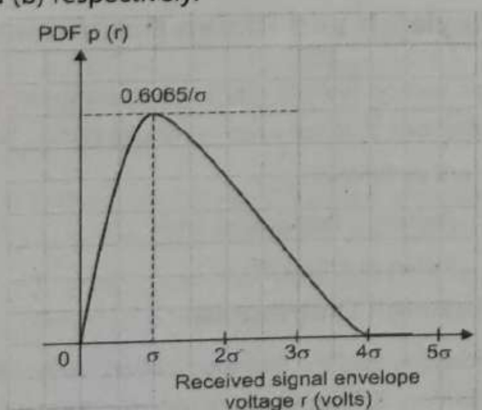


Fig. 3.22.2(a) : PDF of Rayleigh distribution

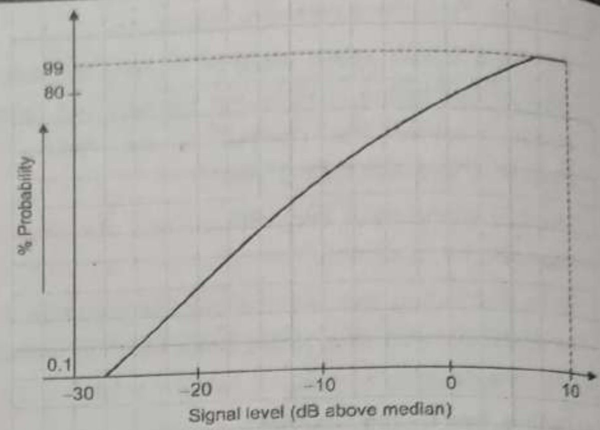


Fig. 3.22.2(b) : CDF of Rayleigh distribution

CDF of Rayleigh distribution :

– The CDF (cumulative distribution function) of Rayleigh distribution is used for obtaining the probability that received signal envelope does not exceed the specified value R.

– The CDF the Rayleigh distribution is expressed as follows :

$$P(R) = \Pr(r \le R) = \int_0^R P(r)\, dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

The mean value :

– The mean value r_{mean} of Rayleigh distribution is given by,

$$R_{mean} = E[r] = \int_0^\infty r p(r)\, dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\,\sigma$$

Variance :

– The variance of Rayleigh distribution is given by sigma square.

– It represents the ac power in the signal envelope which is given by,

$$\sigma_r^2 = E[r^2] - E^2[r] = \int_0^\infty r^2 p(r)\, dr - \frac{\sigma^2 \pi}{2}$$

$$\therefore \sigma_r^2 = \sigma^2\left(2 - \frac{\pi}{2}\right) = 0.4292\,\sigma^2$$

Rms value :

– The rms value of the envelope is the square root of the mean square value, or $\sqrt{2}\,\sigma$ where σ is the standard deviation of the original complex Gaussian sigma prior to envelope detection.

- We can obtain the median value of r by solving the following expression :

$$\frac{1}{2} = \int_{0}^{\text{Median}} p(r)\, dr$$

- Hence the median value of r is obtained as follows :

$$r_{\text{mediam}} = 1.177\,\sigma$$

Conclusions :

- Some of the important conclusions from the discussion on Rayleigh distribution are as follows:
  1. The difference between the mean and median is only 0.55 dB
  2. Generally the median is used in practice instead of using mean.
  3. If we use median instead of mean it becomes easy to compare different types of fading contributions.

3.22.2 Rician Fading Distribution :

- In multipath transmission there can be two different types of signal components.
- One of them is the non fading signal component while the others are the fading components.
- The distribution of small scale fading envelope will be **Rician** if a dominant non fading signal component such as line of sight (LOS) path is present in the transmission.
- In such an operating situation the random multipart components are superimposed on the stationary non trading component.
- This process has the effect of adding DC component to the random multipath at the output of an envelope detector.
- The operating situation where a dominant signal is arriving with many weaker multipath signals gives rise to the **Rician** distribution.
- However if the dominant non fading signal becomes weak the composite received signal resembles in noise signal and envelope having the **Rayleigh** distribution.
- Thus as the dominant component fades away the Rician distribution degenerates to the Rayleigh distribution.

PDF of Rician distribution :

- The PDF of **Rician** distribution is given by the following expression :

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{\frac{-(r^2+A^2)}{2\sigma^2}}\, I_0\left(\dfrac{Ar}{\sigma^2}\right) & \text{for } (A \ge 0, r \ge 0) \\ 0 & \text{for } (r < 0) \end{cases} \qquad \textbf{(OT-16)}$$

- The parameter A denotes the peak amplitude of the dominant signal and $I_0(\ )$ is the modified Bessel function of the first kind and zero order.
- **Rician** distribution is often described in terms of a parameter K called as the **Rician** factor, which is defined as the ratio between the deterministic signal power and the variance of the multipath.
- It is given by,

$$K\,(\text{dB}) = 10 \log \frac{A^2}{2\,\sigma^2}\ \text{dB}$$

- or, in terms of DB as,

$$K = A^2 / (2\,\sigma^2)$$

- The **Rician** factor K completely satisfies the **Rician** distribution.
- That means as A tends to zero, K will tend to $-\infty$ dB and as the amplitude of dominant path decreases the **Rician** function degenerates to Rayleigh distribution.
- Fig. 3.22.3(a) shows the Rician PDF and Fig. 3.22.3(b) shows the Rician CDF.

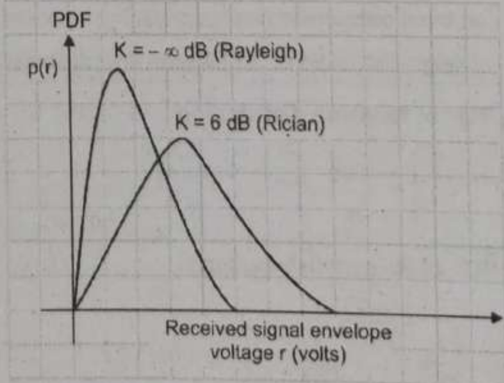


Fig. 3.22.3(a) : PDF of Rician distribution

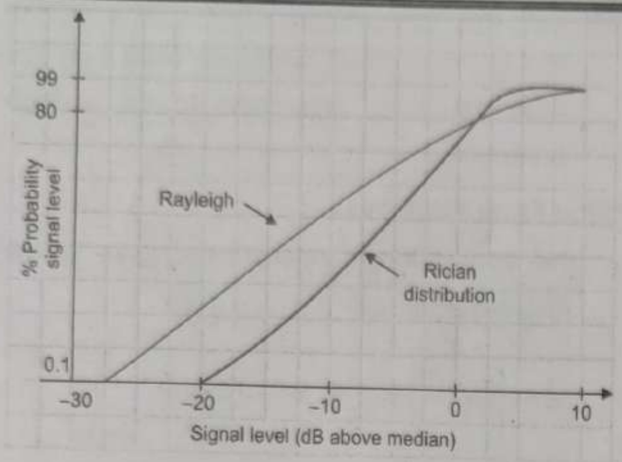


Fig. 3.22.3(b) : CDF of Rician distribution

3.22.3 Difference between Rayleigh and Ricean Distribution :

Table 3.22.1 : Comparison of Rayleigh and Ricean distribution

Sr. No.	Rayleigh distribution	Ricean distribution
1.	It is used for explaining the statistical time varying nature received envelope of a flat fading signal.	The distribution of small scale fading envelope will be **Rician** if a dominant non fading signal component such as line of sight (LOS) path is present in the transmission.
2.	PDF: Refer Eqn.1	PDF: Refer Eqn.2
3.	PDF: Refer Fig. 3.22.2(a)	PDF: Refer Fig. 3.22.3(a)
4.	CDF: Refer Fig. 3.22.2(b)	CDF: Refer Fig. 3.22.3(b)
5.	A multipath signal with no dominant component has Rayleigh distribution.	A multipath signal with a dominant component has Ricean distribution.

Eqn.(1) PDF of Rayleigh distribution :

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} \exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases} \quad \textbf{(OT-11)}$$

Eqn.(2) PDF of Ricean distribution :

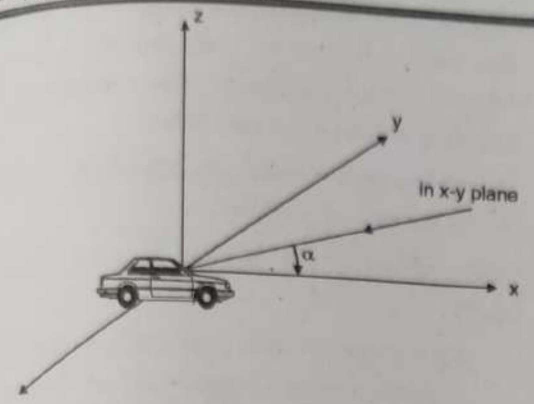
$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{\frac{-(r^2+A^2)}{2\sigma^2}} I_0\left(\dfrac{Ar}{\sigma^2}\right) & \text{for } (A \ge 0, r \ge 0) \\ 0 & \text{for } (r < 0) \end{cases} \quad \textbf{(OT-16)}$$

3.23 Statistical Models for Multipath Fading Channels :

- We can analyze the statistical behavior of the of the mobile radio channel with the help of different models for multipath fading channels.
- Ossana proposed the first multipath model was which was based on the interference of waves incident and reflected from the flat sides of randomly located buildings.
- However this model proved to be nonflexible and therefore, unsuitable for urban areas, where direct path was rarely available for wave propagation.
- Hence, the following multipath channels for mobile radio channels were suggested.
  1. Clarke's model for flat fading
  2. Clarke and Gans fading model
  3. Level crossing and fading statistics
  4. Two ray Rayleigh fading model
  5. Saleh and Valenzuela indoor statistical model
  6. SIRCIM and SMRCIM indoor and outdoor statistical model.

3.23.1 Clarke's Model for Flat Fading :

- The Clarke's model is used to determine the statistical characteristics of the electromagnetic fields of the received signal at the mobile.
- It use a fixed transmitter with a vertically polarized antenna.
- The field incident on the mobile antenna has N azimuthal plane waves with arbitrary carrier phases and arbitrary azimuthal angles of arrival.
- Each of such plane waves has the same average amplitude.
- We assume that for small distances, the scattered components arriving at a receiver experience similar attenuation.
- A diagram of plane waves incident on a mobile that are travelling in the x-direction at a velocity v has been shown in Fig. 3.23.1.



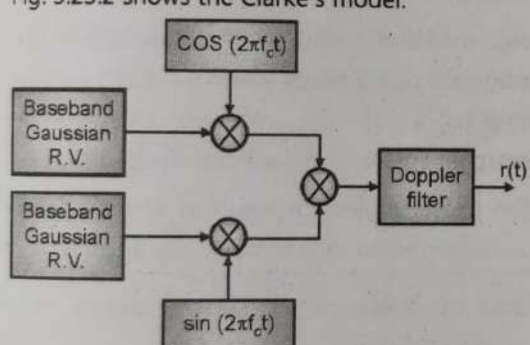
(G-2838) **Fig. 3.23.1 : Plane Waves arriving at random angles**

- We measure the angle of arrival (α) in the x-y plane with respect to the direction of motion.
- Every incident wave on the mobile undergoes a Doppler shift and arrives at the receiver at the same time.
- Due to flat fading, there is no excess delay due to multipath for any of the waves.
- For the n^{th} wave arriving at an angle (α_n) with the x-axis, the Doppler shift is given by,

$$f_n = \frac{v}{\lambda} \cos \alpha_n \qquad ...(3.23.1)$$

where λ : wavelength of the incident wave.

- Fig. 3.23.2 shows the Clarke's model.



(G-2836) **Fig. 3.23.2 : Clarke's model.**

- This model is based on the following assumptions :
  1. Isotropic scattering
  2. There is a linear relationship between input and output
  3. Rayleigh Channel model is generated using two different Gaussian distributions
  4. The parameters T_c and T_s are Gaussian random processes.
  5. At any time, T_c and T_s are uncorrelated zero mean Gaussian random variables.
  6. The channel response envelope, r(t), has a Rayleigh pdf.
- The output as per the Clarke's model is given by,

$$r(t) = [\, T_c(t)^2 + T_s(t)^2]^{1/2}$$

- The Clarke's model was further developed by Gans.
- As derived by Gans, Doppler shift can be included into this channel model by passing r(t) through a filter s(t).

3.23.2 Simulation of Clarke and Gans Fading Model :

- We can use the Clarke and Gans fading model to simulate multipath fading channels in hardware or software.
- The concept of in-phase and quadrature modulation paths (see Fig.3.23.1) by the simulator in order to produce a simulated signal which has spectral and temporal characteristics very close to measured data.

3.23.3 Level crossing and Fading Statistics :

- The following two terms are useful for designing error control codes and diversity methods in mobile communication systems.
  1. The Level Crossing Rate (LCR) and
  2. Average fade duration of a Rayleigh fading signal.

1. The Level Crossing Rate (LCR) :

- The Level Crossing Rate (LCR) is defined as the expected rate at which the Rayleigh fading envelope that is normalized to the local rms signal level, crosses a particular level in a positive-going direction.

2. Average fade duration :

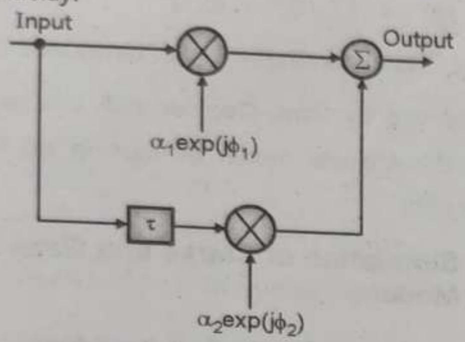
- The average fade duration is defined as the average period of time for which the received signal is below a particular level R.
- The expression for average fade duration for a Rayleigh fading signal, is as follows :

$$\bar{\tau} = \frac{1}{N_R} P_r [\, r \le R \,] \qquad ...(3.23.2)$$

- Where P_r [r ≤ R] is the probability that the received signal r is less than R.

3.23.4 Two-Ray Rayleigh Fading Model :

- The two-ray Rayleigh fading model which is as shown in Fig. 3.23.3 takes into account the multipath time delay.



(G-2837) **Fig. 3.23.3 : Two-ray Rayleigh fading model**

- It is necessary to model the effects of multipath delay spread and fading in the modern mobile communication systems with high data rates.
- The impulse response of the two ray Rayleigh fading model is as follows :

$$h_b(t) = \alpha_1 \exp(j\phi_1)\,\delta(t) + \alpha_2 \exp(j\phi_2)\,\delta(t-\tau) \quad ...(3.23.3)$$

- Where α_1 and α_2 are independent and Rayleigh distributed variables.
- Then, ϕ_1 and ϕ_2 are independent and uniformly distributed variables over the interval $[0, 2\pi]$, and τ is the time delay between the two rays.
- If α_2 is made equal to zero, then the special case of a flat Rayleigh fading channel is obtained as

$$h_b(t) = \alpha_1 \exp(j\phi_1)\,\delta(t) \quad ...(3.23.4)$$

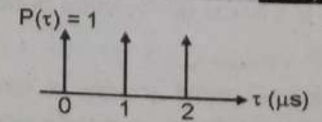
- We can create a wide range of frequency selective fading effects by varying τ.

3.23.5 Saleh and Valenzuela Indoor Statistical Model :

- Consider two vertically polarized omnidirectional antennas that are located on the same floor of a medium sized office building.
- A 10 ns, 1.5 GHz, radar-like pulses are used for the measurements.
- Saleh and Valenzuela reported the results of the above indoor propagation measurements.
- This method is base on averaging the square law detected pulse response while sweeping the frequency of the transmitted pulse.
- We can resolve the multipath components within 5 ns with the help of this method.
- Saleh and Valenzuela demonstrated the following results :
  1. For no line-of-sight path the statistics of the channel impulse response do not depend on the polarization of the transmitting and receiving antennas .
  2. The indoor channel is observed to be very slowly time varying, or quaistatic.
- It was observed that the maximum multipath delay spread is 100 ns to 200 ns within the rooms of a building and 300 ns in its hallways.
- For rms delay spread measured within the rooms, a median of 25 ns and a maximum of 50 ns was obtained.
- The variation in the large-scale path loss with no line-of-sight path is over a 60 dB range and it follows a log-distance power law with the exponent value between three and four.
- This model is based on the assumption that the multipath components arrive in clusters and that the amplitudes of the received components are independent Rayleigh random variables.
- The phase angles are assumed to be independent uniform random variables over the interval $[0, 2\pi]$.

Ex. 3.23.1 : Compute the rms delay spread for the power delay profile in Fig. P. 3.23.1. If BPSK modulation is used, what is the maximum bit rate that can be sent through the channel without needing an equalizer?

S-20, W-20, 4 Marks



(G-2781) **Fig. P. 3.23.1 : Given Figure**

Soln. :

1. **Rms delay spread (σ_τ) :**

- The mean excess delay ($\bar{\tau}$) is given by,

$$\bar{\tau} = \frac{\sum_k P(\tau_k)\,\tau_k}{\sum_k P(\tau_k)}$$

$$\therefore \bar{\tau} = \frac{P(0)\cdot 0 + P(1)\cdot(1) + P(2)\cdot 2}{P(0) + P(1) + P(2)}$$

$$\therefore \bar{\tau} = \frac{(1)(0) + (1)\cdot(1) + (1)\cdot(2)}{1+1+1}$$

$$= 1\ \mu s \quad \text{...(1)}$$

- The mean square excess delay ($\bar{\tau^2}$) is,

$$\bar{\tau^2} = \frac{\sum_k P(\tau_k)\,\tau_k^2}{\sum_k P(\tau_k)}$$

$$\therefore \bar{\tau^2} = \frac{P(0)\cdot(0)^2 + P(1)\cdot(1)^2 + P(2)\cdot(2)^2}{P(0) + P(1) + P(2)}$$

$$= \frac{(1)\cdot(0) + (1)\cdot(1) + (1)\cdot(4)}{1+1+1}$$

$$= 1.667\ \mu s^2 \quad \text{...Ans.}$$

- The Rms delay spread is given by,

$$\sigma_\tau = [\bar{\tau^2} - (\bar{\tau})^2]^{1/2}$$

$$\therefore \sigma_\tau = [1.667 - (1)2\,]^{1/2}$$

$$= 0.8167\ \mu s \quad \text{...Ans.}$$

2. Maximum bit rate :

- In order to ensure that no equalizer is required, the following condition should be satisfied.

$$\frac{\sigma_\tau}{T_S} \leq 0.1$$

$$\therefore T_S \geq \frac{\sigma_\tau}{0.1}$$

$$\therefore T_S \geq \frac{0.8167 \times 10^{-6}}{0.1}$$

$$\therefore T_S \geq 8.167 \times 10^{-6}$$

$$\therefore \text{Maximum bit rate} = R_b = \frac{1}{T_S}$$

$$\therefore R_b = \frac{1}{8.167 \times 10^{-6}}$$

$$= 122.44\ \text{kbps} \quad \text{...Ans.}$$

3.24 Diversity Reception :

- Diversity reception is used in order to minimize the effects of fading.
- 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 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.

3.25 Diversity Techniques : GTU : S-15

University Questions

Q. 1 How do diversity techniques help in improving SNR? **(S-15, 7 Marks)**

Concept :

- Diversity techniques provides wireless link improvement at low cost.
- It is a powerful communication receiver technique.

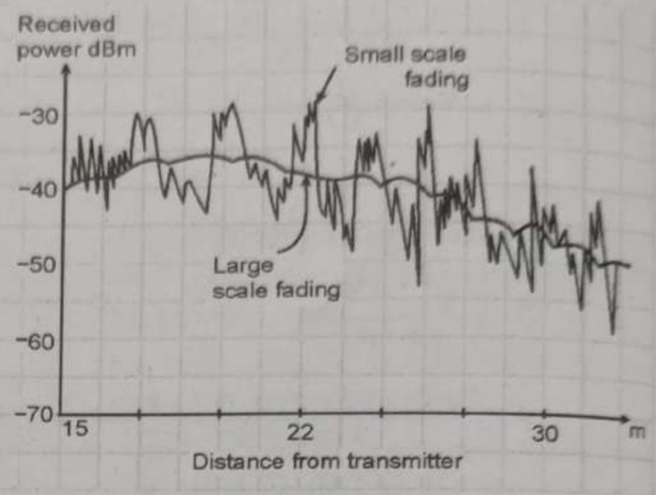
- Diversity requires no training overhead because the transmitter does not require training sequence.
- There are a wide range of diversity implementations.
- Many diversity implementations are very practical and they provide significant link improvement with some additional cost.
- Diversity techniques exploits 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.

Types of Diversity :

- There are two types of Diversity techniques :
  1. Microscopic diversity
  2. Macroscopic diversity

Microscopic diversity :

- 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.



(G-2678) **Fig. 3.25.1 : Two types of fading**

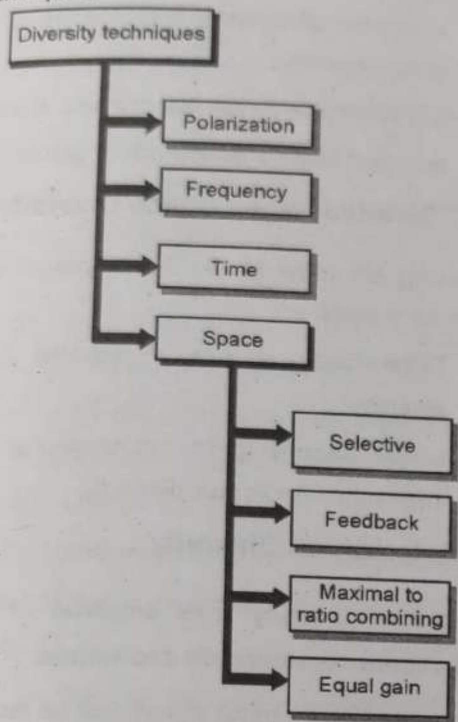
- The small-scale fading in Fig. 3.25.1 reveals that if two antennas are separated by a small part of a meter, one can receive a null signal while other receives a strong signal.
- A receiver can mitigate small scale fading effects by choosing the best signal at all times, this is known as antenna or space diversity.

Macroscopic diversity :

- 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.

3.26 Types of Diversity Techniques :

- Fig. 3.26.1 shows the types of the Diversity techniques.



(G-2828) Fig. 3.26.1 : 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.

3.26.1 Space Diversity : **GTU : W-14, W-19**

University Questions

Q. 1 Explain the following diversity techniques briefly:

1. Space diversity techniques
2. Frequency diversity techniques

(W-14, 7 Marks)

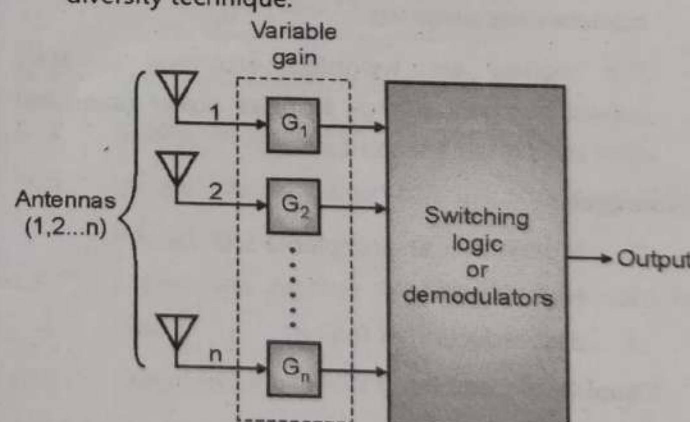
Q. 2 Explain the Space diversity techniques briefly.

(W-19, 4 Marks)

- The space diversity technique is also known as antenna diversity.
- This is one of the most popular diversity technique used in the wireless systems.
- Conventional wireless communication systems includes an elevated base station antenna and a mobile antenna close to the ground.
- In the conventional system, there is no guarantee of a direct path between the transmitter and the receiver.
- There is possibility of a number of scatterers in the surrounding area of the mobile that occurs a Rayleigh fading signal.
- The received signals from spatially separated antennas on the mobile will have basically uncorrelated envelopes for antenna separations of one half wavelength or more.
- Antenna space diversity technique is used in the design of base station.
- In order to provide diversity reception, multiple base station receiving antennas are used at each cell site.
- The scatterers are generally occurs on the ground in the surrounding area of the mobile.
- Hence, the base station antennas are considerably spaced far apart in order to achieve decorrelation.
- The base stations are separated in the order of several tens of wavelengths.
- Thus the space diversity can be used at either the base or mobile station or both.

Block diagram :

- Fig. 3.26.2 shows the block diagram of a space diversity technique.



(G-2829) Fig. 3.26.2 : 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.

3.26.1.1 Classification of Space Diversity Reception Methods : GTU : W-14, W-19

University Questions

Q. 1 Explain the following diversity techniques briefly:
1. Space diversity techniques
2. Frequency diversity techniques

(W-14, 7 Marks)

Q. 2 Explain the Space diversity techniques briefly.

(W-19, 4 Marks)

- The Space diversity reception methods can be classified into the following four categories
  1. Selection diversity
  2. Feedback or scanning diversity
  3. Maximal ratio combining
  4. Equal gain diversity

1. Selection Diversity :

- In this method the branches having the strongest received signal will be selected.

2. Feedback or Scanning Diversity :

- In this method 'n' signals are scanned in a proper sequence and monitored to pick up a signal in the sequence that is above the predetermined threshold value.

3. Maximal Ratio Combining :

- In this method, the signals from all of the 'n' branches are weighted.
- The signals are weighted according to their individual signal voltage to noise power ratios and then the signals are combined.

Advantages :

1. It generates an acceptable SNR value.
2. High accuracy.
3. Best reduction of fading.

4. Equal Gain Combining :

- In this method, all the diversity branches are added with the same weighing factor.
- The signals from each diversity branches are co-phased that provides equal gain factor.
- The disadvantage of this technique is, it degrades the SNR value by 0.5 dB at the output of the combiner if two branches are involved.

3.26.1.2 Advantages of Space Diversity :

- Following are some of the advantages of Space diversity technique :
  1. A number of diversity branches are allowed in space diversity.
  2. It is applicable to the macroscopic diversity.
  3. No need of extra bandwidth or power.

3.26.1.3 Disadvantages Space Diversity :

- Following are some of the disadvantages of Space diversity technique :
  1. Large hardware size is required for space diversity.
  2. Larger antenna spacing is needed at the base station in microscopic diversity.

3.26.2 Polarization Diversity :

- Polarization Diversity uses antennas of different polarizations . i.e Horizontal and vertical.
- Two uncorrelated fading signals will be received if a signal is transmitted by a pair of polarized antennas and received by another pair of antennas.
- This is due to fading variations by horizontal and vertical polarizations and different reflection coefficient values of the tall building walls.

Advantage :

1. No need of additional space and bandwidth.

Disadvantage :

1. Polarization Diversity required 3 dB extra power.
2. Only two diversity branches are allowed.

3.26.3 Frequency Diversity : GTU : W-14

University Questions

Q. 1 Explain the following diversity techniques briefly:
1. Space diversity techniques
2. Frequency diversity techniques

(W-14, 7 Marks)

- 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 :

1. It allows several diversity branches .

Disadvantages :

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

3.26.4 Time Diversity :

- 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.

Review Questions

Q. 1 Define and explain multipath fading.

Q. 2 Explain the need of propagation models.

Q. 3 Write a note on : Large scale and small scale fading models.

Q. 4 Explain the function of free space propagation model.

Q. 5 State and explain Friis free space equation.

Q. 6 Define the terms EIRP and ERP.

Q. 7 Define the term path loss and obtain its expression for the free space model.

Q. 8 Define Fresnel reflection and the factors governing its value.

Q. 9 With neat diagrams derive the expressions for the reflection coefficient for the dielectric medium with E-field polarization parallel / perpendicular with POI.

Q. 10 Define intrinsic impedance of a dielectric medium.

Q. 11 Obtain the expressions for the reflection coefficients if the first medium is air and the other is dielectric medium with E- field polarization parallel / perpendicular with POI.

Q. 12 Plot the graphs of reflection coefficient versus incident angle for both types of polarizations.

Q. 13 Derive the exact and approximate expressions for total received E-field for the two ray / ground reflection model.

Q. 14 State the advantages of two ray model.

Q. 15 State the disadvantages of two-ray model.

Q. 16 Define Doppler shift.

Q. 17 Define diffraction and state Huygen's principle.

Q. 18 What is Huygen's principle of diffraction ? Explain knife-edge diffraction model

Q. 19 With the help of Frenzel knife edge geometry obtain the expression for the excess path length and the associated phase angle.

Q. 20 What are Frenzel zones ? What are they used for ?

Q. 21 Explain the term multiple knife edge diffraction model.

Q. 22 Define scattering and explain how the roughness of a surface is measured from the value of h.

Q. 23 Define the Radar Cross Section (RCS).

Q. 24 Explain the factors influencing small scale fading.

Q. 25 What is coherence bandwidth ?

Q. 26 Obtain the expression for the Doppler shift if a mobile is moving at a velocity v and receiving the signal from a remote source S.

Q. 27 Give classification of small scale fading.

Q. 28 Define the following terms : Slow fading, fast fading, flat fading and frequency selective fading.

❑❑❑

Syllabus : Introduction, Comparisons of multiple Access Strategies TDMA,CDMA, FDMA, OFDM, CSMA Protocols, NOMA.

Chapter 4

Multiple Access Techniques

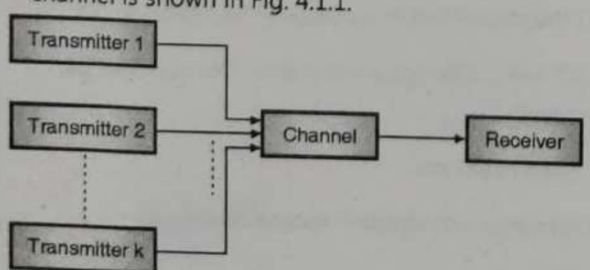
Syllabus

Introduction, Comparisons of multiple Access Strategies TDMA,CDMA, FDMA, OFDM , CSMA Protocols, NOMA.

Chapter Contents

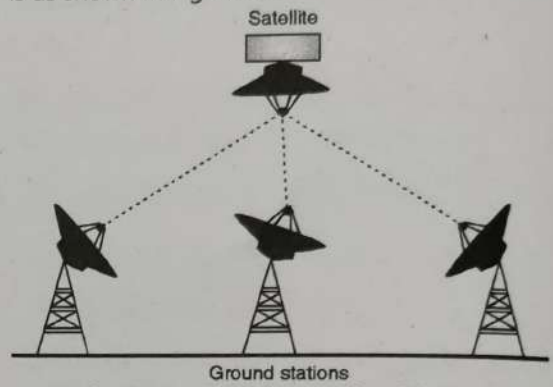
4.1 Multiple Access :

- A wireless system which provides simultaneous communication links to many subscribers does not have unlimited spectrum available.
- In fact only a fixed limited finite amount of radio spectrum (or number of channels) is available to provide service to multiple users simultaneously.
- Therefore, the available spectrum must be utilized optimally and efficiently without compromising on the quality of communication.
- The multiple access techniques have been developed to share the available limited spectrum among many subscribers simultaneously for achieving high subscriber capacity and desired quality of communications.
- Various multiple access techniques used in wireless communications, are : Frequency-Division Multiple Access (FDMA), Time-Division Multiple Access (TDMA), Spread- Spectrum Multiple Access (SSMA), and Space-Division Multiple Access (SDMA).
- The objective of all these multiple access strategies is to maximize the spectrum utilization.
- The choice of an access method will greatly affect the capacity and quality of service provided by a wireless network.
- The practical wireless communication systems use a combination of one or more of these multiple access strategies.
- One type of multiple access system in which a large number of users sharing the same communication channel is shown in Fig. 4.1.1.



(E-894) Fig. 4.1.1 : A multiple access system

- The common channel in this diagram can be the uplink in a satellite communication system or it can be a cable or it can be a frequency band.
- For example, in a mobile communication system, the users of the network will be the transmitters and the receiver is the base station.
- The second type of multiuser communication system is as shown in Fig. 4.1.2.



(E-895) Fig. 4.1.2 : Second type of multiuser system

- Here, a single transmitter (satellite) sends information to multiple receivers.
- The other examples of such system are the radio and TV broadcast systems.

4.1.1 Frequency Division Duplexing (FDD) :

- The frequency division duplexing (FDD) technique uses two different frequency bands for every communication link between the mobile subscriber and the cell-site namely : forward channel and reverse channel.
- Forward channel is defined as the radio channel used for transmitting the information from the base station to the mobile i.e. in the forward direction.
- Reverse channel is defined as the radio channel used for transmitting the information from a mobile to base station i.e. in the reverse direction.
- On the duplex channel pair, FDD allows simultaneous bidirectional full-duplex radio transmission and reception for both the mobile subscriber and the base station.
- The duplex spacing between each forward and reverse channel is constant, all over the system.

4.1.2 Time Division Duplexing (TDD) :

- The other technique Time division duplexing (TDD) uses time instead of frequency for providing both forward and reverse links simultaneously.

- Several mobile subscribers share a single radio channel.
- They share a single channel by taking their respective turns for the transmission of data in the time domain.
- Every mobile subscriber is enabled to access the channel in the assigned time slots only.
- Each duplex channel has been given both, a forward and a reverse time slot, to make the bidirectional full duplex communication possible.
- The transmission and reception of voice/data appears to be continuous to the subscribers because the time division between the forward and reverse time slot is generally very small.

4.2 Multiple Access Techniques :

GTU : S-15

University Questions

Q. 1 Which are various multiple access schemes used in wireless communications? **(S-15, 7 Marks)**

Definition :

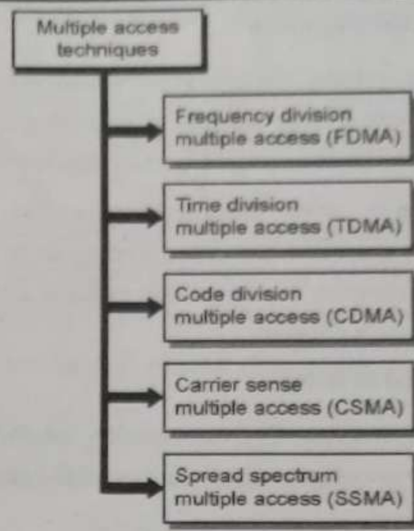
- The multiple access techniques are the techniques in which the total bandwidth of the common link is shared in the frequency domain, time domain or through codes.

Need of multiple access :

- A multiple access technique is not necessary if we have only one user.
- But if there are multiple users who need to share a wireless communication system, then we need to use a multiple access system.

Classification of Multiple Access Techniques:

- Depending on the method of sharing there are five multiple access techniques as given below :
  1. FDMA : Frequency Division Multiple Access
  2. CDMA : Code Division Multiple Access.
  3. TDMA : Time Division Multiple Access
  4. CSMA : Carrier Sense Multiple Access
  5. SSMA : Spread Spectrum Multiple Access
- Fig. 4.2.1 shows the classification of multiple access techniques.



(O-1434) Fig. 4.2.1 : Classification of multiple access techniques

1. **Frequency Division Multiple Access (FDMA) :**

- In Frequency Division Multiple Access (FDMA), a different frequency band is assigned to individual users. All users transmit simultaneously.

2. **Time Division Multiple Access (TDMA) :**

- In the Time Division Multiple Access (TDMA) system a separate time slot is allotted to each user and only one user is allowed to transmit or receive at any instant of time.

3. **Code Division Multiple Access (CDMA) :**

- In Code Division Multiple Access (CDMA) systems, the narrowband message signal is multiplied by a large bandwidth carrier called spreading signal.
- In CDMA each user is given a unique code sequence or signature sequence.
- This sequence allows the user to spread the information signal across the assigned frequency band.
- In CDMA the bandwidth as well as time of the channel is shared by the users.

4.2.1 Types of Multiple Access Based on the Bandwidth Availability :

- Depending on the available bandwidth that can be allocated to the users, we can classify the multiple access systems as follows :
  1. Narrowband systems.
  2. Wideband systems.

1. **Narrowband systems :**

- In these systems, the available frequency spectrum is divided into a large number of narrowband channels i.e. the channels having very small bandwidth.
- The guard bands (frequency separation between adjacent channels) are introduced so as to minimize the interference between the forward and reverse links on each channel.

2. **Wideband systems :**

- In these systems, the transmission bandwidth of a single channel is larger than the total bandwidth of the channel.
- In these systems a large number of transmitters transmit in the same frequency band.

4.3 Frequency Division Multiple Access (FDMA) : GTU : S-15, W-15, S-18, S-19

University Questions

Q. 1 Which are various multiple access schemes used in wireless communications? **(S-15, 7 Marks)**

Q. 2 Write short note on Frequency Division Multiple Access (FDMA). **(W-15, 7 Marks)**

Q. 3 Describe the features of FDMA technique. **(S-18, 4 Marks)**

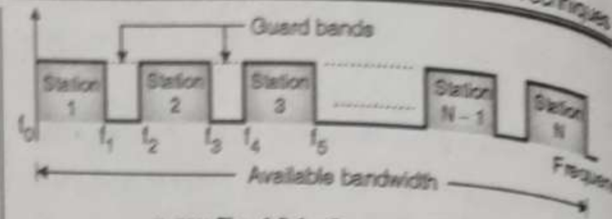
Q. 4 Explain Frequency Division Multiple Access (FDMA) in wireless communication with figure. **(S-19, 3 Marks)**

Principle :

- In the frequency division multiple access (FDMA), the available channel (medium) bandwidth is shared by all the stations.
- That means each station will have its own specific slot reserved in the entire channel bandwidth.
- So each station uses its allocated frequency band to send its data.
- Each band is thus reserved for a specific station. e.g. the frequency band f_0 to f_1 is for station-1, then f_2 to f_3 is for station-2 and so on.

Concept :

- The concept of FDMA is illustrated is Fig. 4.3.1.



(L-739) **Fig. 4.3.1 : Concept of FDMA**

- **Guard bands** are provided in between the adjacent frequency slots. e.g. $(f_1 - f_2)$ is a guard band between the bands allotted to stations 1 and 2. Guard bands avoid the adjacent channel interference.
- FDMA is used in cellular phones and satellite networks.
- An FDMA/FDD system (FDD is frequency division duplex) used in mobile phones; each user is assigned a pair of frequencies, one for the forward channel and other for the reverse channel.

4.3.1 Features of FDMA : GTU : W-15, S-18

University Questions

Q. 1 Write short note on Frequency Division Multiple Access (FDMA). **(W-15, 7 Marks)**

Q. 2 Describe the features of FDMA technique. **(S-18, 4 Marks)**

- The features of FDMA are as follows :
  1. The overall channel bandwidth is being shared by the multiple users. Therefore a number of users can transmit their information simultaneously.
  2. If a FDMA channel is not in use, it will be idle and cannot used by any other user. Therefore FDMA does not utilize the available spectrum efficiently.
  3. If a frequency band (channel) is assigned to a user in FDMA, then the mobile unit and the base station start transmitting simultaneously.
  4. The adjacent frequency bands in the FDMA spectrum are likely to interfere with each other. Therefore it is necessary to include the guard bands between the adjacent frequency bands.
  5. FDMA needs near to ideal RF filtering to reduce the adjacent channel interference.
  6. The mobile unit based on FDMA needs to use a duplexers in order to isolate signals from the transmitter and receiver operating simultaneously.

7. No code words and synchronization is not required.
8. Power efficiency is reduced.
9. FDMA is an old and proven system and is used for the analog signals.
10. The complexity of FDMA systems is less.
11. FDMA is a continuous transmission method. So few bits are required for overhead purposes (like synchronization and framing bits).

4.3.2 Nonlinear Effects in FDMA : GTU : W-15

University Questions

Q. 1 Write short note on Code Division Multiple Access (CDMA). Describe non linear effects in FDMA. Also write equation for number of channels that can he simultaneously supported in a FDMA system.

(W-15, 7 Marks)

- In a FDMA system, the same antenna is being shared by many channels at the base station.
- The power amplifiers or the power combiners are nonlinear because they are being operated at or near saturation to obtain maximum power efficiency.
- These nonlinearities result in signal spreading in the frequency domain and generate the so called intermodulation (IM) frequencies.
- Intermodulation is the process of the generation of undesirable harmonics.
- These harmonics will be outside the mobile radio band as well as inside it.
- These frequencies are undesired RF radiation which can interfere with other channels in the FDMA systems.
- Thus spreading of the spectrum results due to nonlinearity of power amplifiers.
- This results in adjacent-channel interference.
- Harmonics generated outside the mobile radio band would cause interference to the adjacent mobile services, while those present inside the band cause interference to other users in the mobile system .

Guard bands :

- In order to avoid the effects of nonlinearity, **guard bands** are introduced in between the adjacent channels.
- However introduction of guard bands reduces the spectrum efficiency of FDMA system because guard bands do not carry any information.

4.3.3 Number of FDMA Channels :

- The number of channels that can be simultaneously supported in a FDMA system is given by,

$$N = \frac{B_t - 2\,B_{guard}}{B_c}$$

- where B_t is the total spectrum allocation, B_{guard} is the guard band allocation and B_C is the channel bandwidth.

Ex. 4.3.1 : If the total spectrum allocated to an FDMA system is 12.5 MHz, guard band between the adjacent channels is 10 kHz, and channel bandwidth is 30 kHz, calculate the number of channels supported by the FDMA system.

Soln. :

Given : B_t =12.5 MHz, B_{guard}=10 KHz, B_c=30 KHz

To find : N

- The number of channels available in the FDMA system is given as

$$N = \frac{B_t - 2\,B_{guard}}{B_c}$$

- Substituting the values we get,

$$N = \frac{10 \times 10^6 - 2 \times 10 \times 10^3}{30 \times 10^3}$$

$$\therefore N = 416$$ **...Ans.**

Ex. 4.3.2 : If a cellular operator is located 10 MHz for each simplex band and if B_t is 10 MHz, B_{guard} is 10 KHz and B_c is 30 KHz, find the number of channels available in a FDMA system.

Soln. :

Given : B_t = 10 MHz, B_{guard} = 10 KHz

B_c = 30 KHz

- For an FDMA system

$$N = \frac{B_t - 2\,B_{guard}}{B_c}$$

$$\therefore N = \frac{10 \times 10^6 - 2 \times 10 \times 10^3}{30 \times 10^3}$$

$$= 332.66$$

$$N = 333$$

- Each cellular carrier is allocated 333 channels.

4.3.4 Merits of FDMA : GTU : W-15

University Questions

Q. 1 Write short note on Frequency Division Multiple Access (FDMA). **(W-15, 7 Marks)**

- Some of the important merits of FDMA are as follows :
  1. All the stations can operate continuously all 24 hours without having to wait for their turn to come.
  2. The power required for transmission depends on the number of channels being transmitted.
  3. The signal to noise ratio is improved due to the use of FM.
  4. No synchronization is necessary.
  5. FDMA is a less complex system.

4.3.5 Demerits of FDMA : GTU : W-15

University Questions

Q. 1 Write short note on Frequency Division Multiple Access (FDMA). **(W-15, 7 Marks)**

- Some of the important demerits of FDMA are as follows :
  1. Each channel can use only a part of the total bandwidth.
  2. In spite of guard bands being provided, there is some adjacent channel interference present.
  3. Due to the nonlinearity of the system the inter modulation products are generated.
  4. It can process only one phone circuit at a time.
  5. The cell site cost of FDMA systems is high.
  6. The bandwidth of FDMA channels is narrow.

4.4 Time Division Multiple Access (TDMA) :

GTU : S-15, W-15, S-17, S-18, S-19, W-19

University Questions

Q. 1 Which are various multiple access schemes used in wireless communications? **(S-15, 7 Marks)**

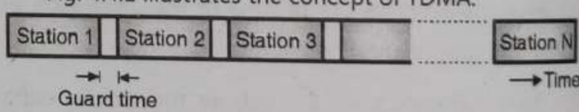
Q. 2 Describe: Time Division Multiple Access (TDMA) in detail. Write the equation for efficiency of TDMA and The number of channels in TDMA system. **(W-15, S-17, W-19, 7 Marks)**

Q. 3 Write the equation for efficiency of TDMA and Number of channels in TDMA. **(S-18, 3 Marks)**

Q. 4 Explain Time Division Multiple Access (TDMA) in wireless communication with figure. **(S-19, 4 Marks)**

Principle :

- TDMA stands for Time Division Multiple Access. In TDMA, the entire bandwidth can be used by every user (station) but not simultaneously.
- A station can use the entire bandwidth only for the allocated time slot.
- Thus each channel is allocated a time slot only during which it can send its data.
- Thus the time is shared, but the frequency band is not shared.
- Fig. 4.4.1 illustrates the concept of TDMA.



(L-740) **Fig. 4.4.1 : Concept of TDMA**

- **Guard times** are introduced between the adjacent time slots in order to prevent any cross talk.
- No data transmission takes place during the guard times.
- Thus TDMA systems transmit data in a buffer-and-burst method, and the transmission for any station is discontinuous.
- This means that, TDMA is more useful for digital data we need to use some digital modulation with it.
- TDMA finds its application in cellular phones and satellite networks.

TDMA frame structure :

- The TDMA systems transmit data in **burst and buffer** method.
- The transmission from different users in interfaced into a repeating frame structure as shown in Fig. 4.4.2.

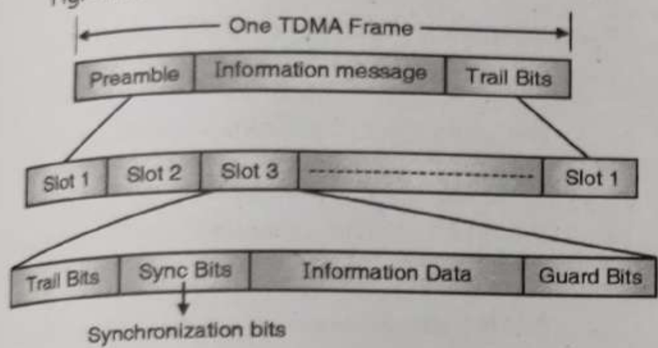


Fig. 4.4.2 : TDMA frame structure

- A frame consists of a number of slots. Each frame consists of preamble, an information message and trail bits.
- Half of the time slots will be used for the forward link channels and the remaining half for reverse link channels.
- The preamble field comprises the address and synchronization data that both the base stations and subscribers use to identify each other.
- The guard bits are used to provide synchronization of different receivers between, different time slots and frames.
- It is assumed that there are "N" number of slots for N users so that each user can access the channel in their allowed time slot.
- The TDMA/FDD systems have identical frame structure that can be used for forward or reverse transmission, but the carrier frequencies will be different for both the links.

4.4.1 Number of Channels in TDMA System :

GTU : W-15, S-17, S-18, W-19

University Questions

Q. 1 Describe: Time Division Multiple Access (TDMA) in detail. Write the equation for efficiency of TDMA and The number of channels in TDMA system. **(W-15, S-17, W-19, 7 Marks)**

Q. 2 Write the equation for efficiency of TDMA and Number of channels in TDMA. **(S-18, 3 Marks)**

- The number of channel slots that can be provided in a TDMA system is given by the following expression.

$$N = \frac{m\,(B_t - 2\,B_{guard})}{B_c}$$

- Where,

  m : Maximum number of TDMA users supported on each radio channel

  B_t : Total spectrum allocation

  B_{guard} : Guard band allocated at the edge of allocated spectrum

  B_c : Channel bandwidth

4.4.2 Efficiency of TDMA System :

GTU : W-15, S-17, S-18, W-19, S-20, W-20

University Questions

Q. 1 Describe: Time Division Multiple Access (TDMA) in detail. Write the equation for efficiency of TDMA and The number of channels in TDMA system. **(W-15, S-17, W-19, 7 Marks)**

Q. 2 Write the equation for efficiency of TDMA and Number of channels in TDMA. **(S-18, 3 Marks)**

Q. 3 Discuss the frame efficiency of TDMA with apt equations. **(S-20, W-20, 4 Marks)**

- The efficiency of a TDMA system is a measure of the percentage of the data that is transmitted.
- The transmitted data has information for providing overhead for the access scheme.
- The frame efficiency η_f is the percentage of bits per frame that contain transmitted data.
- The number of overhead bits per frame is expressed as,

$$b_{overhead} = N_r\, b_r + N_t\, b_p + N_t\, b_g + N_r\, b_g$$

- Where,

  N_r : Number of reference bursts per frame

  N_t : Number of traffic bursts per frame

  b_r : Number of overhead bits per reference burst

  b_p : Number of overhead bits per preamble in each slot

  b_g : Nmberof equivalent bits in each guard time interval

- The total number of bits per frame b_f is,

$$b_T = T_f R$$

Where T_f = Frame duration R : Channel bit rate

– Thus, the frame efficiency is,

$$\eta_f = \left(\frac{1 - b_{overhead}}{b_T}\right) \times 100 \%$$

4.4.3 TDMA Features :

– The important features of TDMA are as follows :

1. TDMA is used for the transmission of data and digital voice signals.
2. It is necessary to include "guard times" between the adjacent channels for reducing the cross talk.
3. Synchronization is necessary in TDMA.
4. Power efficiency of TDMA is better than that of the FDMA.
5. TDMA is a method of time division multiplexing the digitally modulated carriers between various earth stations in a satellite network through a common satellite transponder.
6. Each earth station transmits a **short burst** of digitally modulated carrier during the time slot assigned to it in the TDMA frame
7. Since TDMA uses different time slots for transmission and reception, the duplexers are not required to be used.
8. The number of time slots in a TDMA system is determined by parameters like bandwidth, modulation method etc.
9. As TDMA transmits data in bursts and not continuously, the battery consumption is reduced considerably.
10. In TDMA, the handoff process is simple.

4.4.4 Advantages of TDMA :

– The important advantages of TDMA are as follows :

1. At any instant of time, the carrier from only one station is present at the transponder. This reduces the intermodulation distortion.
2. TDMA is suitable for transmission of digital information.
3. It is possible to store the digital information, change the rate etc. in TDMA.

4.4.5 Advantages of TDMA over FDMA :

– The advantages of TDMA over FDMA are as follows :

1. In TDMA since only one station is present at any given time, the intermodulation products will not get generated.
2. The entire channel bandwidth can be allotted to a single channel at given instant of time. This is particularly advantageous for the digital channels which demand larger bandwidths.
3. The frequency selective fading does not affect the TDMA to the extent it affect the FDMA.
4. TDMA is well suited for the digital signals therefore it can be easily used for data transmission.
5. As only one channel is being transmitted at a time it is not necessary to separate out various channels at the receiver.

4.4.6 Disadvantages of TDMA :

– The important disadvantages of TDMA are as follows:

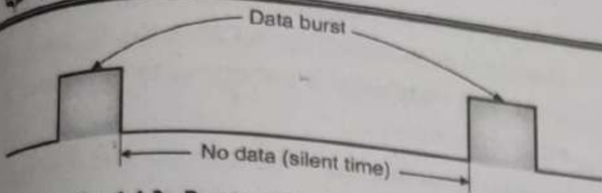
1. Precise synchronization is required.
2. Bit and frame timing must be achieved and maintained.

4.4.7 Problems with FDMA and TDMA :

– The problem with the FDMA and TDMA system is that, the channel is basically divided into independent sub-channels.

– That means each sub-channel in the FDMA is allotted to a single user and each time slot in TDMA has been allotted to a separate single user.

– The FDMA and TDMA systems however prove to be inefficient when the data from the users is bursty in nature as shown in Fig. 4.4.3.



(E-906) **Fig. 4.4.3 : Bursty data signal with low duty cycle**

- This type of data has low value of duty cycle. i.e. the time for which data is being transmitted is much shorter than the time for which data is not being transmitted.
- Under such circumstances where the transmission from different users is bursty and low duty cycle, the FDMA and TDMA system will not be very efficient.
- A large percentage of the available time or frequency slots do not convey any information and therefore are wasted.
- Such a type of data is observed in computer communication networks and to some extent, in the mobile cellular communication systems carrying digitized voice.

4.5 Code Division Multiple Access (CDMA) :

GTU : S-15, W-15, S-19

University Questions

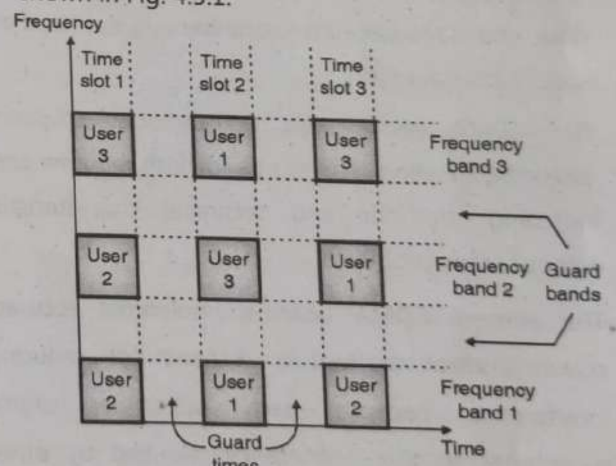
Q. 1 Which are various multiple access schemes used in wireless communications? **(S-15, 7 Marks)**

Q. 2 Write short note on Code Division Multiple Access (CDMA). Describe non linear effects in FDMA. Also write equation for number of channels that can he simultaneously supported in a FDMA system. **(W-15, 7 Marks)**

Q. 3 Explain Code Division Multiple Access (CDMA) in wireless communication with figure. **(S-19, 4 Marks)**

Concept :

- An alternative to FDMA and TDMA is an another system called code division multiple access (CDMA).
- In CDMA more than one user is allowed to share a channel or sub channel with the help of direct-sequence spread spectrum (DS-SS) signals.
- In CDMA each user is given a unique code sequence or signature sequence.
- This sequence allows the user to spread the information signal across the assigned frequency band.
- At the receiver the signal is recovered by using the same code sequence.
- At the receiver, the signals received from various users are separated by checking the cross-correlation of the received signal with each possible user signature sequence.
- In CDMA the users access the channel in a random manner.
- Hence the signals transmitted by multiple users will completely overlap both in time and in frequency.
- The CDMA signals are spread in frequency. Therefore the demodulation and separation of these signals at the receiver can be achieved by using the pseudorandom code sequence.
- CDMA is sometimes also called as spread spectrum multiple access (SSMA).
- In CDMA as the bandwidth as well as time of the channel is being shared by the users, it is necessary to introduce the guard times and guard bands as shown in Fig. 4.5.1.



(E-907) **Fig. 4.5.1 : Structure of CDMA showing the guard bands and the guard times**

- CDMA does not need any synchronization, but the code sequences or signature waveforms are required to be used.
- In CDMA one channel carries all the transmission simultaneously.
- As the same channel is used by several users, there may be a problem of **near-far effect.**

- The near-far problem occurs if the power of each user within the cell is not controlled such that they appear equal at the base station.
- To minimize the near-far problem power control is essential in CDMA systems.
- The main advantage of CDMA when compared to other multiple access methods is reduced level of interference.

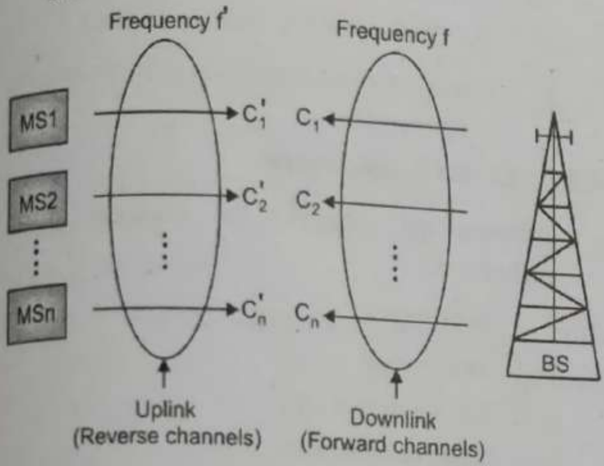
4.5.1 Spread Spectrum and CDMA :

- The spread spectrum is the modulation technique which is highly tolerant of all types of interferences.
- The spread spectrum technique is the basis for the access technique called as spread-spectrum multiple access or code-division multiple access (CDMA).
- In CDMA multiple access technique, every transmitting individual mobile subscribers occupies the complete available frequency spectrum.
- That means, the same spectrum, at the same time can be occupied by several mobile subscribers.
- In a CDMA environment, it is possible to accomplish the mixing of different types of traffic such as voice, data, and video because subscribers do not need any specific coordination.
- The CDMA system can accommodate different subscribers having different bandwidth requirements, switching methods and technical characteristics without many problems.
- The efficient CDMA systems, implement accurate power control of mobile stations for reducing interference because each subscriber signal contributes to the interference received by other subscribers.
- In CDMA since all subscribers are using the entire spectrum, it is necessary to spread their signals with a specific PN code, in order to distinguish a subscriber signal from other signals.
- All subscribers in the CDMA transmit information simultaneously with the use of the same carrier frequency.
- Therefore each subscriber in CDMA has its own code word. This code word is orthogonal to code words of other subscribers.
- In order to detect the information, the receiver must know the exact code word used by the transmitter.
- The receiver performs a time correlation operation for detecting the signal.
- An interesting feature of spread spectrum modulation CDMA is that, all other code words except the intended one appear as noise.
- To minimize this noise power at the receiver end the signal power should be high.
- In CDMA, one unique code is assigned to every subscriber and different codes are used for different subscribers.
- Each subscribers uses its code to mix with each information bit before transmitting it.
- These encoded bits, can be decoded by using the same code at the receiver.
- The receiver would interpret the received information as noise if there is any mismatch between the code allotted to it and the code used by the received signal.
- The CDMA technique uses a wider frequency band for every subscriber.
- In this system, the PN code generator generates different spread-spectrum codes and these codes are assigned to each subscriber.
- In CDMA, many subscribers share the same frequency.

4.5.2 Basic Structure of CDMA System :

- Fig. 4.5.2 shows the basic structure of a CDMA system.
- **Forward channel** is defined as the radio channel used for transmitting the information from the base station to the mobile i.e. in the forward direction. It is also known as **downlink** as shown.
- **Reverse channel** is defined as the radio channel used for transmitting the information from a mobile station to base station i.e. in the reverse direction.

- It is also called as **uplink** as shown.
- As shown in Fig. 4.5.2, different mobile stations transmit their signals C_1', C_2', ... at the same frequency or channel f' on the uplink towards the base station.



(OT-23)**Fig. 4.5.2 : Structure of a CDMA system**

- They use the unique code sequences assigned to them to produce these transmitted signals.
- Similarly the base station will transmit signals C_1, C_2, C_3, ... etc at some different frequency f on the downlink.
- These signals are produced by using the unique code sequences assigned to different mobile stations.
- On receiving these signals from the base station, each mobile station will decode the signals by using the codes assigned to them to obtain the original band signal.

4.5.3 Salient Features of CDMA Systems :

GTU : S-20, W-20

University Questions

Q. 1 Explain salient features of CDMA. **(S-20, W-20, 4 Marks)**

- Following are the important features of CDMA systems :

1. CDMA technique is used in some 2G digital cellular systems like IS-95 and most of the third-generation cellular systems.
2. In CDMA, many subscribers share the same frequency in combination with FDD or TDD.
3. As the number of active subscribers is not limited, a CDMA system has a soft capacity. With Increase in the number of active subscribers the noise floor increases in a linear way. Therefore, there is no absolute limit on the number of active subscribers.
4. With increase in the number of active subscribers, the performance of the system gradually degrades for all active subscribers.
5. As the signal in CDMA is spread over a large spectrum, multipath fading is considerably reduced.
6. The inherent frequency diversity will moderate the effects of small-scale fading because the spread spectrum bandwidth is larger than the coherence bandwidth of the channel.
7. The channel data rates in CDMA are very high. It results in the extremely short duration of the symbol or chip and typically much less than the channel delay spread.
8. In CDMA system, Multipath delayed by more than a chip will appear as noise because PN sequences have low autocorrelation.
9. In order to improve reception by collecting time-delayed versions of the required signals, a RAKE receiver can be used to improve the reception.
10. As CDMA uses co-channel cells in adjacent cells, it can use macroscopic spatial diversity scheme in order to provide soft hand-off.
11. Mobile station controller (MSC) can simultaneously monitor the signal strength of a particular subscriber from two or more base stations which allows it to perform soft hand-off if required.
12. At any time, the MSC can select the best version of the received mobile signal without the need of switching frequencies.
13. If spreading sequences of different subscribers are not exactly orthogonal then the self-jamming problem occurs.

14. If the received signal power of a required subscriber at the cell-site is less than that of the undesired subscribers then the near-far problem occurs.
15. In CDMA system, each subscriber operates independently without knowledge of other subscribers.

4.5.4 Multiple Access Techniques in Cellular Systems :

- Table 4.5.1 shows the different multiple access techniques and multiplexing technique used in analog and digital cellular communication system.

Table 4.5.1 : Multiple access techniques in cellular systems

Sr. No.	Type of cellular system	Standard	Multiplexing technique	Multiple access technique
1.	1G Analog Cellular	AMPS	FDD	FDMA
2.	US Digital Cellular	USDC	FDD	TDMA
3.	2G Digital Cellular	GSM	FDD	TDMA
4.	Pacific Digital Cellular	PDC	FDD	TDMA
5.	US Narrowband Spread Spectrum Digital Cellular	IS-95	FDD	CDMA
6.	3G Digital Cellular	W-CDMA	FDD/TDD	CDMA
7.	3G Digital Cellular	Cdma2000	FDD/TDD	CDMA

4.5.5 Advantages of CDMA :

- Some of the advantages of CDMA are :
  1. It does not need any synchronization.
  2. More number of users can share the same bandwidth.
  3. Sharing of bandwidth as well as time is possible.
  4. Due to codeword allotted to each user, interference (crosstalk) is reduced.

4.5.6 Disadvantages :

- Some of the disadvantages of CDMA are :
  1. The CDMA system is more complicated.
  2. Guard band and guard time both are required to be provided.

4.5.7 CDMA Applications :

- Following are some of the important CDMA applications :
  1. Voice services
  2. Data services
  3. Circuit switched data
  4. Packet switched data
  5. Message services
  6. CDMA radio
  7. Location based services
  8. CDMA radio channel

4.6 Spread-Spectrum Multiple Access (SSMA) : GTU : S-15

University Questions

Q. 1 Discuss the concept of spread spectrum. **(S-15, 7 Marks)**

- A cellular system is designed with an objective to reuse the radio spectrum allocated to it over a large area as many times as possible.
- Either FDMA or TDMA technique can be used within a cell to share the wireless medium.
- However FDMA and TDMA systems have a major drawback when used in cellular systems, that the reuse distance is limited by worst-case co-channel interference.

Definition of spread spectrum :

- In the telecommunication or radio communication spread spectrum techniques are the methods by which a signal generated with a particular bandwidth is spread deliberately in the frequency domain to produce a signal with much wider bandwidth.

(E-1998) **Fig. 4.6.1 : Principle of spread spectrum technique**

Concept of SSMA :

- The spread spectrum multiple access (SSMA) is a technique that uses signals which have a transmission bandwidth several times higher than the minimum required RF bandwidth.
- In other words the spread-spectrum technique spreads the information-bearing data signal over a large bandwidth.
- Due to this, the SSMA allows many subscribers in adjacent cells to use the same spectrum simultaneously.
- SSMA is immune to multipath interference and robust capability for multiple access.
- However the drawback of SSMA is that it is not very bandwidth efficient when used by a single subscriber.
- There systems become bandwidth efficient when used for multiple subscribers because many subscribers can share the same spread spectrum bandwidth without interfering with one another.

Working of Spread Spectrum Technique :

- Spread spectrum can be defined as a transmission technique in which the transmitted data occupies a larger bandwidth than required.
- The process of bandwidth spreading is achieved at the transmitter by using of a code that is independent of the subscriber data.
- Then at the receiver the same code is used to demodulate the received data.
- The SS systems use certain modulation techniques which spread the information signal with bandwidth R_b, to occupy a much larger transmission bandwidth R_c.
- Thus in SS systems the transmission bandwidth R_c is much larger than the signal bandwidth R_b.
- In FDMA system, the available frequency spectrum is divided into N subscribers.
- Hence the channel bandwidth allotted to each subscriber is $B_c = B_t / N$.
- In spread-spectrum techniques, there is no such spectrum division.
- Instead, multiple subscribers are permitted to use the entire or any part of the spectrum when transmitting simultaneously.
- SS techniques have higher immunity to noise and interference as they use wideband, noise-like signals.
- These signals are difficult to demodulate, detect, intercept or jam than narrowband signals.
- Spread signals intentionally occupy much wider bandwidth than the actual bandwidth of the information signals, to behave as more noise-like.
- These signals use fast code signals called as spreading signals, with a data rate much higher than the data rate of the information signal.
- These spreading codes are referred to as **pseudorandom or pseudonoise (PN)** codes or (PN) sequence.
- A pseudo-noise (PN) sequence is defined as a coded sequence of 1s and 0s with certain auto-correlation properties.
- The PN sequence is a random sequence which is impressed on the transmitted signal at the transmitter to spread the signal randomly over a large frequency spectrum.
- Due to the random nature of the PN sequence, the S.S. transmitted signals appears to be the noise signal to all the receivers except the desired receiver.
- The power levels used by spread-spectrum transmitters are similar to that of any narrowband transmitters.
- Spread spectrum are considered as a digital modulation technique, with wide frequency spectra.
- A modulated signal can be qualified as a spread spectrum signal, if it satisfies the following two criteria :
- The bandwidth of the transmitted signal is much greater than that of the information data signal.

- Orthogonal PN code sequence determines the actual transmitted bandwidth on-the-air.

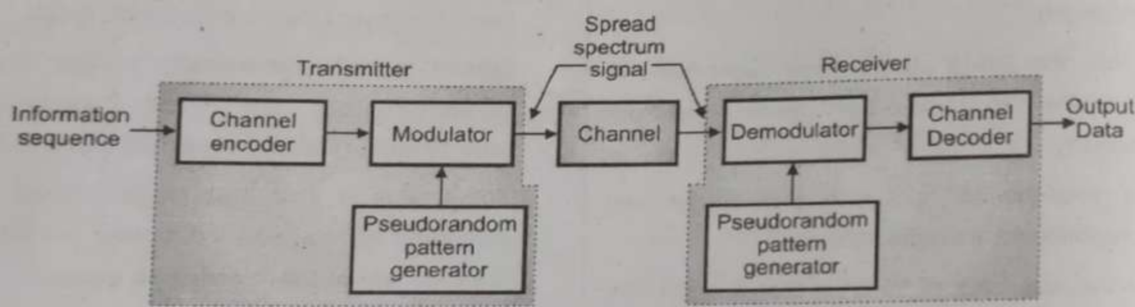
Importance of S.S :

- The spread spectrum communication is a very secure communication.
- An unwanted person cannot receive the S.S. communication.
- This aspect of S.S. communication protects the information from hackers.
- It is therefore used in military as well as non-military communication applications.

4.6.1 Model of Spread Spectrum Modulation System :

Block diagram :

- The block diagram shown in Fig. 4.6.2 illustrates the basic elements of a spread spectrum digital communication system.
- It consists of a transmitter, a communication channel and a receiver.



(E-471) **Fig. 4.6.2 : Model of spread spectrum digital communication system**

Operation of transmitter :

- The information sequence at the input of the system is a binary information sequence.
- The same signal is recovered at the output of the system as output data signal.
- In addition to these basic building blocks of a digital communication system, two additional blocks called "pseudo-random pattern generator" are used as shown in Fig. 4.6.2.
- One of them is connected to the modulator on the transmitter side whereas the other is connected to the demodulator on the receiving side.
- Both these generators are identical to each other.
- These generators generate a pseudorandom or pseudonoise (PN) binary sequence.
- It is impressed on the transmitted signal at the modulator.
- Thus the modulated signal along with the pseudorandom sequence travels over the communication channel.
- This sequence spreads the signal randomly over a wide frequency band.
- Thus the output of the modulated signal is a spread spectrum signal.

Operation of the receiver :

- The pseudorandom sequence is removed from the received signal, by the other "pseudorandom generator" operating at the receiver.
- Thus the pseudorandom pattern generators operate in synchronization with each other.
- The synchronization between these pattern generators is achieved before the beginning of the signal transmission.
- This is done by transmitting a fixed pseudorandom bit pattern which a receiver can recognize even in presence of interference.
- Once this synchronization is established, it is possible to begin the transmission.
- Thus in the spread spectrum receiver, the receiver can demodulate the transmitted signal if and only if a

known pseudo-noise sequence has been transmitted along with the information signal.

4.7 Direct Sequence Spread Spectrum (DSSS) Multiple Access :

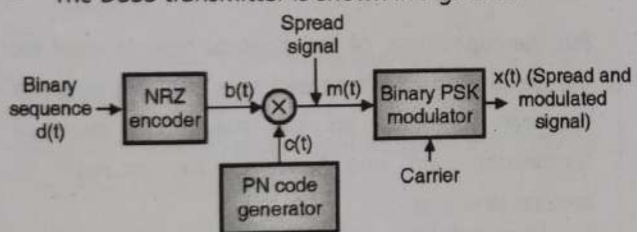
- One of the important spread spectrum technique is called as **"Direct Sequence Spread Spectrum"** (DS-SS) technique.
- The DS-SS technique can be used in practice for transmission of signal over a bandpass channel such as the satellite channel.
- For such an application, the coherent binary phase shift keying (BPSK) is used as modulation scheme in the transmitter and receiver. The transmitter is as shown in Fig. 4.7.1.

Definition :

- Direct Sequence Spread Spectrum (DSSS) is a spread spectrum technique in which the original data signal is multiplied with a PN spreading code.
- This results in a wideband time continuous scrambled signal.

DSSS Transmitter :

- The DSSS transmitter is shown in Fig. 4.7.1.



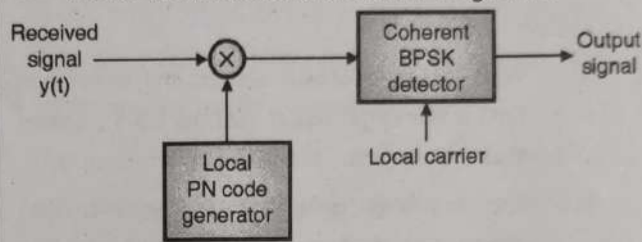
(E-480) **Fig. 4.7.1 : DSSS transmitter**

Operation :

- The binary sequence d (t) is converted into NRZ signal b (t) by applying d(t) to the NRZ encoder.
- The NRZ signal b (t) at the output of the NRZ encoder is then used to modulate the PN sequence c (t) generated by the PN code generator.
- The transmitter of Fig. 4.7.1 uses two stages of modulation.
- The first stage uses a product modulator or multiplier with b (t) and c (t) as its inputs and the second stage consists of a BPSK modulator.
- The modulated signal at the output of the product modulator i.e. m (t) is the spread version of the original input and it is used to modulate the carrier for BPSK modulation.
- Thus the BPSK modulator will modulate the spread signal (SS) to produce a DS-SS BPSK signal.
- The transmitted signal x (t) is thus a direct sequence spread BPSK i.e. DS-BPSK signal.

DS-SS Receiver :

- The DS-BPSK receiver is as shown in Fig. 4.7.2.



(E-482) **Fig. 4.7.2 : The DS-SS receiver**

Operation :

- At the receiver we have to generate the replica of the original PN-sequence used at the transmitter.
- The received signal y(t) and the locally generated replica of the PN - sequence are applied to a multiplier.
- This is the first stage of multiplication. The multiplier performs the de-spreading operation.
- Output of multiplier is then applied to a coherent BPSK detector with a locally generated synchronous carrier applied to it.
- At the output of the coherent BPSK detector we get back the original data sequence i.e. d(t).

Synchronization :

- For proper operation, the spread spectrum system requires a local PN sequence at the receiver to by **synchronized** with the PN sequence at transmitter.

4.7.1 Advantages of DS-SS System :

- Following are some of the advantages of DS-SS system :
  1. This system has a very high degree of discrimination against the multipath signals.

Therefore the interference caused by the multipath reception is minimized successfully.

2. The performance of DS-SS system in presence of noise is superior to other systems such as FH-SS system.
3. This system combats the intentional interference (jamming) most effectively.

4.7.2 Disadvantages of DS-SS System :

- Following are some of the disadvantages of DS-SS system :
  1. With the serial search system, the acquisition time is too large. This makes the DS-SS system slow.
  2. The sequence generated at the PN code generator output must have a high rate. The length of such a sequence needs to be long enough to make the sequence truly random.
  3. The channel bandwidth required, is very large. But this bandwidth is less than that of a FH-SS system.
  4. The synchronization is affected by the variable distance between the transmitter and receiver.

4.7.3 Applications of DS-SS System :

- Some of the important applications of the DS-SS system are as follows :
  1. To combat the intentional interference (jamming).
  2. To reject the unintentional interference.
  3. To minimize the self interference due to multipath propagation.
  4. In the low probability of intercept (LPI) signal.
  5. In obtaining the message privacy.
  6. Code division multiple access with DS-SS.

4.8 Frequency Hop Spread Spectrum (FH-SS) Multiple Access :

Definition :

- FHSS is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels using a PN sequence known to both transmitter and receiver.

Principle of operation of (FH – SS) system :

- In this system the data is used to modulate a carrier.
- The data modulated carrier is then **randomly hopped** from one frequency to the other.
- Due to this, the spectrum of transmitted signal is spread sequentially rather than instantaneously.

When to use FHSS ?

- In the DS-SS system discussed in the previous section, the NRZ data sequence b (t) modulates the PN sequence.
- The product signal [$m(t) = b(t) \times c(t)$] is spread instantaneously in the frequency domain due to this process.
- The capacity of DS-SS system to reject the intentional interference (jamming) is dependent on the "processing gain PG".
- The processing gain PG = (T_b / T_c). Hence PG increases if the chip period T_c is decreased which in turn permits a greater transmission bandwidth and more chips per bit.

Problem :

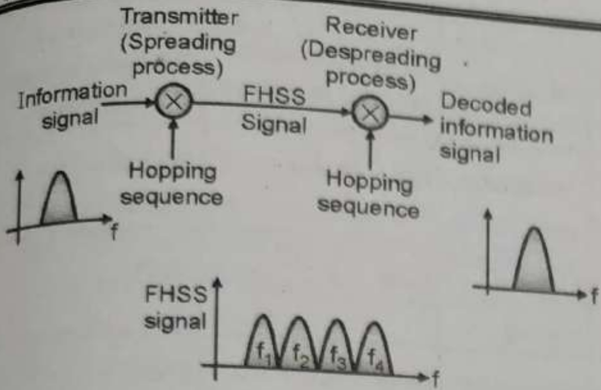
- But the capabilities of the physical devices used for the generation of PN spread spectrum signal put a practical limitation on the maximum value of "processing gain" and hence on the capability to combat jamming.
- Under some operating conditions the maximum attainable processing gain $PG_{(max)}$ is not sufficiently high for combating the jamming.
- Under such conditions an alternative system called Frequency Hop (FH) spread spectrum.

Types of modulation :

- A common modulation technique used is the M-ary frequency shift keying (MFSK).
- The combination of frequency hopping (FH) and MFSK is known as FH / MFSK.

4.8.1 Operation of FHSS :

- Refer Fig. 4.8.1 to understand the principle of FHSS.



(0-1105) **Fig. 4.8.1 : Basic concept of FHSS technique**

- The frequency hopped multiple access technique is based on the frequency hopping spread spectrum (FHSS) modulation scheme.
- The SS signal with a wideband frequency spectrum is generated in a different manner in a frequency hopping technique.
- In frequency hopping, the transmission frequency is periodically changed over a wide band.
- The rate of hopping from one frequency to another depends on the information rate.
- Whereas the specific order in which the signal occupies the frequencies is a function of a code sequence.
- The set of possible carrier frequencies say f_1, f_2, f_3, f_4 is called the **hopset.**
- Hopping occurs over a frequency band that includes a number of channels.
- We may define each channel as a spectral band with a central frequency in the hopset and a sufficient bandwidth.
- The bandwidth of a channel is called the instantaneous bandwidth whereas, the bandwidth of the spectrum over which the hopping takes place is called the total hopping bandwidth.
- The FHSS transmitter sends data by changing (hopping) the transmitter carrier frequencies from frequency to the other in a seemingly random manner, which is known only to the desired receiver.
- As shown the bandwidth of a frequency-hopping signal is 'w' times the number of frequency slots available, and the bandwidth of each hop channel is equal to 4w.

FHSS transmitter and receiver :

- In an FHSS transmitter and receiver a pseudorandom (PN) frequency hopping sequence is used as shown in Fig. 4.8.1.
- At the transmitter it is used for changing the radio signal frequency randomly across a broad frequency band in a random manner.
- In this way in FHSS, the radio transmitter frequency hops from one channel to the other channel in a predetermined but pseudorandom sequence.
- The received signal at the receiver is despread by using a frequency synthesizer which is controlled by a pseudorandom sequence generator.
- The PN sequence generator is synchronized to the transmitter's pseudorandom sequence generator.

4.8.2 Types of Frequency Hopping :

- Depending on the rate of frequency hopping, the FH/MFSK systems are classified into two categories :
  1. Slow frequency hopping.
  2. Fast frequency hopping.

1. Slow frequency hopping :

- The slow frequency hopping is the type of FHSS in which the **symbol rate R_s** of the MFSK signal is an integer multiple of the hop rate R_h.
- That means several symbols are transmitted corresponding to each frequency hop.

$\therefore$ Each frequency hop $\Rightarrow$ Several symbols.

- Thus frequency hopping takes place slowly.

2. Fast frequency hopping :

- It is the type of FHSS in which the hop rate R_h is an integer multiple of the MFSK **symbol rate R_s.**
- That means during the transmission of one symbol, the carrier frequency will hop several times.

$\therefore$ Each symbol transmission $\Rightarrow$ Several frequency hops.

- Thus the frequency hopping takes place at a fast rate.

4.8.3 Advantages of FH-SS System :

- Some of the major advantages of FH-SS system are as follows :
  1. The synchronization is not greatly dependent on the distance.
  2. The serial search system with FH-SS needs shorter time for acquisition.
  3. The processing gain PG is higher than that of DS-SS system.

4.8.4 Disadvantages of FH-SS System :

- Some of the major disadvantages of FH-SS system are as follows :
  1. The bandwidth of FH-SS system is too large (in GHz).
  2. Complex and expensive digital frequency synthesizers are required to be used.

4.8.5 Applications of FHSS :

- FHSS is being used in a number of applications. The two most important of them are as follows :
  1. Wireless local area networks (WLAN) standard for Wi-Fi.
  2. Wireless personal area network (WPAN) standard of Bluetooth.

4.8.6 Comparison of DS-SS and FHSS :

Sr. No.	Parameter	Direct sequence spread spectrum	Frequency hopping spread spectrum
1.	Definition	PN sequence of large bandwidth is multiplied with narrow band data signal.	Data bits are transmitted in different frequency slots which are changed by PN sequence.
2.	Chip rate	It is fixed $R_c = \frac{1}{T_c}$	$R_c = \max(R_h, R_s)$
3.	Modulation technique	BPSK	M-ary FSK
4.	Processing gain	$PG = \frac{T_b}{T_c} = N$	$PG = 2^l$
5.	Effect of loading	Less	More
6.	Acquisition time	Long	Short
7.	Effect of distance	This system is distance relative	Effect of distance is less

4.9 Orthogonal Frequency Division Multiplexing (OFDM) : GTU : S-17, W-19

University Questions

Q. 1 Write a short note on OFDM. (S-17,W-19, 7 Marks)

- 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.

4.9.1 Orthogonality : GTU : S-17, W-19

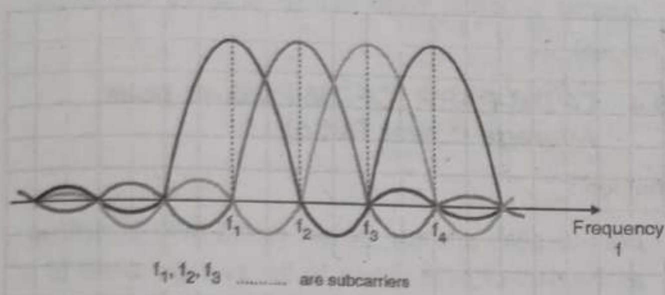
University Questions

Q. 1 Write a short note on OFDM. (S-17, W-19, 7 Marks)

Definition :

- 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.
- We can 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. 4.9.1.

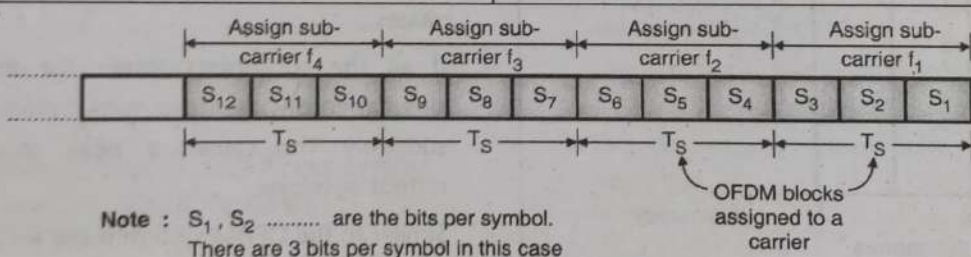


(E-1334) Fig. 4.9.1 : Orthogonal signals in frequency domain (principle of OFDM)

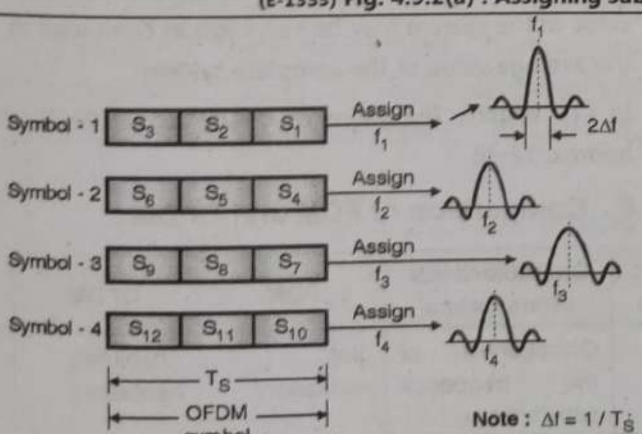
- Note that the subcarriers f_1, f_2 ....etc are placed at the null points of all the other subcarriers.
- This automatically eliminates the interference among the adjacent subcarriers.
- Due to this type of placement of subcarriers, the total bandwidth of the OFDM system is much less than that of the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

4.9.2 Assigning the Subcarriers :

- In OFDM, single information stream or frame is split into multiple symbols and a separate carrier is assigned to each symbol or a group of symbols.
- All this information is transmitted simultaneously through these multiple carriers.
- There are two ways of assigning the subcarriers, as follows :
- Consider one OFDM frame. Then read the first group of bits/symbol and assign one subcarrier to it.
- Then read another group of bits / symbol and assign another subcarrier to it, and continue.
- Note that all these subcarriers are orthogonal to each other.
- T_s represents the duration of each symbol. This is as shown in Fig. 4.9.2(a).



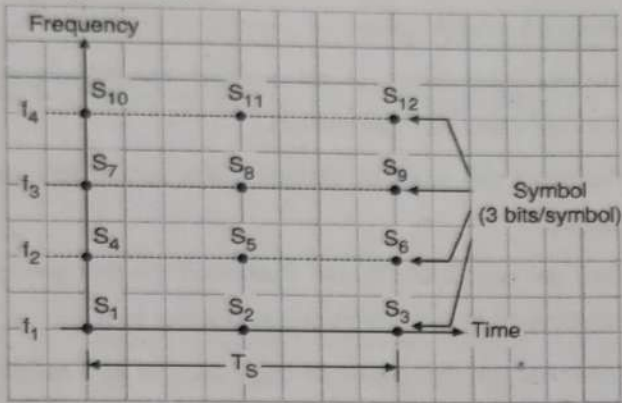
(E-1335) Fig. 4.9.2(a) : Assigning subcarriers to each symbol containing 3 bits



(E-1336) Fig. 4.9.2(b) : Serial to parallel conversion and mapping into frequency domain components after modulation in OFDM

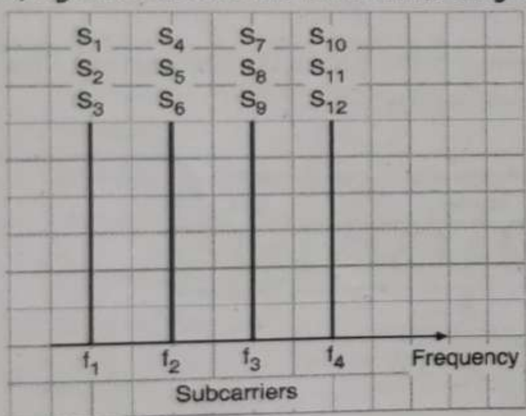
- All the symbols are then arranged in parallel as shown in Fig. 4.9.2(b) and an orthogonal subcarrier (f_1, f_2 ......) is assigned to it.
- In the second method of assigning the subcarriers the bits/symbol of the whole OFDM frame are read and then a matrix is formed in which each element represents a symbol (or word).
- The whole frame is then represented as a time versus frequency plot as shown in Fig. 4.9.3(a).
- Note that each point in this lattice represents a symbol (word).

- Thus f_1 is assigned to the first symbol consisting of bits S_1, S_2, S_3.
- Then f_2 is assigned to the second symbol consisting of bits S_4, S_5, S_6 and so on.
- The symbols (group of bits) are then used to modulate different orthogonal subcarriers as shown in Fig. 4.9.3(b).



(a) Lattice representation

(E-1337) Fig. 4.9.3 : Second method of carrier assignment

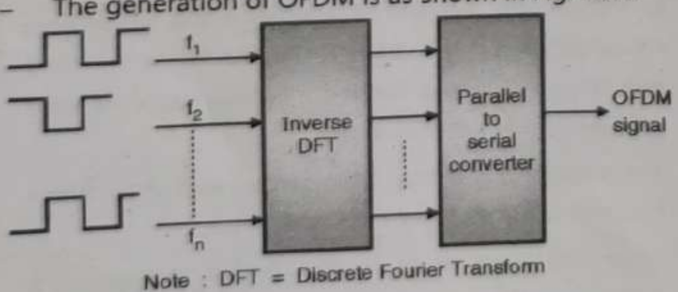


(b) Subcarrier assignment

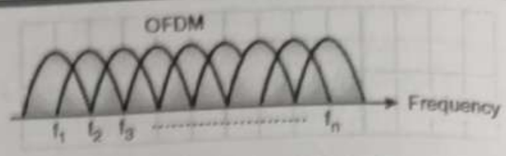
(E-1337) Fig. 4.9.3 : Second method of carrier assignment

4.9.3 Generation of OFDM Signals :

- The generation of OFDM is as shown in Fig. 4.9.4.



(E-1339) Fig. 4.9.4(a) : Block schematic of OFDM



(b) Frequency spectrum

(E-1339) Fig. 4.9.4 : Principle of OFDM

- The symbols will first modulate different orthogonal carriers f_1, f_2 ...., f_n.
- Then they are applied to the inverse DFT block.
- The output of IDFT block is then applied to the parallel to serial converter to produce the OFDM signal.

4.9.4 OFDM-PAPR (OFDM-Peak-to-peak Average Power Ratio) :

Definition :

- 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.

4.9.5 Comparison of FDM and OFDM :

Sr. No.	Characteristics / Parameters	FDM	OFDM
1.	Orthogonality of the frequency sub carriers.	Not necessary.	Absolutely necessary.
2.	Time and frequency synchronization.	Not necessary.	Necessary.

Sr. No.	Characteristics / Parameters	FDM	OFDM
3.	Number of carriers.	It is a single carrier oriented system.	It is a multicarrier system.
4.	Guard bands.	Large guard bands between adjacent channels are used.	Guard bands are not used.
5.	Spectral efficiency.	Low spectral efficiency as FDM has higher overall bandwidth.	High spectral efficiency as OFDM has lower overall bandwidth.
6.	Frequency spectrum.	See Fig. A.	See Fig. B.

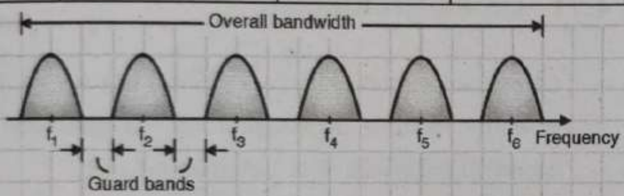


Fig. A : FDM Spectrum

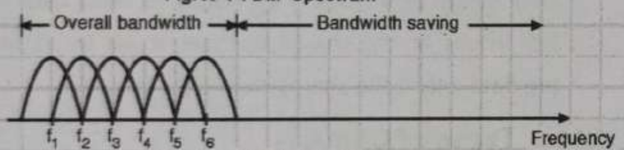


Fig. B : OFDM Spectrum

(E-1338)

4.10 OFDMA (Orthogonal Frequency Division Multiple Access) :

Concept of OFDMA :

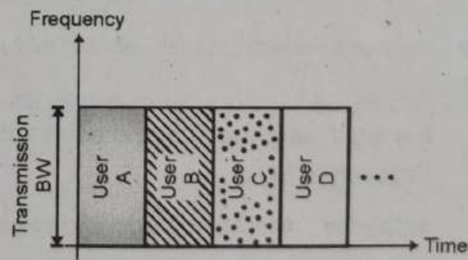
- Orthogonal frequency-division multiple access (OFDMA) is a multi-user version of the orthogonal frequency-division multiplexing (OFDM) digital modulation scheme.
- Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users.
- This allows simultaneous low-data-rate transmission from several users.
- OFDM is a technique in which bandwidth is divided into several **orthogonal** frequency subcarriers, without any guard band between them.
- There is still no interference between the adjacent subcarriers because they are orthogonal to each other.

Orthogonality :

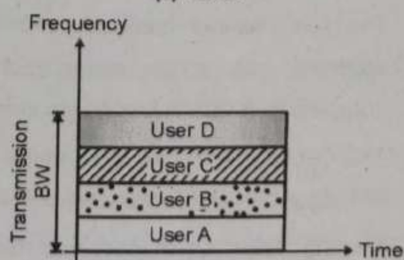
- Signals are orthogonal if they are uncorrelated to each other.
- In other words the cross correlation between the orthogonal signals is zero.
- An important characteristic of the orthogonal signals is that when they are combined or added together they do not interact with one another.
- This noninterference is a very important characteristics of the orthogonal signals.
- It allows multiple information signals to be transmitted over a common channel and detected perfectly without any interference.

Principle of Operation :

- Refer Fig. 4.10.1 to understand the principle of operation of OFDMA.
- It shows that in OFDMA, each user is given a different subcarrier as well as a time slot to transmit/receive its signals.
- It allows better spectral efficiency and simple equalization at the receiver.
- Even though there is overlapping in time and frequency domain still there is no mutual interference when the sampling is done at subcarrier positions.

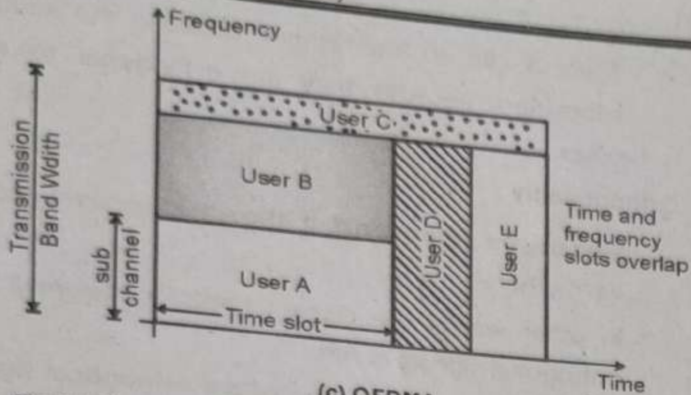


(a) TDMA



(b) FDMA

Fig. 4.10.1(Contd...)



(c) OFDMA

(GT-52) Fig. 4.10.1 : OFDM signal representation in time frequency domain

4.10.1 Features of OFDMA :

– The important features of OFDMA are as follows :

1. Flexibility of allocating various frequency bands.
2. Reduced interferences from neighbouring cells.
3. Reduced interferences within the cell.
4. Enables single-frequency network coverage, where coverage problem exists and gives excellent coverage.
5. Offers frequency diversity by spreading the carriers all over the used spectrum.
6. Scalability
7. Robustness to multipath channels.

4.10.2 Disadvantage of OFDMA :

– The important disadvantages of OFDMA are as follows :

1. It is highly sensitive to timing errors and carrier frequency offsets.
2. Subcarrier allocation algorithms used at transmitter introduces complexity.
3. The fast channel feedback information and adaptive sub-carrier assignment is more complex than CDMA fast power control
4. The OFDM electronics is complex due to the FFT algorithm and forward error correction.
5. Dealing with co-channel interference from nearby cells is more complex in OFDM than in CDMA.

4.10.3 Applications of OFDMA :

– The important applications of OFDMA are as follows :

1. The mobility mode of the IEEE 802.16 (Wireless MAN standard,) commonly referred to as WiMAX,
2. The wireless LAN (WLAN) standard IEEE 802.11ax,
3. The IEEE 802.20 mobile Wireless MAN standard, commonly referred to as MBWA,
4. MoCA 2.0,
5. The downlink of the 3GPP Long-Term Evolution (LTE) fourth-generation mobile broadband,
6. Multiuser satellite communication,
7. 4G LTE (Long term evolution) network.

4.11 CSMA Protocols :

– Carrier sense multiple access (CSMA) is a simple, yet powerful multiple access protocol. Its operation is based on the principle of "listen before talk".

– That means any node that wants to send data will first listens on the shared channel. It will try to send the data only if the shares channel is free.

4.11.1 Types of CSMA :

– The two main types of CSMA are as follows :

1. CSMA with collision detection (CSMA-CD) and
2. CSMA with collision avoidance (CSMA-CA).

– The principle of operation of CSMA-CD is that it tries to detect a collision and resends the packet if a collision takes place.

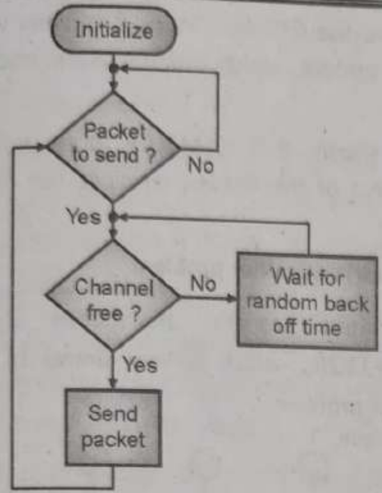
– However the CSMA-CA is based on the principle of avoiding the collision in the first place.

– Therefore it is more useful, performs better and more preferred.

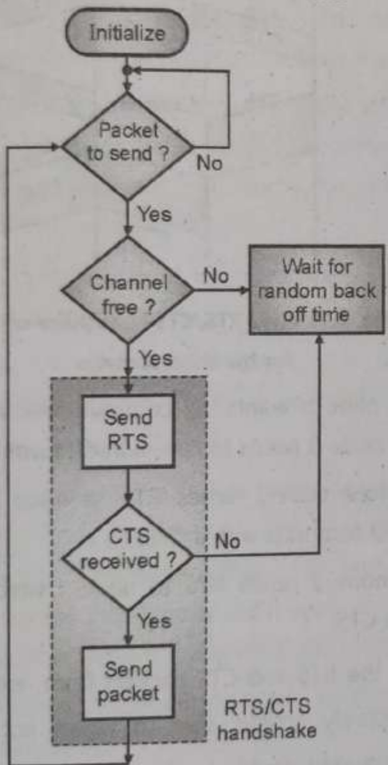
– Hence we will focus our discussion on CSMA-CA.

4.11.2 Flow diagram of CSMA-CA :

– The flow diagram of the CSMA-CA protocol without and with RTS / CTS handshake are as shown in Fig. 4.11.1(a) and (b) respectively.



(0-977)**Fig. 4.11.1(a) : Flow diagram of CSMA-CA protocol without RTS / CTS handshake**



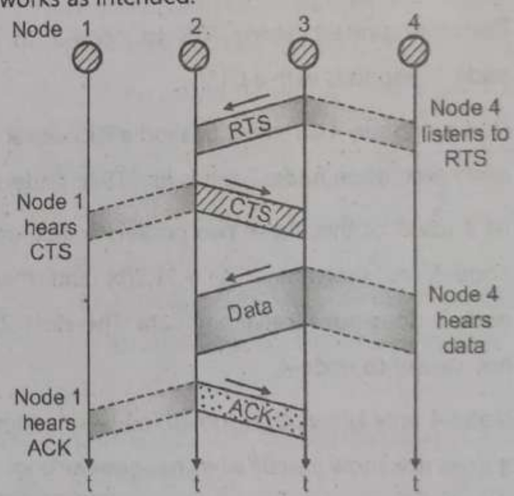
(0-978) **Fig. 4.11.1(b) : Flow diagram of CSMA-CA protocol with RTS / CTS handshake**

4.11.3 RTS/CTS Handshake :

- It is assumed that all nodes are always in idle listening mode.
- A node that has a packet to send, will first listen on the channel if there is any traffic.
- If it finds the channel to be free, it will send a special message, called ready-to-send **(RTS).**
- On receiving the RTS packet the receiver sends a short answer called clear-to-send **(CTS).**
- This procedure is called RTS-CTS handshake.
- After receiving the CTS packet, the sending node will be ready to send the application data and can optionally listen for an ACK packet.
- If the sending node finds the channel to be busy, then it waits for a random amount of time called **random back-off,** until the channel becomes free again.
- The RTS/CTS handshake helps to avoid collisions. Fig. 4.11.2 shows some examples of RTS / CTS handshake.

First scenario: Normal operation :

- The first scenario has been illustrated in Fig. 4.11.2(a), which is the regular case of operation i.e. everything works as intended.

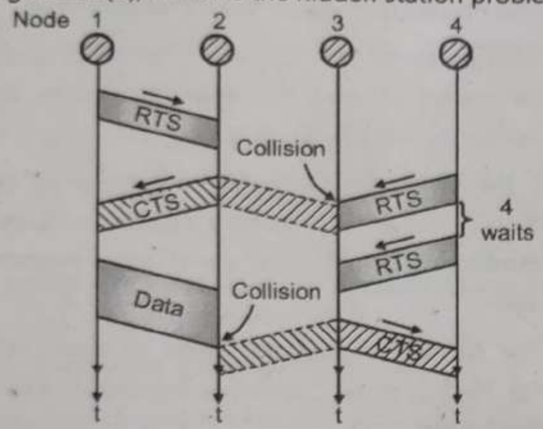


(0-986) **Fig. 4.11.2(a) : RTS / CTS handshake of CSMA-CA in normal operation**

- It graphically demonstrate the communication between nodes-2 and 3.
- Node-3 sends the RTS signal to node-2, which responds by sending the CTS signal.
- The RTS/CTS messages successfully shut down the neighbouring nodes (nodes-1 and 4).
- Hence they will not transmit and disturb the communication between nodes-2 and 3.
- This is how the RTS-CTS handshake supports the collision avoidance by shutting down nodes around the sender and the receiver.

Second scenario: Hidden station problem

- The second scenario has been illustrated in Fig. 4.11.2(b), which is the hidden station problem.

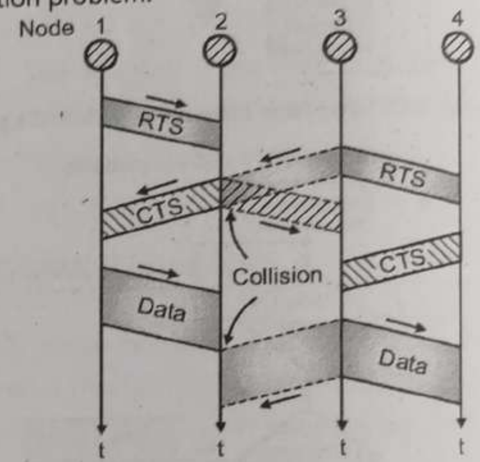


(O-987) **Fig. 4.11.2(b) : RTS/CTS handshake of CSMA-CA with hidden station problem**

- Node-1 wants to communicate with node-2 while node 4 wants to communicate with node 3.
- Therefore node-1 sends RTS to node-2 to which node-2 responds with a CTS.
- However node-4 attempts to send a RTS signal at the same time when node-2 sends its CTS to node-1.
- As a result of this, these two packets collide only for node-3, as shown in Fig. 4.11.2(b) and therefore node-3 does not receive any data. Therefore it does not answer to node-4.
- Node-4 only knows that something went wrong. But it does not know exactly what has gone wrong.
- Therefore it back-offs randomly and retries after sometime.
- The next RTS from node 4 is successfully received at node-3 and its responds with a CTS, which interferes at node-2 with the data sent by node-1 and the communication between nodes-1 and 2 gets interrupted.
- This scenario is a clear example of the hidden terminal problem.
- In this scenario node 3 would have been successfully shut down, if it would have received the CTS from node-2.
- Instead the CTS from node-2 collided with the RTS from node-4, which did not allow node-3 to shut down.
- This shows that CSMA-CA does not solve the problem of the hidden terminal, but only makes it better.

Third scenario: Another problem

- The third scenario has been illustrated in Fig. 4.11.2(c), which is very similar to the hidden station problem.



(O-988) **Fig. 4.11.2(c) : RTS/CTS handshake of CSMA-CA for the third scenario**

- Here node-1 wants to communicate with node-2 while node-3 wants to communicate with node-4.
- Therefore node-1 sends RTS to node-2, to which node-2 responds with a CTS.
- Also node-3 sends RTS to node-4 which responds with a CTS.
- Here, the RTS and CTS packets from nodes-3 and 2 respectively collide, due to which node-3 is not properly shut down.
- Therefore communication between nodes-1 and 2 and between nodes-3 and 4, continues to take place until their data packets collide.

4.11.4 Types of CSMA / CA : GTU : S-18, W-19

University Questions

Q. 1 Explain: 1-persistent CSMA, non-persistent CSMA, p-persistent CSMA. **(S-18, 3 Marks)**

Q. 2 Explain: 1-persistent CSMA and p-persistent CSMA. **(W-19, 3 Marks)**

- The final question to be answered is, what to do if the channel is busy and a node cannot send the RTS / CTS packets ?
- We have the following options to solve this problem :
  1. 1-persistent CSMA
  2. Non-persistent CSMA
  3. P-persistent CSMA
  4. O-persistent CSMA.

1. 1-persistent CSMA :

- In this scheme the station which wants to transmit, continuously monitors the channel until it is idle and then transmits immediately.
- The disadvantage of this strategy is that if two stations are waiting then they will transmit simultaneously and collision will take place.
- If collision occurs then the sender backs off for a random amount of time and attempts again.
- The problem in this scheme is that if many senders are waiting for the channel to become free, then all of them will attempt at exactly the same time which results in collisions.
- This problem could be solved only by the random back-off mechanism.
- Thus, the 1-persistant CSMA is in fact CSMA-CD rather than CSMA-CA. It is used in Ethernet.

2. Non-persistent CSMA :

- In this scheme, if a station wants to transmit a frame and it finds that the channel is busy (some other station is transmitting) then it will wait for a random amount of time after which it again checks the status of the channel and transmits if the channel is free.
- Note that the sender does not monitor the channel continuously.
- Therefore in the non-persistent CSMA, less number of collisions occur. However it has a drawback of much larger delays.

3. P-persistent CSMA :

- The possibility of such collisions and retransmissions is reduced in the p-persistent CSMA.
- In this scheme all the senders sense the channel continuously until it becomes idle.
- However the waiting stations are not allowed to transmit simultaneously as soon as the channel becomes idle.
- A station is assumed to be transmitting with a probability "p".
- For example if $p = 1/6$ and if 6 stations are waiting then on an average only one station will transmit and others will wait.
- If a station chooses not to send, then it has to wait for a small amount of time and repeat the procedure.
- This version is a tradeoff between the 1-persistent and non-persistent versions of CSMA and has the advantages of better use of the channel and lower delays.
- The P-persistent CSMA is used in Wi-Fi and the lower layer of Zigbee.

4. O-persistent CSMA :

- The O-persistent CSMA is the time scheduled version of CSMA.
- In this scheme there is a central network controller which assigns a fixed transmission order to the nodes and they wait for their turn to transmit their data.
- Thus O-persistent CSMA is based on the TDMA approach.

Note : The biggest disadvantage of CSMA-CA protocol is the high energy consumption of nodes in the network. This is because CSMA-CA never puts the nodes in the sleep mode. Hence the battery on the sensor nodes will be exhausted very soon (typically in one or two hours.

4.12 Comparison of Multiple Access Strategies :

GTU : S-12, W-12, W-13, S-18, W-19

University Questions

Q. 1 Compare CDMA, FDMA and TDMA in terms of concept, key resources, sharing of resources, Bandwidth efficiency, system flexibility and system complexity. **(S-12, 6 Marks)**

Q. 2 Compare TDMA,FDMA and CDMA Technology for cellular systems. **(W-12, 7 Marks)**

Q. 3 Comparison of TDMA and CDMA multiple Access Techniques in detail. **(W-13, 7 Marks)**

Q. 4 Compare TDMA, FDMA and CDMA techniques. **(S-18, 4 Marks)**

Q. 5 Compare FDMA with CDMA technique. **(W-19, 3 Marks)**

Table 4.12.1 : Comparison of Multiple Access Strategies

Sr. No.	Prameter	FDMA	TDMA	CDMA	OFDMA
1.	Concept	Overall band width is shared among many stations.	Time sharing takes place.	Sharing of bandwidth and time both takes place.	It is possible to share both bandwidth and time.
2.	Interference	Due to nonlinearity of transponder amplifiers, inter modulation products are generated due to interference between adjacent channels.	Due to incorrect synchronization there can be an interference between the adjacent time slots.	Both type of interferences will be present.	Interferences are low due to use of orthogonal carriers
3.	Synchronization	Synchronization is not necessary.	Synchronization is essential.	Synchronization is not necessary.	Synchronization is not necessary.
4.	Code word	Code word is not required.	Code word is not required.	Code words are required.	Code word is not required
5.	Guard times and bands	Guard bands between adjacent channels are necessary.	Guard times between adjacent time slots are necessary.	Guard bands and Guard times both are necessary.	Guard bands and Guard times both are necessary.
6.	Hand-over	Hard handover	Soft handover	Soft handover	
7.	Key resources	FDMA allocates a separate frequency slot to each user.	TDMA allows only one user to transmit at any given time.	CDMA allows the use of same carrier frequency and can simultaneously transmit.	OFDMA uses a set of orthogonal sub carriers allotted to different users.
8.	Sharing of resources.	Each user is allocated a unique channel. No other user can share that channel when a call is in progress.	Each user makes use of non-overlapping time slots. The data transmission occurs in bursts.	Each user has its own pseudorandom codeword that is orthogonal to other keywords.	It shows that in OFDMA, each user is given a different subcarrier as well as a time slot
9.	System complexity	Low	Higher	Higher	Very high
10.	System flexibility	Simple and Robust, inflexible	Flexible	Flexible	Flexible.
11.	Application	First generation mobile phones	GSM, IS-36	IS-95	LTE

4.13 NOMA :

- Non-orthogonal multiple access (NOMA) is one of the most promising multiple access techniques in next-generation wireless communications.
- As compared to the orthogonal frequency division multiple access (OFDMA), which is the orthogonal multiple access (OMA) technique, NOMA has the following advantages :
  1. Enhanced spectrum efficiency,
  2. Reduced latency with high reliability, and
  3. Massive connectivity.
- The NOMA system serves multiple users using the same resources in terms of time, frequency, and space domain.

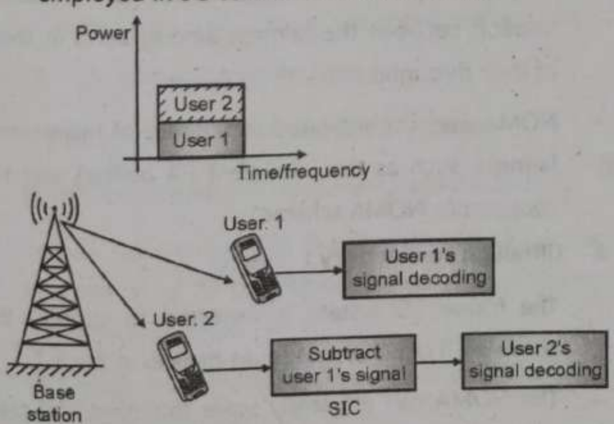
- NOMA can achieve a higher data rate compared to OMA.
- However, the required processing of NOMA can be higher than OMA.
- In recent years, non-orthogonal multiple access (NOMA) schemes have received significant attention for the fifth generation (**5G**) cellular networks.
- This is due to the ability of **NOMA** to serve multiple users using the same time and frequency resources.
- Recent studies demonstrate that NOMA has the potential to used in various 5G communication applications such as, Machine-to-Machine (M2M) communications and the Internet-of-Things (IoT).
- NOMA can accommodate many more users via non-orthogonal resource allocation.

How does NOMA work?

- In NOMA, each user operates in the same band and at the same time where they are distinguished by their power levels.
- NOMA uses superposition coding (SC) at the transmitter such that the successive interference cancellation (SIC) receiver can separate the users both in the uplink and in the downlink channels.
- A **non orthogonal** transmission is not sensitive to errors of synchronization.

Block diagram :

- The block diagram of NOMA is as shown in Fig. 4.13.1 which is a multiple access technique employed in 5G cellular wireless network.



(G-2793) **Fig. 4.13.1: NOMA in downlink**

- The main function of NOMA is to serve multiple UEs (User Equipments) using a single 5G-NB (Node B or Base Station) on same time/frequency resources.
- There are two main techniques employed in NOMA for multiple access :

1. **Power domain :**

- In power domain, NOMA achieves multiplexing based on different power levels.

2. **Code domain :**

- In the code domain, NOMA achieves multiplexing based on different codes.

Transmit side :

- Refer Fig. 4.13.1. A special coding called **superposition coding (SC)** is used in NOMA at the transmitter end.
- NOMA assigns different power levels to different users.
- As shown in Fig. 4.13.1, the base station transmits superposed signals to User-1 and User-2.
- Here, User-2 uses high gain and User-1 uses low gain as shown, in order to successfully receive signals with different power levels.
- Hence, User-2 is known as a strong user while User-1 is known as a weak user.

Receive side:

- At each receiver, NOMA uses **SIC** (Successive interference cancellation) technique to retrieve data.
- On the receiving side, User-2 (strong user) substracts signal of user-1 through SIC and later decodes its own signal.
- Whereas, User-1 (weak user) treats signal of User-2 as noise and decodes its own signal directly as shown in Fig. 4.13.1 .

Type of modulation :

- **5G** technology implements quadrature phase shift keying (QPSK) as the lowest order **modulation** format.
- It has a demerit of providing the slowest data throughput and the advantage of providing the most robust link which can be **used** when signal levels are low or when interference is high.

4.13.1 Classification of NOMA :

- We divide NOMA schemes into two categories :
  1. Power-domain multiplexing and
  2. Code-domain multiplexing.
- Power-domain NOMA attains multiplexing in power domain and code-domain NOMA achieves multiplexing in code domain.
- One way of implementing power-domain NOMA is utilizing superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver.
- SC allows the transmitter to transmit multiple users' information at the same time.
- To decode the superposed information at each receiver, SIC technique can be used.
- The main idea of SIC is that user signals are successively decoded.
- After one user's signal is decoded, it is subtracted from the combined signal before the next user's signal is decoded.

4.13.2 Resource Management in NOMA Networks :

- One of the main challenges in NOMA networks is to attain a compromise between the bandwidth efficiency and the energy efficiency.
- This can be achieved with the help of following resource management techniques :
  1. Intelligent control of the PA of the superimposed signals
  2. Dynamic scheduling of the users for the sub-channels
  3. Forming spatially correlated clusters.

4.13.3 Implementation Challenges of NOMA :

- Although NOMA is a promising candidate for 5G and beyond, there are several implementation challenges to be tackled, such as
  1. Error Propagation in SIC
  2. Channel Estimation Error and Complexity for NOMA
  3. Security Provisioning for NOMA
  4. Maintaining the Sustainability of NOMA With RF Wireless Power Transfer

4.13.4 Performance Enhancement :

- It is possible to improve the performance of NOMA by integrating it with various effective wireless communications techniques, such as cooperative communications, multiple-input multiple-output (MIMO), beam forming, space–time coding, network coding, etc.

4.13.5 Advantages of NOMA :

- By invoking the SC technique, the BS transmits the superposition coded signals of all users.
- Then, the channel gains of the users are sorted in the increasing or decreasing order.
- In the traditional OMA schemes, strongest user benefits from the highest power, which is not always the case for NOMA.
- The NOMA transmission schemes exhibit the following main advantages :

1. High bandwidth efficiency :

- NOMA exhibits a high bandwidth efficiency and hence improves the system's throughput, because it allows multiple users to exploit each resource.

2. Fairness :

- An important feature of NOMA is that it allocates more power to the weak users.
- Therefore, NOMA can guarantee an attractive tradeoff between the fairness among users in terms of their throughput.
- NOMA uses sophisticated techniques of maintaining fairness, such as the intelligent PA policies and the cooperative NOMA scheme.

3. Ultrahigh connectivity :

- The future 5G system is expected to support the connection of billions of smart devices in the IoT.
- The NOMA can efficiently solve this nontrivial task, with the help of its non-orthogonal characteristics.

- The convectional OMA requires the same number of frequency/time RBs as the number of devices.
- However, NOMA is capable of serving them by using less RBs.
- In short, it offers massive connectivity by serving more uses simultaneously.

4. **Compatibility :**

- Due to the mature status of SC and SIC techniques, NOMA can be compatible with the existing multiple access techniques.
- In fact, it can be invoked as an "add-on" technique for any existing OMA techniques.

5. **Flexibility:**

- With an appropriate integration of coding, modulation, and subcarrier allocation, the NOMA systems can yield a low-complexity, high flexibility design.

6. **Lower latency :**

- NOMA offers lower latency due to simultaneous transmission all the time rather than dedicated scheduled time slot.

7. **Higher QoS :**

- It has a better QoS (Quality of Service) to all the users due to its flexible power control algorithms.
- It helps in increasing cell-edge throughput and better user experience at cell-edges.

8. **Enhanced performance :**

- The NOMA along with MIMO (Multiple Input Multiple Output) delivers an enhanced performance.

4.13.6 Drawbacks of NOMA :

- Following are the disadvantages of NOMA:

1. **Higher complexity and low energy efficiency :**

- Each of the users within the cluster need to decode information of all the other users even one having worst channel gains.
- This leads to complexity in the receiver. Moreover energy consumption is higher.

2. **Erroneous detection :**

- If error occurs in single user due to SIC, decoding of all the other users information will be erroneous.
- This limits maximum number of users.

3. **Limit on active number of users :**

- For the power domain concept in NOMA to work properly at the receiver, there should be an adequate channel gain difference between the users.
- This limits effective number of user pairs served by clusters.

4. **Sensitivity to gain information :**

- Each user needs to feedback channel gain information back to Base Station.
- Hence, NOMA performance depends on the correctness of this information.

5. **Higher security threats :**

- Although NOMA technique offers a number of advantages, the enhanced information sensing ability of more users, leads to higher security and privacy threat.

6. **Possibility of interference :**

- Since the principle of NOMA is to allow multiple users to be superimposed on the same resource, this leads to interference for such systems.

4.13.7 Comparison of OMA and NOMA :

Sr. No.	Parameter	NOMA	OMA
1.	Full form	Non-Orthogonal Multiple Access	Orthogonal Multiple Access
2.	Receiver complexity	High	Low
3.	Energy consumption	More	Less
4.	Number of users/cluster	Lower	Higher
5.	Number of user pairs	Less	More
6.	System throughput	Larger	Smaller

Review Questions

Q. 1 Define FDMA.

Q. 2 Explain the principle of FDMA.

Q. 3 What are the disadvantages and advantages of FDMA ?

Q. 4 Define TDMA.

Q. 5 Explain the principle of TDMA.

Q. 6 What are the disadvantages and advantages of TDMA ?

Q. 7 What are the disadvantage of FDMA and TDMA ?

Q. 8 Define CDMA.

Q. 9 Explain the principle of CDMA.

Q. 10 State the advantages of CDMA over FDMA and TDMA.

Q. 11 State the advantages of TDMA over FDMA

Q. 12 Compare FDMA, TDMA and CDMA, OFDMA.

Q. 13 How is SS signal different from the normal one ?

Q. 14 Name various types of SS systems.

Q. 15 Define a PN sequence.

Q. 16 What is meant by a maximum length sequence ?

Q. 17 State the important properties of the maximum length sequence.

Q. 18 What is the BW of spread signal ?

Q. 19 What is the BW of an unspread signal ?

Q. 20 Explain the principle of CSMA.

Q. 21 Write a note on CSMA/CA.

Q. 22 Explain different types of CSMA/CA.

Q. 23 Define NOMA.

Q. 24 Explain the principle of NOMA.

Q. 25 What are the disadvantages and advantages of NOMA ?

□□□

Syllabus : GSM system architecture, Radio interface, Protocols, Localization and calling, Handover, Authentication and security in GSM, GSM speech coding.

Chapter 5

Wireless Systems-GSM

Syllabus

GSM system architecture, Radio interface, Protocols, Localization and calling, Handover, Authentication and security in GSM, GSM speech coding.

Chapter Contents

5.1 Global System for Mobile (GSM) :

Definition :

- The Global System for Mobile Communications **(GSM)** is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices such as mobile phones and tablets.
- Various mobile systems developed over the years are GSM, NA-TDMA, CDMA, PDC etc.
- The only multiple access technique in analog cellular systems is FDMA (frequency division multiple access) but the digital cellular systems can use either TDMA or CDMA for them.
- The long form of **GSM** is global system for mobile communications, it is a digital mobile system and it uses **TDMA** for multiple access.
- We know that in TDMA each user is allowed to use the radio channel only for a fixed duration of time.
- During this time slot, the user is allowed to utilize the entire bandwidth of the channel.
- Therefore the data is transmitted in the form of bursts.
- A European group called CEPT began to develop the GSM-TDMA system in 1982.
- The first GSM system was implemented in Germany in 1992. It was named as D_2.
- GSM is a second generation cellular system standard.
- It was developed in order to solve the fragmentation problems of the first generation cellular systems. GSM is the world's first cellular system to specify the digital modulations.

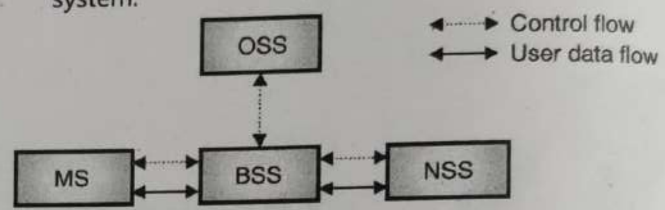
GSM : The European TDMA Digital Cellular Standard :

- Global System for Mobile is world's first cellular system based on digital modulation.
- By the mid-2010s, it achieved over 90% market share, and started operating in over 193 countries.
- The 2G networks were developed as a replacement for first generation (1G) analog cellular networks.
- The GSM standard originally described a digital, circuit-switched network optimized for full duplex voice telephony.
- A GSM system has maximum 200 full duplex channels per cell.
- Each cell has different uplink and downlink frequency.
- It uses a combination of FDM, TDM and slotted ALOHA to handle the channel access.

5.2 GSM System Architecture :

Simplified block diagram :

- Fig. 5.2.1 shows the basic architecture of a GSM system.



(D-895) **Fig. 5.2.1 : GSM architecture**

- It shows that the GSM system consists of many subsystems such as :
  1. Mobile station (MS).
  2. Base station subsystem (BSS).
  3. The network and switching subsystem (NSS).
  4. Operating subsystem (OSS).

Mobile station (MS) :

- This equipment is used to support the connections of the external terminals such as a PC or FAX.

Base station subsystem (BSS) :

- The BSS and MS are connected to each other via a radio interface.
- It is also connected to NSS in the same way. GSM operation is based on the open system inter connection (OSI) model.

Network and switching subsystem (NSS) :

- NSS as shown in Fig. 5.2.3 uses an intelligent network (IN).
- A signaling NSS is one of the main switching function of GSM.

- The primary job of NSS is the management of the communication between GSM users and other communication users.

5.2.1 Detail Architecture of GSM :

GTU : W-13, S-14, S-15, W-15, S-16, W-17, S-18, S-19, W-19

University Questions

Q. 1 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

Q. 2 Draw the architecture of GSM system and explain each block in brief. **(S-14, 7 Marks)**

Q. 3 Give differences between HLR and VLR functions. **(S-15, 7 Marks)**

Q. 4 Draw GSM system architecture and explain it in detail. **(W-15, Marks 7)**

Q. 5 Describe in details GSM architecture with necessary block diagram and its various blocks. **(S-16, 7 Marks)**

Q. 6 With the help of a neat sketch, describe GSM architecture. **(W-17, 7 Marks)**

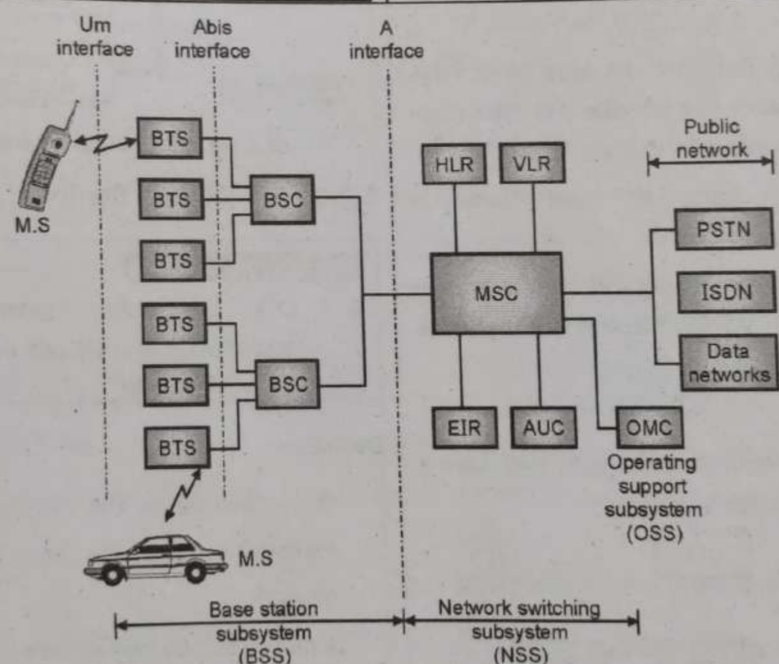
Q. 7 Draw and explain the GSM system architecture. **(S-18, 7 Marks)**

Q. 8 Draw GSM system architecture and explain its working principle in detail. **(S-19, 7 Marks)**

Q. 9 Draw and Explain GSM system architecture. **(W-19, 7 Marks)**

Block diagram :

- The detail architecture of a GSM system is shown in Fig. 5.2.2.
- 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

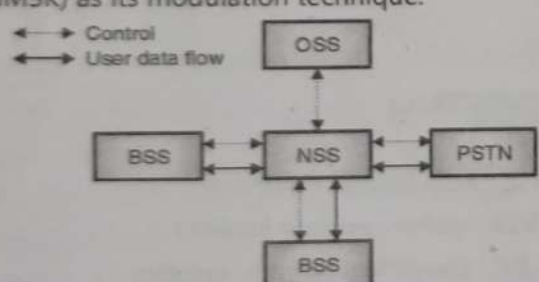
(GT-8) **Fig. 5.2.2 : GSM system architecture**

- 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.

Modulation :

- The GSM uses the Gaussian minimum shift keying (GMSK) as its modulation technique.



(D-896) **Fig. 5.2.3 : NSS external environment**

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.

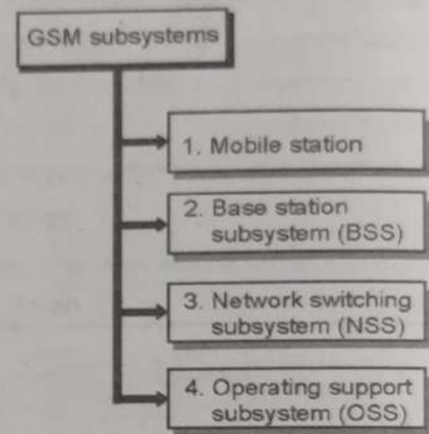
5.2.2 Various Subsystems in GSM :

GTU : W-13

University Questions

Q. 1 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

- Refer Fig. 5.2.4 which shows various subsystems in GSM. We will discuss them in detail in this section.



(GT-6) **Fig. 5.2.4 : Different subsystems in GSM**

5.2.3 MS (Mobile Station) :

GTU : W-13

University Questions

Q. 1 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

Definition :

- MS is defined as the physical mobile handset or equipment used by the subscriber to access the GSM network.
- A mobile station may include :
  1. MT : Mobile Termination
  2. TE : Terminal Equipment
  3. TA : Terminal Adapter.

Types of MS :

- Types of MS are as follows :
  1. Vehicle mounted station
  2. Portable station
  3. Handheld station.

- In practice MS is divided in two parts : a mobile terminal (MT) and a SIM.
- **A mobile terminal** consists of hardware and software.
- It is simply the mobile handset, which manages all the functions related to radio and human interface.
- **SIM (Subscriber Identity Module)** is a small card, plugged into mobile terminal.
- The mobile service providers provides a SIM card for every GSM subscriber. It is microprocessor based entity implemented on smart card.
- MS cannot communicate with any user or network unless it has the SIM card inserted in it.
- MS has various number identities as follows :
  1. IMSI - International Mobile Subscriber Identity
  2. TMSI - Temporary Mobile Subscriber Identity
  3. IMEI - International Mobile Equipment Identity

5.2.4 BSS (Base Station Subsystem) :

GTU : W-13

University Questions

Q. 1 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

Definition :

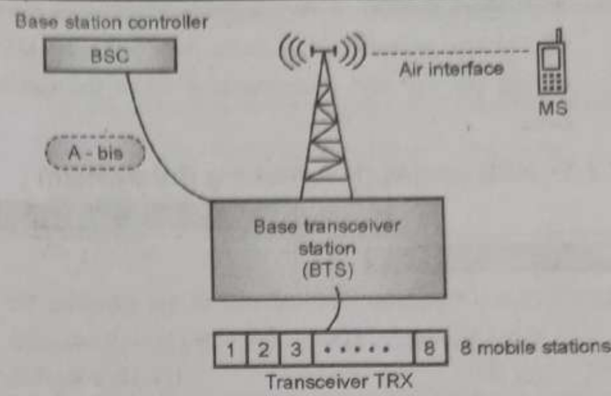
- The BSS or base station subsystem is a GSM subsystem, which manages all the signalling and traffic between MS and NSS.
- BSS is connected to MS and NSS via a radio interface.

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.

Block diagram :

- Fig. 5.2.5 shows the simplified block diagram of the base station subsystem.



(G-2734) **Fig. 5.2.5 : Base station subsystem (BSS)**

- The BSS consists of a BTS (Base Transceiver Station)and a BSC (Base Station Controller).

1. BTS (Base Transceiver Station) :

- As shown in Fig. 5.2.5 a BTS consists of a directional antenna equipment to transmit and receive radio signals.
- The transceiver (TRX) acts as the central unit of the BTS.
- The TRX manages wireless links between up to 8 MSs by using a single pair of frequencies.
- The TRX also an important device called TRAU (Transcoder Rate Adaptation Unit) for encoding and decoding of the speech and rate adaptation function of the data.
- A BSC is connected to and controls multiple BTSs, out of which some are co-located at the BSC and others may be remotely distributed and connected to the BSC through microwave links or dedicated lease lines.

2. BSC (Base Station Controller) :

- A BSC is a high quality switch, which controls hundreds of BTSs simultaneously.
- A BSC controlling two BTSs, itself handles the mobile handovers between them without involving the MSC.
- This reduces burden on the MSC.
- The other function of BSC is to provide cell configuration data and to control of RF power levels in BTSs.
- It also assigns free radio channels in the TRX for the link to the mobile station.

- BSC is also maintains the radio path between MSs during the call and disconnects it when the call is over.

5.2.5 NSS (Network Switching Subsystem) :

GTU : W-12, W-13, S-15, S-20, W-20

University Questions

Q. 1 Briefly Describe the functions of the following for GSM Systems. (1) MSC (2) VLR (3) HLR (4) AUC (5) EIR. **(W-12, 5 Marks)**

Q. 2 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

Q. 3 Give differences between HLR and VLR functions. **(S-15, 7 Marks)**

Q. 4 Draw a neat sketch of GSM architecture and state the functions of the following: BSC, MSC, VLR, HLR, AUC. **(S-20, W-20, 7 Marks)**

- As shown in Fig. 5.2.5 the Base Station Subsystem (BSS) forwards the signals to the Network Switching Subsystem (NSS), which consists of main switching center (MSC), various databases and mobility management units.
- The main unit of NSS is MSC (Mobile Switching Center).
- There are the following five functional entities associated with the MSC :
  1. HLR : Home Location Register
  2. VLR : Visitor Location Register
  3. EIR : Equipment Identity Register
  4. AUC : Authentication Center
  5. GMSC : Gateway MSC
- The function of NSS is to manage the communication between GSM network and users from other networks like PSTN, ISDN, Data networks etc.

Mobile Switching Centre (MSC) :

- MSC (Mobile Switching Center) is the main unit of NSS. 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.

1. HLR (Home Location Register) :

- HLR is the database of permanent subscriber information, which contains important user information like address, account status and preferences.
- The HLR stores the following two types of information :
  1. Subscriber information
  2. Mobile information
- **HLR** performs the following **functions** :
  1. Identification : HLR stores two very important numbers called IMSI and MSISDN (Mobile Station International Subscriber Directory Number), which are used in call routing between MSC and a particular MS. These unique numbers are necessary to identify a particular MS.
  2. Subscriber service provision : HLR also provides information about the offered services such as, teleservices, bearer services or supplementary services.
  3. VLR address : The VLR address is required (which is a temporary data), when MS is roaming. It also provides the cipher keys for encryption and decryption.

2. VLR (Visitor Location Register) :

- VLR database is used to temporarily store the IMSI and customer information for each roaming subscriber.
- Whenever a roaming MS enters the new MSC area it undergoes registration process as follows:

Registration process :

1. VLR identifies that the particular MS belongs to some other MSC area.
2. VLR communicates with HLR in the home network of that MS.
3. VLR constructs the GT (Global Title) from IMSI so as to allow communication between VLR and Home HLR.
4. VLR generates MSRN (Mobile Subscriber Roaming Number) to allow MS to use the current network when in roaming.
5. MSRN is sent to home HLR as well.

- VLR stores the following :
  1. MSRN
  2. TMSI
  3. Home location of the MS
  4. Supplementary services data of MS
  5. MSISDN
  6. IMSI
  7. GT
  8. Local MS identity if used VLR works in association with HLR and AUC.

3. EIR (Equipment Identity Register) :

- It is the database of all the legitimate, and faulty MSs.
- It stores IMEI of every MS, which is provided by the equipment manufacturer.
- Its function is to keep track of all the valid and invalid mobile equipment in the area.

4. AUC :

- AUC is the database that stores the secret authentication keys for each subscriber.
- It also generates security related parameters for protection purposes.
- The same secret key is stored in SIM card.
- The secret key is never transmitted on air for security reasons.
- AUC always works with HLR to carry out authentication successfully.

5. GMSC :

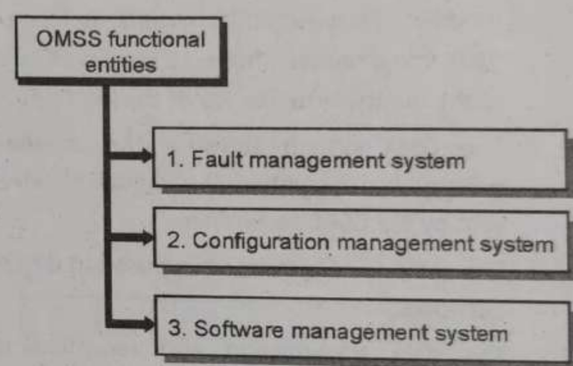
- All the calls to a GSM network are routed through GMSC which first identifies the correct HLR and authenticates it.
- It also communicates with other networks and provides gateway function for external network communication with GSM network.

5.2.6 OMSS : Operation and Maintenance Subsystem : GTU : W-13

University Questions

Q. 1 Draw the block diagram of the reference architecture of GSM and explain the function of each subsystem. **(W-13, 7 Marks)**

- The three functional entities in OMSS are as shown in Fig. 5.2.6.



(GT-5) **Fig. 5.2.6 : Functional entities in OMSS**

- The fault management system invokes alarms from the BSS elements when there is a fault.
- The fault is then resolved either by software or by technicians.
- The function of the Configuration Management is to install and maintain the software of the newly setup BSS network elements.
- It's other functions include management of hardware inventory list and changing operation parameters like frequencies of BTS etc.
- The software management system installs new software or updates and manages the software inventory lists.

5.2.7 Characteristics / Features of GSM Standard :

– Some of the important characteristics/features of GSM standard are as follows :

1. GSM can support more subscribers in the given spectrum.
2. The short messaging service (SMS) is provided by the GSM standard, that allows its subscribers to transmit and receive character text messages.
3. GSM has a subscriber identity module **(SIM)**, which is a memory device that stores all the important information like subscriber's identification number.
4. Each subscriber is allotted a four digit personal ID number that activates service from any GSM phone. The SIMs are smart cards or plug-in modules. Each subscriber needs to insert his SIMs into a mobile phone, to receive GSM calls to the number irrespective of the location.
5. The GSM system provides the **on-the-air privacy** by encrypting the digital bit stream sent by the GSM transmitter.
6. The same GSM phone can be used in different networks.
7. The data transmission and reception rate supported across GSM networks is 9600 bps.
8. GSM also supports FAX transmission and reception at 9.6 kbps.
9. The size of GSM handsets is much smaller.
10. GSM supports the facilities like call forwarding, call on hold, conferencing, Calling Number Identification Presentation (CLIP) and international roaming.
11. GSM is compatible with ISDN , PSTN as well as other telephone company services.

– Following are the two most important GSM features :

1. Subscriber Identity Module (SIM)
2. On air privacy.

1. Subscriber Identity Module (SIM) :

– The SIM card of a GSM phone is nothing but a memory device that stores some very important information like, identification number of the subscriber, the type of network and the countries in which the services can be provided to the subscriber.

– In addition it also stores the unique privacy key for the subscriber for decrypting the encrypted received messages and other important information.

– A SIM is required to activate service for any GSM phone.

– Without a SIM all GSM mobile phone cannot operate.

2. On air privacy :

– On-air privacy is the second important feature of GSM.

– On-air privacy indicates that the GSM system ensures some kind of privacy of the transmitted signal.

– The analog FM cellular system calls can be easily monitored because no on air privacy is provided.

– However the GSM transmitters use encryption to encode the signals before transmitting them which makes them a lot safer and hard to monitor.

Ex. 5.2.1 : Match the following terms with its most appropriate function/use. **W-14, 7 Marks**

Ans. :

Term	Function/use
VLR	Stolen phone numbers
HLR	Network and country codes
EIR	Current location of the subscriber
MSC	Verification of the SIM
IMSI	Identity of an user
SIM	Temporary storage
AuC	Handover

Term	Function/use
VLR	Temporary storage
HLR	Current location of the subscriber
EIR	Stolen phone numbers
MSC	Handover
IMSI	Network and country codes

Term	Function/use
SIM	Identity of an user
AuC	Verification of the SIM

5.3 GSM Radio Interface : GTU : S-15

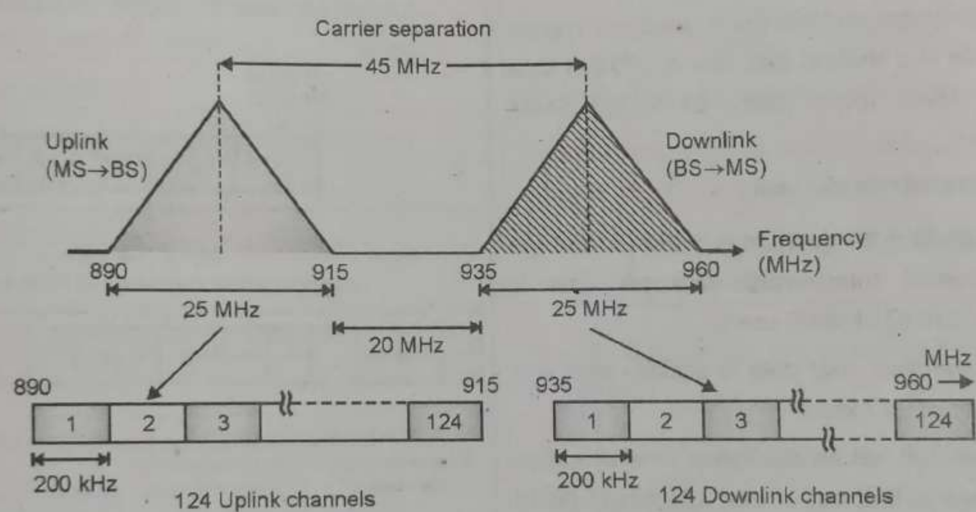
University Questions

Q. 1 How does GSM radio subsystem work? **(S-15, 7 Marks)**

- Radio transmission parameters are the important parameters of the GSM standard, related to the transmission of data or signals.
- They include the frequencies used for forward and reverse transmission, bandwidths, duplexing technique, number of time slots, number of users etc.

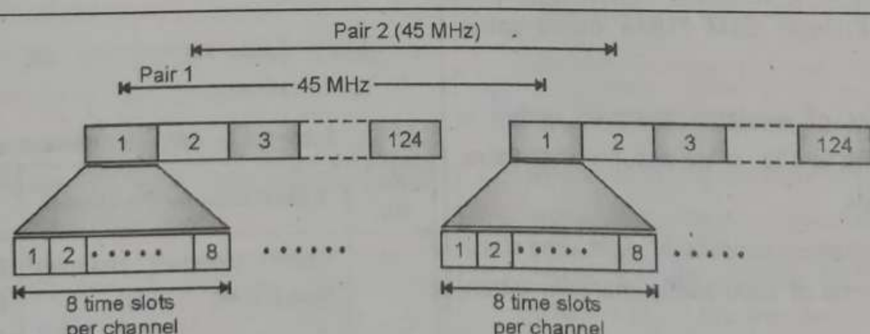
Frequency bands :

- The frequency bands in GSM have been shown in Fig. 5.3.1(a).
- Two bands, one for the **uplink** (reverse link), and the other for **downlink** (forward link), each with a bandwidth of 25 MHz, have been assigned to the GSM system.
- The frequency band assigned for the **uplink** (reverse link), is from 890 MHz to 915 MHz (uplink is transmission by mobile stations to base stations).



(GT-3) **Fig. 5.3.1(a) : GSM frequency bands**

- Fig. 5.3.1(b) shows the spectrum of GSM standard. Time along each carrier is divided into 8 slots as shown in Fig. 5.3.1(b).



(G-2735) **Fig. 5.3.1(b) : Uplink / Downlink channels and time slots in GSM**

- The frequency band assigned for the **downlink** (forward link), is from 935 MHz to 960 MHz (downlink is transmission by base stations to mobile stations).
- These frequency bands are assigned to GSM in Europe and this GSM is known as GSM 900.
- A duplex transmission is realized in a Frequency Division Duplex **(FDD)** mode.

- That means two different sets of frequencies are used for the uplink and downlink.
- The available forward and reverse frequency bands of 25 MHz are divided into 200 kHz wide channels called ARFCNs (Absolute Radio Frequency Channel Numbers).
- Note that 124 × 200 kHz = 24.8 MHz.
- The ARFCN denotes a forward and reverse channel pair which is separated in frequency by 45 MHz and each channel is time shared between as many as eight subscribers using TDMA.
- Each of these eight subscribers uses the same ARFCN and occupies a unique timeslot (TS) per frame.

Channel data rate :

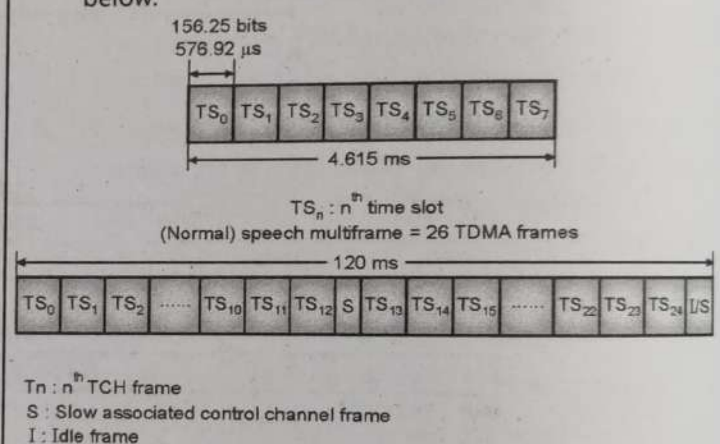
- Radio transmissions on both the forward and reverse link are made at a channel data rate of 270.833 kbps (1625.0/6.0 kbps) using binary BT = 0.3 GMSK modulation.

Channel transmission rate per user :

- Thus, the signaling bit duration is 3.692 μs, and the effective channel transmission rate per user is 33.854 kbps (270.833 kpbs/8 users).
- With GSM overhead, user data is actually sent at a maximum rate of 24.7 kbps.
- Each TS (time slot) has an equivalent time allocation of 156.25 channel bits, but of this, 8.25 bits of guard time and six total start and stop bits are provided to prevent overlap with adjacent time slots.
- Each TS has a time duration of 576.92 ms as shown in Fig. 5.3.2, and a single GSM TDMA frame spans 4.615 ms.
- The total number of available channels within a 25 MHz bandwidth is 125 if we assume that there are no guard bands.
- Since each radio channel consists of eight time slots, there are thus a total of 1000 traffic channels within GSM.
- In practical implementations, a **guard band** of 100 kHz is provided at the upper and lower end of the GSM spectrum, and only 124 channels are implemented.
- Table 5.3.1 summarizes the GSM air interface.

A Physical Channel :

- The combination of a TS number and an ARFCN constitutes a physical channel for both the forward and reverse link.
- Each physical channel in a GSM system can be mapped into different logical channels at different times.
- That is, each specific time slot or frame may be dedicated to either handling traffic data (user data such as speech, facsimile, or teletext data), signaling data (required by the internal workings of the GSM system), or control channel data (from the MSC, base station, or mobile user).
- GSM provides explicit assignments of time slots and frames for specific logical channels, as described below.



(G-2780) **Fig. 5.3.2 : The speech dedicated control channel frame and multiframe structure**

5.3.1 GSM air Interface Specifications :

- Table 5.3.1 summarizes the GSM air interface specifications.

Table 5.3.1 : GSM air interface specifications

Sr. No.	Specification / Parameter	Value
1.	Uplink (reverse channel) frequencies	890-915 MHz (Europe) 1850-1910 MHz (US PCS)
2.	Downlink (forward channel) frequencies	935-960 MHz (Europe) 1930-1990 MHz (US PCS)

Sr. No.	Specification / Parameter	Value
3.	ARFCN number	0 to 124 and 975 to 1023
4.	Transmitter/ receiver frequency spacing	45 MHz
5.	Transmitter/ receiver slot spacing	3 time slots
6.	Frequency spectrum bandwidth	25 MHz
7.	Duplexing	FDD
8.	Multiple access	FDMA/TDMA
9.	Number of full duplex channel	124
10.	ARFCN channel spacing	200 kHz
11.	Number of users per frame	8
12.	Type of modulation	0.3 GMSK
13.	Channel data rate	270.833 kb/s
14.	Frame duration	4.615 mS
15.	Time slot period	576.9 μS
16.	Bit period	3.692 μS
17.	Interleaving (max. delay)	40 ms
18.	Voice coder bit rate	13.4 kbps

Ex. 5.3.1 Select the most appropriate option :

GSM cellular services uses,

(a) FDMA for multiple channel access and FDMA for multiple users

(b) FDMA for multiple channel access and TDMA for multiple users

(c) TDMA for multiple channel access and FDMA for multiple users

(d) TDMA for multiple channel access and TDMA for multiple users **S-12, 2 Marks**

Ans. : (c)

Ex. 5.3.2 : Calculate gross bit rate / user / second, data rate / user / second and gross bit rate / physical channel for GSM system. **S-12, 8 Marks**

Soln. :

- In GSM eight subscribers use the same ARFCN and occupy a unique time slot per frame.

1. Data rate / second :

- Radio transmissions on the forward and reverse link is carried out at a data rate given by,

$$\text{Data rate / second} = \frac{1625.0}{6.0} = 270.833 \text{ kbps} \quad \text{...Ans.}$$

2. Channels transmission rate per user :

- The data rate is 270.833 kbps. Therefore, for eight users, the effective channel transmission rate per user is given by,

$$\text{Channel transmission rate} = \frac{270.833 \text{ kbps}}{8 \text{ users}} = 33.854 \text{ kbps}$$

3. Gross bit rate / user / second :

- The gross bit rate per user per second is given by,

Gross bit rate / user / second

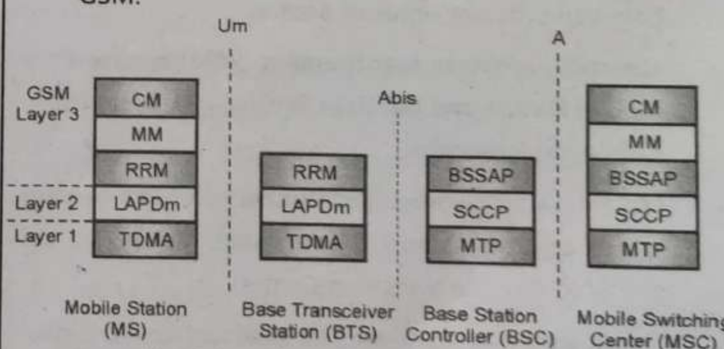
$$= \frac{456 \text{ bits}}{20 \text{ ms}} = 22.8 \text{ kbps} \quad \text{...Ans.}$$

4. Gross bit rate / physical channel :

Gross bit rate/physical channel is equal to 22.8 kbps for full rate and it is equal to 11.4 kbps for half rate . **...Ans.**

5.4 GSM Signalling Protocol Architecture :

- Fig. 5.4.1 shows the signalling Protocol Structure in GSM.



(G-1892) **Fig. 5.4.1 : Signaling protocol structure in GSM**

- In the signalling protocol structure in GSM there are three general layers depending on the interface.
- **Layer 1** is the physical layer. It makes use of the channel structures over the interface.
- **Layer 2** is data link layer. Across the U_m interface (Refer Fig. 5.4.1), the DLL is actually a modified version of the **Link Access Protocol D(LAPD)** used in ISDN.
- It is called as the LAPDm.

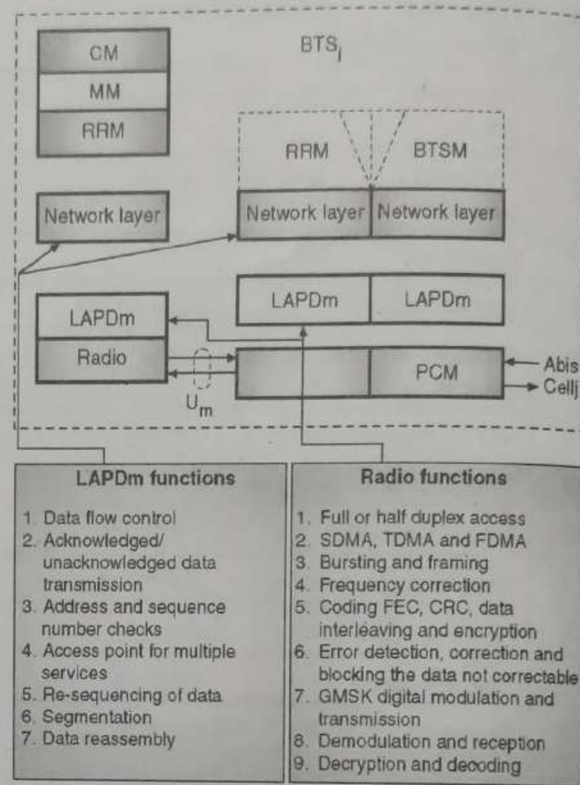
- Across the **A** interface, as shown in Fig. 5.4.1 the message transfer part layer 2 of signal system number 7 (SS7) has been used.
- The air interface of GSM consists of TDMA time slots and FDMA frequency bands.
- LAPDm protocol is used over the air interface between the base station trans-receiver and the mobile device.
- Some additional control information, apart from the actual data is required to be used for transmitting the information to a desired destination.
- It is called as the signalling message.
- The signalling channels are time division multiplexed on an aggregate of the TDM slots.
- Layer-3 of the GSM signalling protocol is divided into the three following sub-layers :
  1. Mobility Management (MM).
  2. Radio Resource Management (RRM) and
  3. Connection Management (CM) for calls routing.
- The layer-3 protocol is used for different purposes of mobility, communication of network resources, code format and call related management messages between different network entities.
- The radio recourse management (RRM) between the Mobile Station and the Base Station Subsystem (BSS), can be implemented.
- Mobility Management and Connection Management is the communication between the Mobile Station and MSC (Mobile Switching Centre).
- The A interface uses an SS7 protocol called Signal Correction Control Protocol (SCCP) that supports communication between the MSC and BSS and the network messages between the individual subscribers and the MSC.

5.4.1 GSM Interfaces :

- As shown in Fig. 5.4.1 there are three different interfaces present in GSM system they are :
  1. Um : Interface between MS and BTS.
  2. Abis : Interface between BTS and BSC.
  3. A : Interface between BSC to MSC.

5.4.2 Mobile Station-Base Transceiver Station Signaling Protocols :

- Fig. 5.4.2 shows the functions and protocol layers between the MS and BTS.



(G-1893) Fig. 5.4.2 : Functions and protocol layers between the MS and BTS

Radio interface / Physical layer :

- Radio (U_m interface) is the physical layer between the Mobile Station (MS) and the Base Transceiver Station (BTS).
- The data link layer is supposed to control the flow of packets sent to and coming from the network layer and provide access to different services.
- LAPDm (Link Access Protocol D-channel modified) is the data link layer protocol, which is located between MS and BTS.
- Refer Fig. 5.4.2 that enlists the functions of LAPDm.
- It does not use any flag for frame delimitation. Instead, the frame delimitation is taken care of by the physical layer that defines the frame boundaries.
- The information carrying field in LAPDm is differentiated field from the fill-in bits (used to fill the transmission frame) with the help of the length indicator.

- A 3-bit Service Access Point Identifier **(SAPI)** used as an address field in LAPDm.
- It can take eight different values from 0 to 7.
- Out of them, SAPI 0 is used for call control, MM and RRM signaling where as SAPI 3 is used for SMS.
- All other fields are reserved for future purpose.

Network Layer Sub layers :

- The network layer has the following three sub layers :
  1. Connection Management (CM)
  2. Mobility Management (MM)
  3. Radio Resource Management (RRM)

1. Connection Management (CM) for calls routing :

- The CM sub layer protocol has been designed to support the following three aspects of a call :
  1. Call establishment,
  2. Call maintenance and
  3. Call termination.
- It also controls and supports the functioning of SMS, supplementary services and DTMF signaling.

2. Mobility Management (MM) :

- This network sub layer has been designed to handle the issues related to mobility management when a mobile station travels from one cell to the other.
- The functions of MM are as follows :
  1. Registration.
  2. Update the location.
  3. Authentication
  4. Identification.
  5. Maintaining a reliable communication with the upper layers.
  6. To use TMSI allocated by VLR in place of IMSI at HLR.

3. Radio Resource Management (RRM) :

- This network sub layer is supposed to handle the following issues in setting up point-to-point communication between a mobile device and network: establishment, maintenance and release of RRM connection.
- RRM is used for data and user signaling.
- This sub layer carries out procedures such as, selection, reselection, and the hand off process.
- When RRM is established, it handles the reception of BCCH and CCCH as well.
- A mobile station always initiates the RRM session, either in response to a paging message or in order to make a call .
- The functions of RRM are as follows :
  1. To manage the quality of radio link.
  2. Assignment of frequency.
  3. It provides options for frequency hopping sequence.
  4. Measurements of signal strength.
  5. To manage the handover process.
  6. RRM session management.
  7. To manage synchronization.

5.4.3 Abis Interface / Base Transceiver Station (BTS)-Base Station Controller (BSC) Signaling Protocols :

- The interface between the BTS and BSC that carries out the traffic and maintenance data is the known as the **Abis interface** which is standardized for GSM systems.
- A wired network such as PSTN, ISDN, PSPDN etc. is used to connect the BTS and BSC.
- The voice signal is encoded into the 64 kbps PCM format in a PSTN network.
- The same format is also used by the Abis interface.
- PCM coding techniques are different from 22.8 kbps. TCH radio interface U_m (between MS and BTS). Therefore a translation between the coding formats is essential.
- This is done by translating the TCH bits received from caller mobile station (MS) to 64 kbps PCM and then from PCM to TCH for receiver MS.
- The voice quality gets affected due to the translation and retranslation.
- Therefore, a procedure called **TFO (tandem free operation)** is adopted, to improve the voice quality at the BTSs, BSCs and MSCs.

- The data link layer protocol for the Abis interface between the BTS and BSC is **LAPD (link access protocol D channel)** which prescribes the standard procedure for D-channel of ISDN.
- The network layer protocol between the BTS and BSC is called as BTSM (BTS management).

5.4.4 A Interface / Base Station Controller (BSC) – Mobile Switching Centre (MSC) Signaling Protocols :

- The physical layer between the BSC and MSC uses PCM multiplexing.
- The MSC is connected to the networks such as PSTN, ISDN and other data networks that use either 64 kbps PCM or 2.048 Mbps CCITT that carries 32 PCM channels.
- The interface between BSC and MSC is the A interface.
- The type of communication between BSCs and MSCs is wired communication.
- MTP (message transfer protocol) and SCCP (signal correction control protocol) are the two data link layer protocols between the BSC and MSC.
- Both of them are parts of SS7 (Signaling System No. 7) used by A interface.
- The network layer protocol that is used at BSC is BSSAP (Base Sub System Application Protocol).

5.5 Signalling System - 7 (SS7) :

- The common-channel signaling is more flexible and powerful than in channel signaling.
- Hence it is suitable for integrated digital networks. One of the most widely used scheme is signaling system 7 or SS7.
- SS7 has been designed to be an open ended common channel signaling standard which can be used over a variety of digital switched networks.
- Furthermore the SS7 is specifically designed to be used in ISDN.
- SS7 provides an internationally standardized, general purpose common channel signaling system.

5.5.1 Primary Characteristics of SS7 :

- Some of the important primary characteristics of SS7 are as follows :
  1. It is optimized for use in digital telecommunication networks along with control exchanges that utilize 64 kbps digital channels.
  2. It is designed to satisfy the present and future requirements of information transfer for call control, remote control, management and maintenance.
  3. It is designed for transfer of information reliably, in a correct sequence ensuring that there is no loss or duplication of information.
  4. It is suitable for operation over analog channels and at speeds below 64 kbps.
  5. It is suitable for point to point terrestrial and satellite links.

5.5.2 Functions of SS7 :

- It covers all the aspects of control signaling for digital networks.
- To facilitate the routing of control messages in a reliable manner.
- To deliver the control messages.

5.5.3 Features of SS7 :

- In SS7 the control messages are routed through the network for different functions such as setup, maintenance management, termination etc.
- These messages are short blocks or packets. So although the network being controlled is a circuit switched network, the control signaling is implemented using the packet switching technology.
- The mode used is associated channel mode but the use of disassociated mode is also possible.

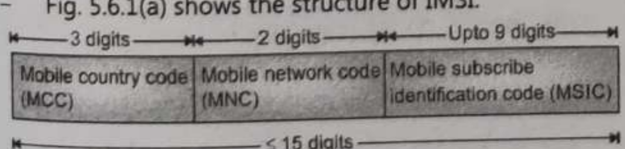
5.6 Identifiers and Addresses used in GSM :

- GSM treats the users and the equipment in different ways.
- Phone numbers, subscribers, and equipment identifiers are some of the known ones.

- There are many other identifiers that have been well-defined, which are required for the subscriber's mobility management and for addressing the remaining network elements.
- Vital addresses and identifiers that are used in GSM are as follows
  1. IMSI (International Mobile Subscriber Identity)
  2. MSIN (Mobile Subscriber Identification Number)
  3. MSRN (Mobile Station Roaming Number) :
  4. Subscriber Identity Module (SIM)
  5. Mobile System ISDN (MSISDN)
  6. LAI (Location Area Identity)
  7. MS Roaming Number (MSRN)
  8. TMSI [Temporary Mobile Subscriber Identity]

5.6.1 IMSI (International Mobile Subscriber Identity) :

- It uniquely identifies the MS. It is used as the key to search any data in the databases from VLR, HLR and GSN.
- IMSI is usually fifteen digit or less unique number.
- Every registered user has an original International Mobile Subscriber Identity IMSI with a valid IMEI.
- When an MS try to make a call, it needs to contact a BS. If BS identifies the MS as a valid subscriber then only it can provide service to MS.
- For this purpose the MS stores certain uniquely defined values like the country of subscription, network type, subscriber ID etc.
- These stored values are known as the International Mobile Subscriber Identity (IMSI).
- Fig. 5.6.1(a) shows the structure of IMSI.



(OT-25)Fig. 5.6.1(a) : Structure of IMSI

- As shown in Fig. 5.6.1(a), the first three digits indicates the mobile country code, the next two digits indicates the mobile network provider code, and the remaining digits (up to 9) indicates the mobile subscriber identification code (MSIC) (i. e. customer ID number).
- To find information about the subscriber's home Public Land Mobile Network (PLMN), IMSI is used.
- All such information is located on the SIM card.

5.6.2 MSIN (Mobile Subscriber Identification Number) :

- It is an identification number of the subscriber in the home network.

5.6.3 MSRN (Mobile Station Roaming Number) :

- Mobile Station Roaming Number MSRN is an temporary location dependent ISDN number, assigned to a mobile station by a regionally responsible Visitor Location Register VLR.
- Using MSRN, the incoming calls are channeled to the MS.

5.6.4 Subscriber Identity Module (SIM) :

- The SIM card of a GSM phone is nothing but a memory device that stores some very important information like, identification number of the subscriber, the type of network and the countries in which the services can be provided to the subscriber.
- In addition it also stores the unique privacy key for the subscriber for decrypting the encrypted received messages and other important information.
- A SIM is required to activate service for any GSM phone.
- Without a SIM all GSM mobile phone cannot operate.

5.6.5 Mobile System ISDN (MSISDN) :

- It is an authentic telephone number of the Subscriber Identity Module (SIM) card displayed on mobile or cellular phones.
- A MSISDN is a subscription in the Global System for Mobile Communications (GSM) or Universal Mobile Telecommunications System (UMTS) networks.

- Based on the SIM card, a mobile station can have many MSISDNs.
- Each subscriber is assigned with a separate MSISDN to their SIM.
- MSISDN number that identifies a subscriber of particular MS's. Fig. 5.6.1(b) shows the structure of MSISDN.
- The GSM actually does not identify a particular mobile phone, but a particular HLR.
- It is the responsibility of the HLR to contact the mobile phone.

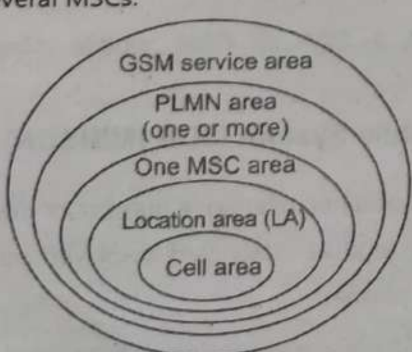
1 to 3 digits	Variable	Variable
Mobile country code (MCC)	National destination code (NDC)	Subscribe number (SN)
≤ 15 digits		

(OT-26)**Fig. 5.6.1(b) : Structure of MSISDN**

- As shown in Fig. 5.6.1(b), the first three digits indicates the mobile country code, the next field is variable that indicates the national destination code (NDC), and the last variable filed indicates the subscriber number.

5.6.6 LAI (Location Area Identity) :

- Within a PLMN, a Location Area identifies its own authentic Location Area Identity LAI.
- The LAI hierarchy is based on international standard.
- The GSM service area is generally divided into a hierarchical structure as shown in Fig. 5.6.1(c) that makes possible the system to access any MS quickly.
- As shown in Fig. 5.6.1(c), each PLMN area is divided into several MSCs.



(OT-24)**Fig. 5.6.1(c) : GSM system hierarchy**

- Each MSC typically contains a VLR.
- The function of VLR is to inform the system if a particular cell phone is roaming.
- If a particular cell phone is roaming, the VLR present in the MSC of a particular cell phone reflects the fact.
- Each MSC is subdivided into many Location Areas (LAs). An LA is a cell or a group of cells.
- LA is useful when the MS is roaming in a different cell but in the same Location area.
- The identifier must include the country code, the mobile network code, and the LA code because any LA has to be identified as a part of the hierarchical structure.

5.6.7 IMSEI (International MS Equipment Identity) / IMEI (International Mobile Equipment Identity) :

- IMEI is a 15 or 17-digit code that uniquely identifies mobile handsets.
- The International Mobile Station Equipment Identity (IMEI) is similar to a serial number which distinctively identifies a mobile station internationally.
- This is allocated by the device manufacturer and registered by the network operator.
- By using IMEI number one can recognize outdated, stolen, or non-functional equipment.
- Each 15-bit long International MS Equipment Identity (IMSEI) number to includes manufacturing Information as shown in Fig. 5.6.1(d).

3 digits	1 or 2 digits	Upto 9 digits
Type approval code (TAC)	Final assembly code (FAC)	Serial number (SN)
≤ 15 digits		

(OT-27)**Fig. 5.6.1(d) : Structure of IMSEI**

- The mobile phone equipment is assigned a type approval code when it passes the interoperability tests.
- As a single mobile phone unit cannot be manufactured at the same place, the final assembly code
- (FAC) field in IMSEI identifies the final assembly place of the mobile phone unit.

- A serial Number (SN) is assigned in order to identify a unit manufactured.
- An extra digit is available to allow additional assignment depending on the requirements.

5.6.8 MS Roaming Number (MSRN) :

- When an MS roam from one MSC into other MSC, that mobile unit has to be identified based on the numbering scheme format used in that MSC.
- To identify that unit, the MS is given a temporary roaming number known MS Roaming Number (MSRN).
- Fig. 5.6.1(e) shows the format of MSRN. HLR stores this MSRN.
- An incoming call to that MS is rerouted to the cell where the MS is currently placed.

1 to 3 digits	Variable	Variable
Mobile country code (MCC)	National destination code (NDC)	Subscribe number (SN)
≤ 15 digits		

(OT-28) **Fig. 5.6.1(e) : Structure of MSRN**

- It consists of three digits of mobile country code, National Destination Code (NDC) and subscriber number.

5.6.9 TMSI [Temporary Mobile Subscriber Identity] :

- The Temporary Mobile Subscriber Identity (TMSI) is most common identity sent between the mobile and a network.
- The moment mobile is switched on, the VLR randomly assigns TMSI to each mobile in the area.
- Whenever the mobile moves to a new geographical area, TMSI has to be updated every time because the TMSI number is local to a location area.
- In order to avoid the subscriber from being identified, and tracked by eavesdroppers on the radio interface, the network can change the TMSI of the mobile at any time.
- TMSI is used in paging a mobile. "Paging" is the one-to-one communication between the base station and the mobile.
- The Size of TMSI is **4 octet** with all hex digits, it can't be all FF because, to indicate that no valid TMSI is available the SIM uses 4 octets with all bits equal to 1.

5.7 GSM Channels : GTU : S-18

University Questions

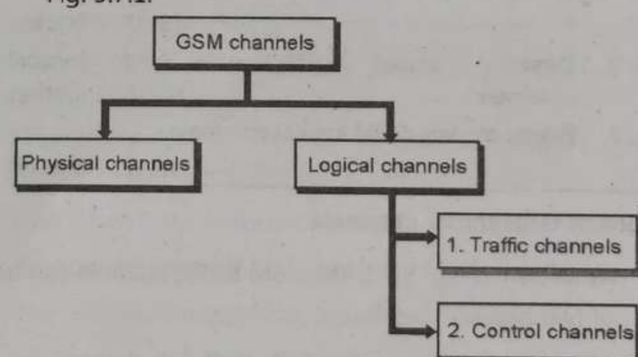
Q. 1 Give the classification of GSM channels. **(S-18, 3 Marks)**

- The GSM channels are classified into two types as follows :

  1. Physical channels and 2. Logical channels.
- The combination of a time slot and ARFCN constitutes a physical channel for both forward and reverse links in GSM.
- Each of these physical channels can be mapped into different logical channels at different times.
- That means we can dedicate each time slot or frame to handle either the traffic data(such as voice, fax or teletext data) or signaling data or control channel data (originated by either MSC, BS or MS)as per requirement.

Classification of GSM Channels :

- The classification of GSM channels is as shown in Fig. 5.7.1.



(GT-28) **Fig. 5.7.1 : Classification of GSM channels**

5.8 GSM Logical Channel :

GTU : S-15, S-16, W-17

University Questions

Q. 1 Briefly explain GSM logical channels. **(S-15, 7 Marks)**

Q. 2 Describe various GSM logical and physical channels **(S-16, 7 Marks)**

Q. 3 Briefly explain GSM logical channels. **(W-17, 7 Marks)**

Types of GSM Logical Channels :

- As shown in Fig. 5.8.1 the GSM logical channels are of two types :
  1. GSM traffic channels (TCHs)
  2. GSM Control channels (CCHs).
- The traffic channels **(TCHs)** are supposed to carry speech or data signals that are encoded into digital form.
- Their functions and formats on forward as well as reverse links are the same.
- The base station uses the control channels to communicate the signaling and synchronization commands to the mobile station.
- The control channels **(CCH)** defined for the forward links and those defined for the reverse links are entirely different.
- The traffic channels can be further classified into six different types whereas control channel can be of more than six types.

5.8.1 GSM Traffic Channels (TCHs) :

GTU : S-15, S-16, W-17

University Questions

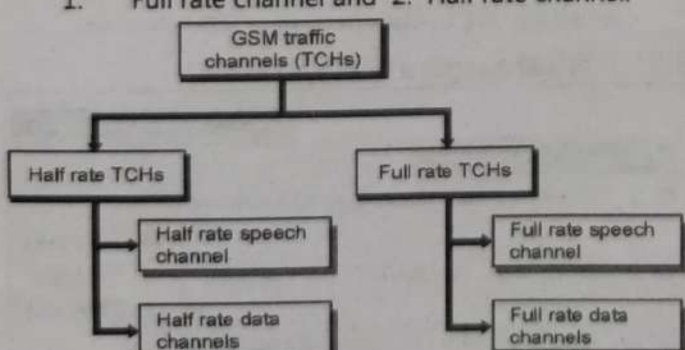
Q. 1 Briefly explain GSM logical channels. **(S-15, 7 Marks)**

Q. 2 Describe various GSM logical and physical channels **(S-16, 7 Marks)**

Q. 3 Briefly explain GSM logical channels. **(W-17, 7 Marks)**

Types of GSM traffic channels :

- As shown in Fig. 5.8.1, the GSM traffic channel can be of two types :
  1. Full rate channel and 2. Half rate channel.



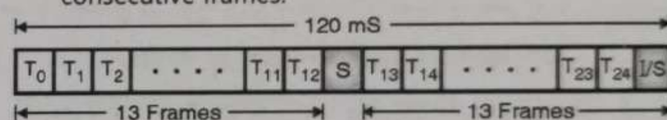
(GT-29) **Fig. 5.8.1 : Types of GSM traffic channels**

Function :

- The traffic channels (TCHs) are supposed to carry speech or data signals that are encoded into digital form.
- Their functions and formats on forward as well as reverse links are the same.
- If used as a **full rate** channel, the user data would occupy one TS (time slot) per frame.
- But if used as a **half rate** channel, the user data would occupy the same TS (time slot) but it is sent in the alternate frames.
- So two half rate channel users share the same time slot but transmitted during the alternate frames.
- Frames of TCH data are broken up after every thirteenth frame and either a slow associated control channel data or idle frames are transmitted.

Multi-frame structure :

- Fig. 5.8.2 shows how the TCH data is transmitted in consecutive frames.



S = Slow associated control channel frame

I = Idle frame

(G-1212) **Fig. 5.8.2 : Multi-frame structure**

- T_0, T_1 .... T_{24} are the TDMA frames. A group of 26 consecutive TDMA frames is called as a **multi-frame** and it is as shown in Fig. 5.8.2.
- The multiframe is also called as the **speech multi-frame**.
- Every fourteenth frame is an **"S" frame** i.e. slow associated control channel frame (SACCH) and twenty eight frame is an **idle frame (I).**
- This frame contains idle bits for the full rate TCH and it contains the SACCH data for half rate TCH.

Full Rate TCH :

- The full rate TCH are expected to support the following full rate speech and data channels :
  1. Full rate speech channel (TCH/FS).
  2. Full rate data channel for 9600 bps (TCH/F 9.6).
  3. Full rate data channel for 4800 bps (TCH/F 4.8).
  4. Full rate data channel for 2400 bps (TCH/ F 2.4).

Half Rate TCH :

- The half rate TCH are expected to support the following half rate speech and data channels :
  1. Half rate speech channel (TCH/HS).
  2. Half rate data channel for 4800 bps (TCH/ H 4.8).
  3. Half rate data channel for 2400 bps (TCH/ H 2.4).

5.8.2 GSM Control Channels (CCH) :

GTU : S-15, S-16, W-17

University Questions

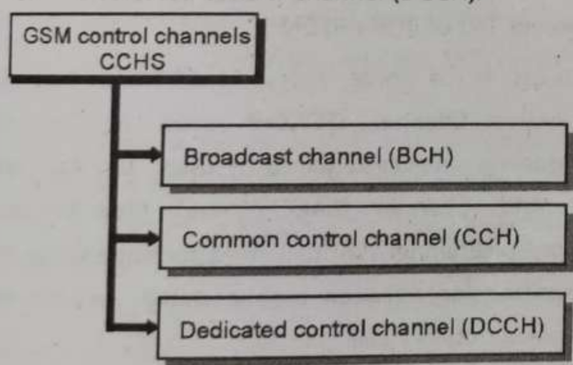
Q. 1 Briefly explain GSM logical channels. **(S-15, 7 Marks)**

Q. 2 Describe various GSM logical and physical channels **(S-16, 7 Marks)**

Q. 3 Briefly explain GSM logical channels. **(W-17, 7 Marks)**

Types of GSM control channels :

- As shown in Fig. 5.8.3, there are three main control channels in GSM :
  1. Broadcast channel (BCH)
  2. Common control channel (CCCH)
  3. Dedicated control channel (DCCH).

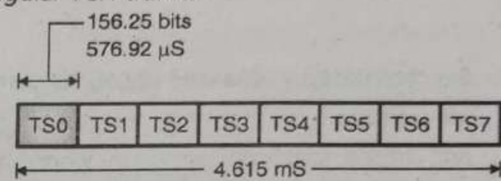


(GT-27) **Fig. 5.8.3 : Types of GSM control channels**

- GSM specification defines 34 standard broadcast channels.

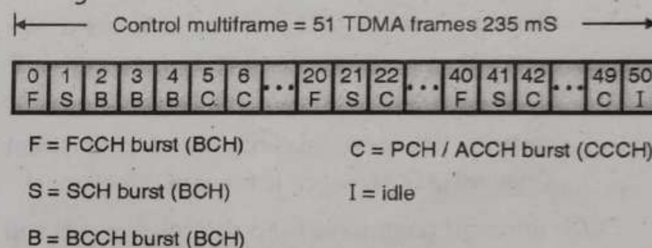
Function :

- The control channels (CCH) defined for the forward links and those defined for the reverse links are entirely different.
- Each control channel is made of many logical channels.
- They are separated in time in order to provide the necessary GSM control functions.
- The BCH and CCCH forward control channels can occupy only the TS0 channel as shown in Fig. 5.8.4.
- These channels are transmitted only during certain frames during a repetitive sequence of 51 frames.
- Such a sequence is called as **control channel multiframe.**
- The TS1 to TS7 channels in Fig. 5.8.4 can carry the regular TCH traffic.

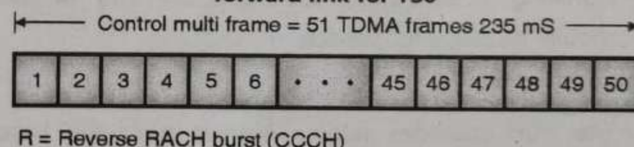


(G-1213) **Fig. 5.8.4**

- The control channel multiframe is as shown in Fig. 5.8.5.



(G-1214(a)) **Fig.5.8.5(a) : The control channel multiframe forward link for TS0**



(G-1214(b)) **Fig. 5.8.5(b) : The control channel multiframe reverse link for TS0**

- The first thirty-four ARFCNs (Absolute Radio Frequency Channel Numbers) have been defined by the GSM as the standard broadcast channels.
- The 51st frame of each broadcast channel does not contain any BCH/CCCH forward channel data.
- Therefore it is considered as an idle frame.
- But the reverse channel CCCH can use the TS0 of any frame to receive subscribers transmissions.
- Even the idle frames can be used for this purpose.
- However DCCH data can be sent during any time slot and any frame, of all the frames that are dedicated only to contain DCCH transmissions.

Broadcast channel (BCH) :

- BCH consists of three different channels :
  1. **Broadcast Control Channel (BCCH)** which is forward link channel used for transmission of information which controls the network, a particular cell and the neighboring cells.
  2. **Frequency Correction Channel (FCCH)** allows mobile station to synchronize its local oscillator's frequency with the exact of the base station
  3. **Synchronization Channel (SCH)** is used for identification of the base transceiver station and frame synchronization, in whose service area the mobile station is situated.

Common Control Channel (CCCH) :

- CCCH consists of three different channels :
  1. Paging Channel (PCH) which is forward link channel.
  2. Random Access Channel (RACH) which is reverse link channel and 3. Access Grant Channel (AGCH) which is forward link channel.
- CCCH are most commonly used control channels and are used to page specific subscribers, assign signaling channels to specific users and receive mobile requests for service.

Paging Channel (PCH) :

- The PCH provides paging signals from the base station to all mobiles in the cell, and notifies a specific mobile of an incoming call which originates from the PSTN.
- The PCH transmits the IMSI of the target subscriber along with a request for acknowledgement from the mobile unit on the RACH.
- PCH may be used to provide cell broadcast ASII text message to all subscribers as part of the SMS feature of GSM.

Random Access Channel (RACH) :

- It is a reverse link channel used by subscriber to acknowledge the page from PCH, and also used by mobiles to originate a call.
- The RACH uses ALOHA access scheme. At the BTS every frame will accept RACH transmission from mobiles during TS0.
- In establishing service the GSM base station must respond to the RACH transmission by allocating a channel and assigning a standalone dedicated control channel for signaling during a call.
- This connection is confirmed by the base station over AGCH.

Access Grant Channel (AGCH) :

- The AGCH is used by the base station to provide forward link communication to the mobile and carries data which instructs the mobile to operate in a particular physical channel with particular dedicated control channel.
- It is the final CCCH message sent by the base station before a subscriber is moved off the control channel.
- It is used by the base station to respond to a RACH sent by a mobile station in a previous CCCH frame.

Dedicated Control Channel (DCCH) :

- There are three DCCH in GSM and they are bidirectional and have same format and function on both forward and reverse links.
- DCCH can exist in any time slot and on any ARFCN except TS0 of BCH ARFCN.
- DCCH is of three types Stand-alone Dedicated Control Channel (SDCCH) used for providing signaling services required by users, fast-Associated control Channel (FACCH) and Slow-Associated Control Channel (SACCH) used for supervisory data transmission between mobile station and the base station during a call.

5.9 Frame Structure of GSM System :

GTU : W-14, S-15, W-17

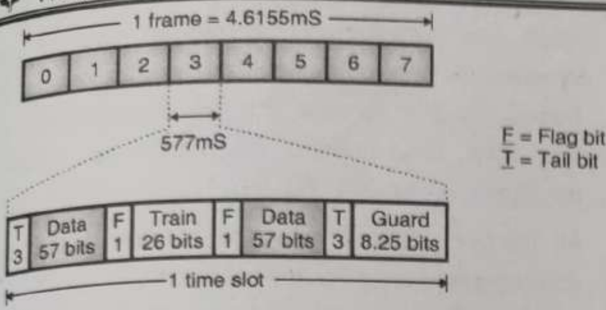
University Questions

Q. 1 Determine frame efficiency of a TDMA frame structure used in GSM system. **(W-14, 7 Marks)**

Q. 2 With the help of timing parameters, explain frame structure for GSM. **(S-15, 7 Marks)**

Q. 3 Draw frame structure for GSM. **(W-17, 3 Marks)**

- Fig. 5.9.1 shows the frame structure of the GSM system.



(G-1215) **Fig. 5.9.1 : Frame structure of GSM system**

- As there are eight such time slots in one frame, the time duration of each frame is given by,

  1 frame $= 8 \times 577\ \mu s = 4.6155$ ms

- Where one time slot corresponds to 577 μsec.
- Fig. 5.9.1 also shows the internal organization of each time slot.
- It consists of flag bits (F), tail bits (T), training interval for equalizer (train bits), data bits and guard time interval.
- The 1-bit flag is always at the beginning of each data burst of 57 bits.
- The three tail-bits are all logical zeros are used in the convolutional decoding of the channel encoded data bits.
- The data bit bursts are of 57 bit length and there are two such data bit bursts per time slot as shown in Fig. 5.9.1.
- The training sequence of 26 bits at the center of each time slot is used for channel equalization.
- The guard time of 8.25 bits has been included at the end of each time slot in order to avoid overlapping of the data bits sent over the adjacent time slots.

Total bits per slot :

- Thus the number of bits corresponding to each time slot can be calculated as follows :

  $(57 \times 2 + 8.25 + 3 \times 2 + 2) = 156.25$ bits.

Overhead bits :

- Out of these 156.25 bits, the number of data bits is only 114.
- Excluding the two flag bits, the remaining bits will be 40.25 which do not carry any information are called as the overhead bits.

Frame efficiency :

- Hence the frame efficiency of GSM is given by,

$$\eta_F = \left(1 - \frac{\text{O.H.bits}}{\text{Total bits}}\right) \times 100$$

$$\eta_F = \left(1 - \frac{40.25}{156.25}\right) \times 100 = 74.24\ \%$$

Ex. 5.9.1 : If a normal GSM time slot consists of 6 trailing bits, 8.25 guard bits, 26 training bits and two traffic bursts of 58 bits of data. Find the frame efficiency. **W-15, 7 Marks**

Soln. :

Given : GSM, trailing bits = 6, guard bits = 8.25

Training bits = 26, two traffic bursts of 56 bits

To find : Frame efficiency.

1. **Total bits per time slot :**

- Total bits per time slots is,

$$b_T = 6 + 8.25 + 26 + (2 \times 56)$$

$$\therefore b_T = 156.25 \text{ bits.}$$

2. **Number of bits per frame :**

- Each GSM frame has eight time slots.

$\therefore$ Number of bits / frame $= 8 \times b_T$

$$\therefore \quad b_F = 8 \times 156.25 = 1250 \text{ bits}$$

3. **Number of overhead bits per frame :**

O.H. bits per time slot $= 6 + 8.25 + 26 = 40.25$

$\therefore$ O.H. bits per frame, $b_{OH} = 8 \times 40.25 = 322$ bits.

4. **Frame efficiency :**

$$\eta_f = \left[1 - \frac{b_{OH}}{b_T}\right] \times 100$$

$$\therefore \eta_f = \left[1 - \frac{322}{1250}\right] \times 100 = 74.24\ \% \quad \text{...Ans.}$$

Ex. 5.9.2 : If GSM uses a frame structure where each frame consists of 8 time slots and each time slot contains 156.25 bits and data is transmitted at 270.833 kbps in the channel find:

1. The time duration of a bit.
2. The time duration of a slot.
3. The time duration of a frame.
4. How long must a user occupying a single time slot wait between two successive transmissions. **W-15, 7 Marks**

Soln. :

Given : GSM frame, 8 time slots.

Bits/TS = 156.25, Data rate = 270.833 kbps

1. Time duration of a bit :

- Data rate = 270.833 kbps i.e. 270.833 kbits are transmitted per second.

$$\therefore \text{ Duration of one bit} = \frac{1}{270.833 \times 10^{-3}}$$

$$= 3.6923\ \mu s \qquad \text{...Ans.}$$

2. Time duration of a slot :

$$\text{Time duration of a slot} = 156.25 \times 3.6923 \times 10^{-6}$$

$$= 567.92\ \mu s \qquad \text{...Ans.}$$

3. Duration of a frame :

$$\text{Duration of a frame} = 8 \times \text{slot duration}$$

$$= 8 \times 567.92\ \mu s$$

$$= 4.615 \text{ ms} \qquad \text{...Ans.}$$

4. Waiting time :

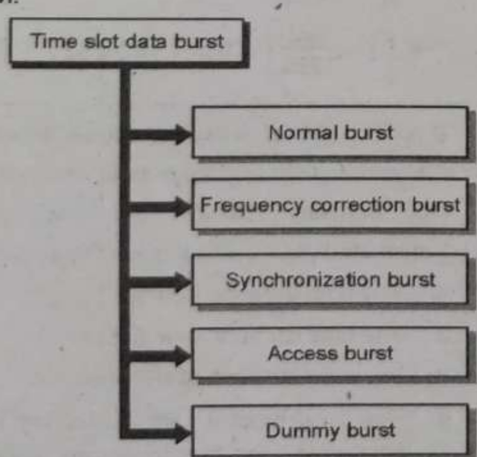
- A user occupying a single TS will have to wait for a duration of seven time slots between two successive transmission.

$$\therefore \text{ Waiting time} = 7 \times 567.92\ \mu s$$

$$= 3.975 \text{ ms} \qquad \text{...Ans.}$$

5.10 GSM Burst Structures :

- Burst is defined as a specific type of data packet.
- Each user transmits a specific type of data packet called as burst during the time slot assigned to it.
- As shown in Fig. 5.10.1, there are five types of data bursts used for various traffic and control bursts in GSM.



(G-2633) Fig. 5.10.1 : GSM burst structures

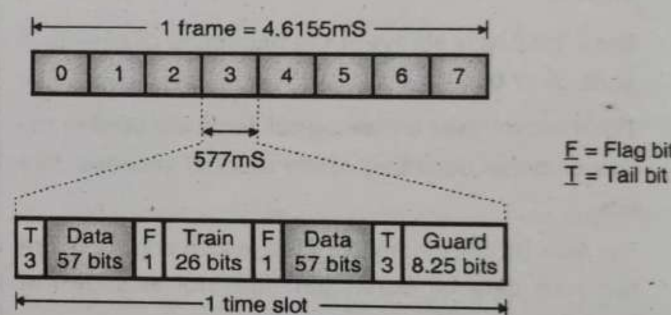
- The first type of burst, called **normal bursts** are used for TCH and DCCH transmissions, on both forward and reverse links.
- Next the **frequency correction** burst and **synchronization** burst are used in TS0 of specific frames, on the forward link, for broadcasting the frequency and time synchronization control messages, as shown in Fig. 5.10.1.
- All mobile stations use the **Access burst** for accessing services from any base station.
- The **dummy burst** is used as filler information(to fill up), for the unused time slots on the forward link.

5.10.1 Normal Burst / Frame Structure of GSM System : GTU : S-12

University Questions

Q. 1 Draw frame format for a normal burst in GSM. **(S-12, 3 Marks)**

- Fig. 5.10.2(a) shows the frame structure of the GSM system.



(G-1215) Fig. 5.10.2(a) : Normal burst structure / Frame structure of GSM system

- As there are eight such time slots in one frame, the time duration of each frame is given by,

$$1 \text{ frame} = 8 \times 577\ \mu s = 4.6155 \text{ ms}$$

Where one time slot corresponds to 577 μsec.

- Fig. 5.10.2(a) also shows the internal organization of each time slot.
- It consists of flag bits (F), tail bits (T), training interval for equalizer (train bits), data bits and guard time interval.
- The 1-bit flag is always at the beginning of each 57 bit information field that carries the data burst in the encrypted form.
- The three tail-bits (T), which are all logical zeros are used in the convolutional decoding of the channel encoded data bits.

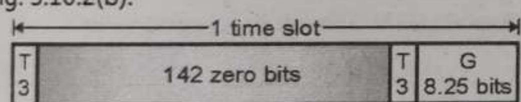
- There are two data bit bursts each of 57 bit length per time slot as shown in Fig. 5.10.2(a).
- The train field at the center of the slot holds a sequence of 26 bits, which is used for channel equalization.
- The guard time of 8.25 bits has been included at the end of each time slot in order to avoid overlapping of the data bits sent over the adjacent time slots.
- The number of bits corresponding to each time slot can be calculated as follows :

  $(57 \times 2 + 8.25 + 3 \times 2 + 2) = 156.25$ bits.
- Out of these 156.25 bits, the number of data bits is only 114 (i.e. 57×2).
- Excluding the two fag bits, the remaining bits will be 40.25 which do not carry any information are called as the overhead bits.
- Hence the frame efficiency of GSM is given by,

$$\eta = \left(1 - \frac{40.25}{156.25}\right) \times 100 = 74.24 \%$$

5.10.2 Frequency Correction Burst :

- Frequency correction burst is as shown in Fig. 5.10.2(b).

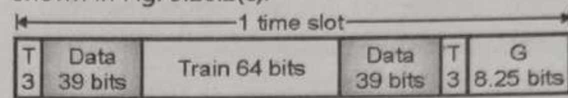


(G-2634) Fig. 5.10.2(b) : Frequency correction burst

- It consists of three zero tail bits T at the start and end of the burst, 142 zero bits between the tail bits and the guard time interval (G).
- This burst format is used only in the FCCH channel.
- The GSM system uses GMSK modulation.
- When this string of 142 zero bits is applied to the modulators, it produces an unmodulated sinusoidal output shifted by 1625/24 kHz with respect to the carrier frequency.
- With the frequency correction channel, this sinusoid helps in the identification of the broadcast carrier.
- This results in the carrier frequency tuning of the mobile station, which allows reception of the other broadcast channels.
- This sinusoid helps to identify the broadcast carrier with the frequency correction channel realized on it.
- Due to this, the mobile station carrier frequency is tuned, allowing for reception of the other broadcast channels.

5.10.3 Synchronization Burst :

- The structure of the synchronization burst is as shown in Fig. 5.10.2(c).

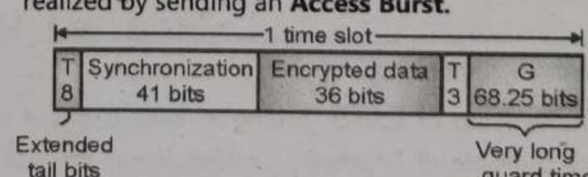


(G-2635) Fig. 5.10.2(c) : Synchronization Burst

- It consists of three tail bits (T) at the beginning and end of the burst, the training sequence of 64 bits at the center of time slot, two fields of 39 encoded data bits on both sides of the training sequence, two flag bits and guard time interval (G).
- In the process of data detection the training sequence is applied to obtain the samples of the channel impulse response.
- These samples are used for data detection.
- As compared to the normal burst a longer training sequence (64 bits) is used in the synchronization burst.
- This would allow more precise estimation of a channel and more reliable data detection.
- Two 39-bit data sequences used in the burst are there for identification of color code (0 - 7) of the base station and the PLMN (Public Land Mobile Network).
- This identifies the network operator to which a user is assigned.
- The data bits are also useful for the synchronization within the time hierarchy of the GSM system.

5.10.4 Access Burst :

- Access burst is as shown in Fig. 5.10.2(d). A system access request issued by the mobile station is realized by sending an **Access Burst.**



(G-2637) Fig. 5.10.2(d) : Access burst

- It is shorter than any other burst used in the system.
- As shown, it consists of eight tail bits(T)at the start and three tail bits (T) at the end of the burst, 41 synchronization bits, 36 bits of encrypted data and extended guard time interval (G) of 68.25 bits.
- To identify the properties of a channel and synchronization of the base station receiver, 41-bit synchronization sequence is required.
- When a mobile station sends an RACH message and it receives an AGCH reply, neither mobile station nor the Base Transceiver Station knows about the timing-advance information.
- Due to this reason, the actual message is relatively short and has an extended guard band (G) in order to make sure that there will be no overlap with the next burst.
- The access bursts can be transmitted by several mobile stations in the same time slot.
- In such a case, collisions can occur and non of the bursts can be accepted.
- After a pseudorandom number of frames, the mobile station tries to send another access burst.

5.10.5 Dummy Burst :

- Dummy burst is as shown in Fig. 5.10.2(e). Note that it is similar to the normal burst but it does not carry any user data information.
- Dummy bursts are placed in the time slots, which are currently idle and not assigned to any user.
- This carrier should have higher mean power than any other carrier applied within the same cell, due to which, this carrier is recognized by the mobile stations which attempt to activate themselves in the system after switching on their power.
- Thus dummy burst is a type of signal stuffing which keeps the mean power of the broadcast channel high enough.
- The base station sends the dummy burst on the base channel.
- As soon as the mobile station is turned on, it can easily discover the base channel.
- In order to avoid the confusion with frequency correction burst the pseudo-random bit sequence is used.

1 time slot

T 3	Mixed 58 bits	Train 26	Mixed 58bits	T 3	G 8.25 bits

(G-2636) **Fig. 5.4.2(e) : Dummy burst**

5.11 Signal Processing in GSM :

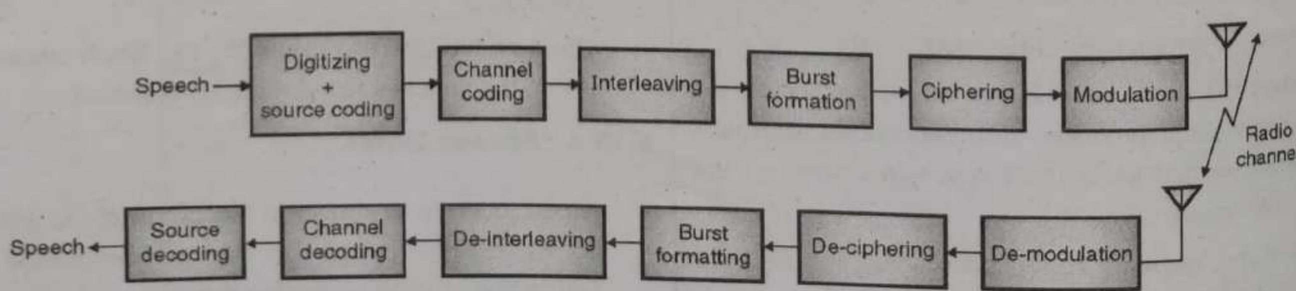
GTU : W-12

University Questions

Q. 1 Explain GSM Speech Processing in Brief. **(W-12, 4 Marks)**

Block diagram :

- Refer Fig. 5.11.1 which shows the block diagram, to understand all GSM operations from transmitter to receiver.



(G-1216) **Fig. 5.11.1 : GSM signal processing**

1. Speech coding :

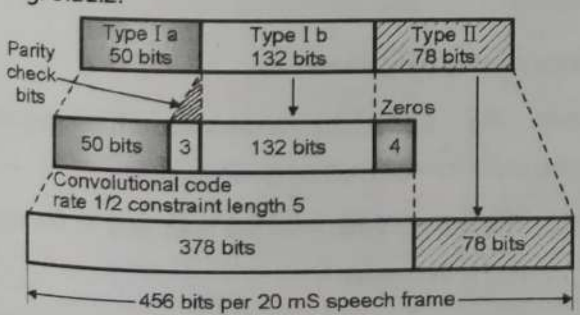
- The working of speech coding in GSM is based on the principle of Residually Excided Linear Predictive Coder (RELP) which uses a Long Term Predictor (LTP).
- The operation of GSM speech coder makes use of a very interesting fact that, each person speaks for about 40% of the total conversation time in a normal conversation,

- Therefore GSM works in the discontinuous transmission mode (DTX) by using a voice activity detector (VAD).
- Due to DTX mode the battery life increases and reduces the radio interference.
- However there is a disadvantage of the DSX mode of operation, called as switched muting.
- The annoying effect of switched muting due to DTX, is reduced by using a comfort noise subsystem (CNS) at the receiving end.
- The length of each speech block is 20 ms. The speech coder provides 260 bits for each speech block.
- Thus 260 bits correspond to 20 ms. Therefore number of bits per second will be equal to :

  $260/(20 \times 10 - 3) = 13{,}000$ bits or 13 kbps.

2. TCH / FS, SACCH and FACCH channel coding :

- The output bits of a speech coder, are arranged into groups, so as to facilitate the error protection.
- Such a grouping is performed on the basis of significance of these bits in contributing to speech quality.
- Out of the total 260 bits in a frame, the most significant 50 bits grouped together to form a group.
- These bits are called as I a bits. Then three parity check bits are added to them. This makes a group of 53 bits.
- The parity check bits are used to detect those errors that cannot be corrected at the receiver.
- These first 53 bits and the next 132 bits are taken and four zeros are appended to them as shown in Fig. 5.11.2.



(G-1217) **Fig. 5.11.2 : Error protection for speech signals in GSM**

- This makes a data block of 189 bits which is then encoded into a sequence of 378 bit for error protection.
- No error protection is provided to the remaining least significant 78 bit from the 260 bits.
- These 78 bits are concatenated to the existing sequence as shown in Fig. 5.11.2.
- Thus the total number of bits per block will be (378 + 78 = 456) a 20 ms frame.

3. Channel coding for data channels :

- The channel coding used for GSM full rate data channels (TCH / F 9.6) is meant to handle 60 bits of user data at 5 ms intervals.

4. Channel coding for control channels :

- The length of GSM control channel messages is 184 bits.
- They are encoded using the **fire codes**.

5. Interleaving :

- The bits travelling from transmitter to receiver, sometimes have to face a problem called fading.
- In order to avoid or minimize the effect of fading on all the 456 bits in a block simultaneously, the speech frame or control frame are divided in eight equal length sub-blocks each containing 57 bits.
- These eight sub blocks are placed one each, over eight consecutive TCH time slots.
- This arrangement ensures that, even if a few bits are lost due to fading, it is possible to use the remaining bits to reconstruct the speech, without a significant loss of information.

6. Ciphering :

- Ciphering is a process of modifying the contents of the eight inter-leaved blocks with the help of some encryption technique.
- The security can be improved further by modifying the encryption algorithm for every call.
- GSM uses two different types of ciphering algorithms called A3 and A5.
- Out of which, A3 prevents the unauthorized network access and A5 ensures the privacy of radio transmission.

7. Modulation :

- The modulation scheme used by GSM is the 0.3 GMSK.

– Here the number 0.3 indicates the 3 dB bandwidth of the Gaussian pulse shaping filter in relation with the bit rate.

8. **Equalization :**

– Equalization process is carried out at the receiver and the type of equalizer for GSM is not specified.

– The selection of equalizer is manufacturer's choice.

9. **Demodulation :**

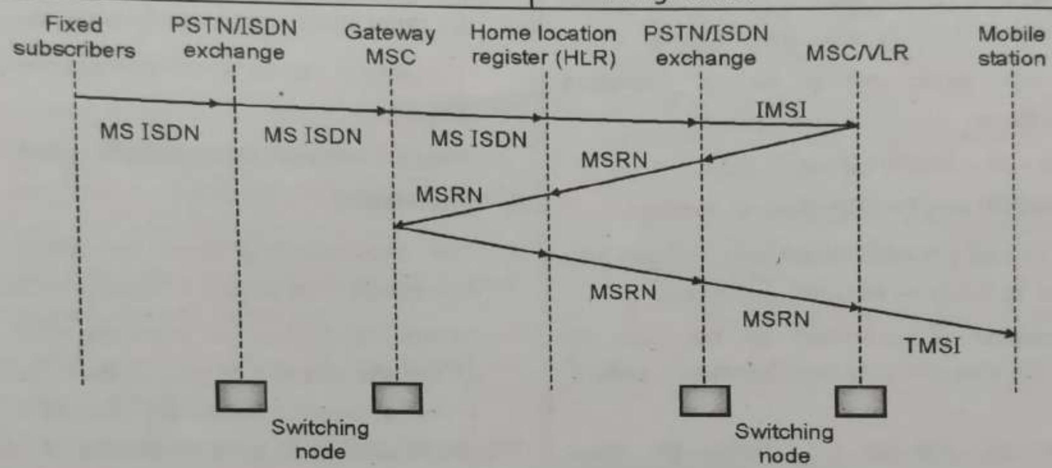
– The receiver carries out the demodulation of the received signal with the help of synchronizer.

– The processes such as deciphering, de-interleaving, channel decoding and speech decoding are carried out after demodulation.

5.11.1 An Example of Call Routing :

– Let us take an example to study the sequence of operation when a fixed network subscriber places a call to a GSM network user.

– Thus a landline originates a call to a mobile user. The call routing procedure for such call has been shown in Fig. 5.11.3.



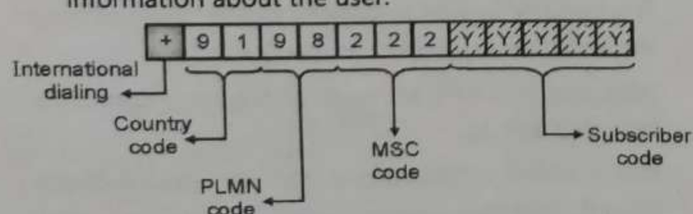
(O-1431) **Fig. 5.11.3 : Call routing process for a call**

MS ISDN :

– Let the number dialed by the fixed subscriber be +9198222YYYYY

– The directory number that is dialed to establish a call with mobile user is called as Mobile Subscriber ISDN **(MS ISDN).**

– As shown in Fig. 5.11.4 this number consists of the country code, the national destination code and the information about the user.



(O-1432) **Fig. 5.11.4 : Concept of MS ISDN**

– The + prefix indicated international dialing. The next two digit code represents the country code.

– For example +91 is the country code for India.

– The next two digits i.e. 98 represent the Public Land Mobile Network (PLMN) number.

– The next three digits represent the MSC code i.e. 222 in Fig. 5.11.4.

– The last five digits YYYYY represent the subscriber number.

Stepwise routing procedure :

– Refer Fig. 5.11.3 to understand the stepwise procedure for call routing given below :

Step 1 : The call is routed from the fixed user to the local PSTN exchange.

Step 2 : The local PSTN exchange searches its routing table to recognize that the call must be to be routed to a mobile network. Hence, it routes the call to MSC of the mobile network.

Step 3 : The MSC of mobile network sends an enquiry to the HLR for understanding the status of the subscriber. Based on the conditions listed below, the GMSC can make a decision of whether to route a call or not.

1. If the called mobile phone is switched off, a message can be played or recorded in the users voice mail.
2. If the mobile user has his subscription charges and bill pending, a message can be played and the call may not routed.

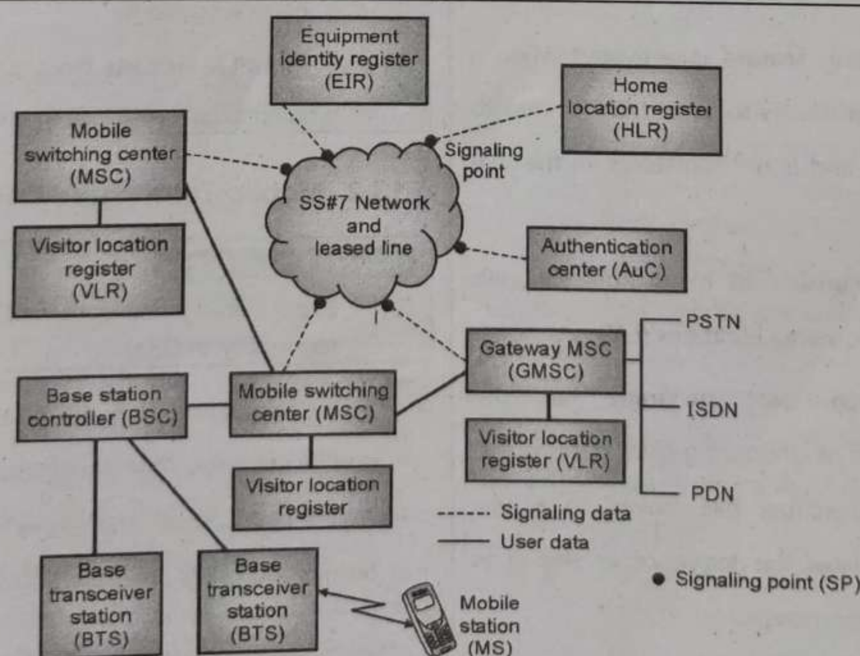
Step 4 : If all the conditions for routing the call are satisfied, then the MSC sends a request to VLR to determine the VLR the location of called mobile phone.

Step 5: If the VLR is the home network, then it will find the Location Area (LA) of the mobile subscriber and will page and determine the location of the phone within the Location Area.

Step 6 : If the VLR has a different PLMN (Public Land Mobile Network), then it will route the call to foreign PLMN through the GMSC (gateway MSC) to the mobile subscriber.

5.12 PLMN Interfaces :

- The administrative region in GSM is called as **PLMN** (Public Land Mobile Network). Fig. 5.12.1 show its configuration.
- The GSM PLMN configuration consists of a central HLR and a central VLR.
- The HLR contains all the necessary information about the subscriber, while the VLR stores the necessary information about data and location of the mobile.
- The MSC needs all the information about the subscriber for establishing a successful call.
- The transmission rate within the switching and management system is 2 MB/s.
- It is known as E1 interface in Europe and India and it can be accomplished with the help of leased links or microwave links.
- The information related to the call between network nodes is processed by the signaling protocol SS7 with the help of ISDN userport **(ISUP).**
- The signaling protocol called **MAP** (Mobile Application Part) is used over the SS7 network to process the mobile specific data.
- The functions of MAP are as follows :
  1. To handle the database transactions such as updates, enquiries, services etc.
  2. To handle the handover/roaming between the MSCs.
- As shown in Fig. 5.12.1, every MSC uses three registers, called **SP** (Signaling Point) as shown in Fig. 5.12.1.



(O-1430) **Fig. 5.12.1 : GSM PLMN configuration**

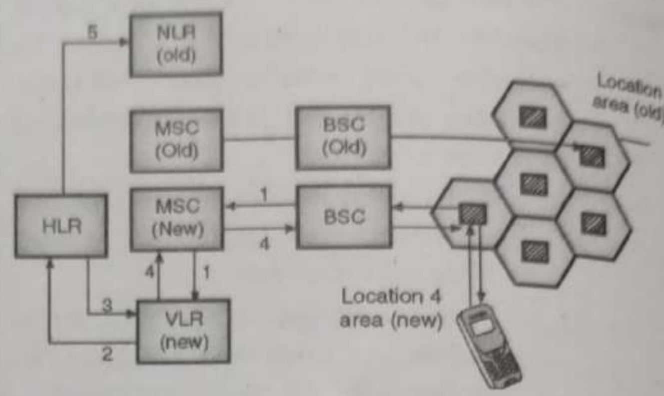
- We can address them with a unique code called as Signaling Point Code **(SPC)**.
- BSSAP (Base Station System Application Part) is the signaling protocol used between the BSS (Base Station System) and MSC (Mobile Switching Centre) over the SS7 network.
- However SS7 is not used within BSS or at the air interface in GSM.

5.13 Calling in GSM :

- In this section we will discuss the following call flow sequences related to GSM :
  1. Registration / Location updating
  2. Mobile terminated call
  3. Mobile originated call

5.13.1 Location Updating :

- In order to receive the incoming calls from a mobile station that moves within and outside the service area, the home network should somehow keep a track of the location of all the active mobile stations.
- The location updating feature is activated when a mobile station either moves to other MSC or tries to access the network and is not registered in the VLR of that location.
- Each service area consists of many adjacent cells recognized by location area identities (LAI).
- The mobile station (MS) generally has the information from the neighbouring base stations and if it sees that a subscriber has moved to a new location then it initiates the sequence as shown in Fig. 5.13.1 and following steps.



(G-1773) **Fig. 5.13.1 : Location updating in GSM**

Location Updating Procedure :

Step 1 : When a new location is identified, the mobile station (MS) sends a request for location update to the new VLR via the BSC and MSC.

Step 2 : The location update message is sent to the HLR from the VLR. This message consists of the address of the VLR (new) and the IMSI of the MS.

Step 3 : The security and service related information for the MS is transferred to the new VLR.

Step 4 : An acknowledgement message is sent to the mobile station as soon as the location update is done successfully.

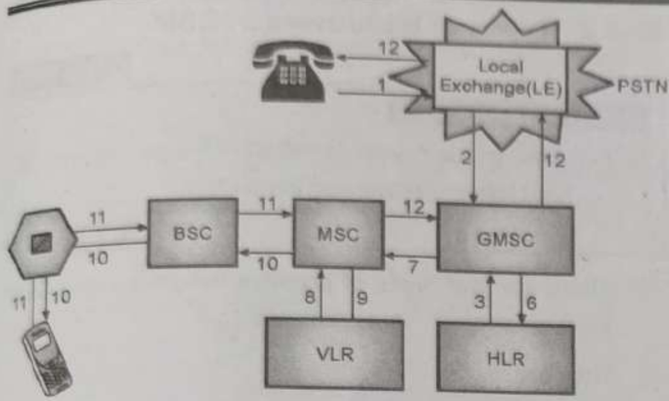
Step 5 : The HLR instructs the old VLR to delete all the information related to the relocated MS.

5.13.2 Mobile Terminated Call : GTU : S-18

University Questions

Q. 1 Explain the process of call origination and call termination in GSM. **(S-18, 7 Marks)**

- A call originating from PSTN and terminating on a mobile station is called as the mobile terminated call.
- Fig. 5.13.2 shows the steps in which a mobile terminated call is processed by GSM.



(G-1774) **Fig. 5.13.2 : Mobile terminated call in GSM**

Step 1 : The call originating landline user dials the Mobile Station ISDN of the mobile user (called party) in GSM.

Step 2 : The Local Exchange sends the call to the GMSC of the called GSM subscriber.

Step 3 : The GMSC searches the HLR for the GSM to obtain the desired routing number.

Step 4 : The HLR requests the current VLR of the called MS to obtain a Mobile station Roaming Number so as to rout the call to the correct MSC.

Step 5 : The current VLR sends the mobile station roaming number to the HLR.

Step 6 : The HLR sends the mobile station roaming number to the GMSC.

Step 7 : The GMSC transfers the call to the MSC by using the MS roaming number.

Step 8 : The MSC enquires about the Location Area Identity (LAI) of the mobile station subscriber to the VLR.

Step 9 : The VLR passes the LAI of the mobile station subscriber to the MSC.

Step 10 : The MSC sends a pager message to the Mobile Station subscriber through BSC. The Mobile Station then sets up the required signaling links.

Step 11 : After establishing the signaling links, the BSC informs the MSC about the same and the call is delivered to the mobile station subscriber.

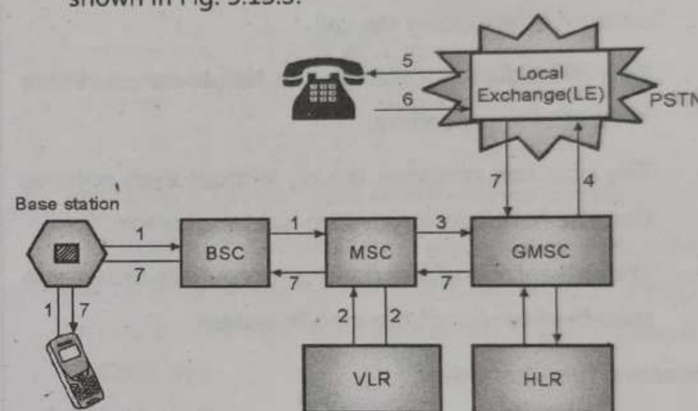
Step 12 : The connection to the calling landline is completed after the mobile subscriber answers the call.

5.13.3 Mobile Originated Call : GTU : S-18

University Questions

Q. 1 Explain the process of call origination and call termination in GSM. **(S-18, 7 Marks)**

- This type of call is originated by a mobile subscriber and it is meant for a landline user.
- First the calling mobile subscriber enters the phone number to be called on the mobile and presses the send key.
- Then the mobile station connects the correct signaling links to the BSC.
- After that the call is processed by following the steps shown in Fig. 5.13.3.



(G-1775) **Fig. 5.13.3 : Originating mobile call in GSM**

Step 1 : The mobile station passes on the dialled number to the MSC via BSC to indicate that it needs service.

Step 2 : The VLR tells the MSC if the mobile station can access the requested service or not. If the MS can access the requested service, then the MSC instructs the BSC to assign the resources required for the call.

Step 3 : The allowed call is then routed to GMSC via MSC.

Step 4 : The GMSC then routes the call to the Local Exchange (LE) of called landline subscriber.

Step 5 : The LE then gives a ring on the called landline terminal.

Step 6 : The landline terminal returns an answer back tone to the LE.

Step 7 : The answer back tone is sent back to the Mobile Station thus completing the call.

5.14 GSM Handoff or Handover :

GTU : S-16

University Questions

Q. 1 What is hand over in GSM? Give comparison of hard hand over and soft hand Over.

(S-16, 7 Marks)

- 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 handover.
- The system will switch the call to a new cell site without interrupting the call.
- This procedure is called as the **handover** procedure or handover procedure.
- The user can continue talking without even noticing that the handover procedure has taken place.
- The advantage of handover procedure is increase in the effectiveness of the mobile system.

Reasons for a handover :

- The two most important reasons for handovers are as follows :
  1. A MS (Mobile Station) moves out of range of a BTS.
  2. If the wired infrastructure decides that the traffic in one particular cell is too high than that in some other cells.

5.14.1 Handover in GSM :

- We have already discussed the concept and need of handover in cellular systems.
- With reduction in the size of a cell, the number of handovers increases.
- However a handover is not supposed to cause a cut-off (also called as a **call drop**).
- The maximum duration for a handover in GSM has been decided to be equal to 60 mS.

5.14.2 Types of Handovers in GSM :

GTU : S-16

University Questions

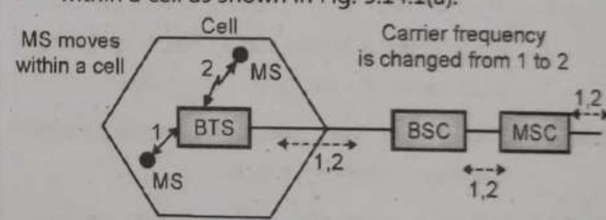
Q. 1 What is hand over in GSM? Give comparison of hard hand over and soft hand Over.

(S-16, 7 Marks)

- There are four types of possible handovers in a GSM system.
- They are :
  1. Intra-cell handover.
  2. Inter cell, Intra BSC handover.
  3. Inter-BSC, Intra-MSC handover.
  4. Inter MSC handover.
- All these have been demonstrated in Fig. 5.14.1.

1. Intra-cell handover :

- The intracell handover happens when a mobile station(MS) moves from one place to the other within a cell as shown in Fig. 5.14.1(a).

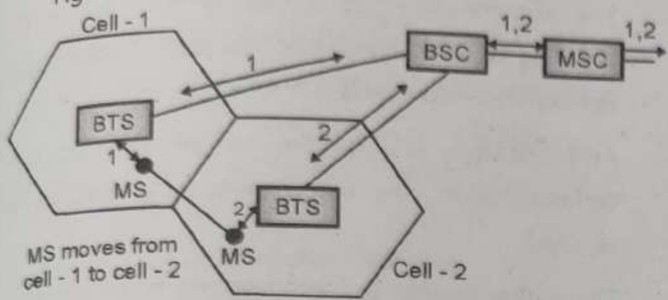


(GT-33) Fig. 5.14.1(a) : The intracell handover in GSM

- If a narrow band interference makes transmission at a certain frequency impossible, then the BSC can decide to change the carrier frequency.
- This will lead to the intra-cell handover.
- As shown in Fig. 5.14.1(a), the MS is operating on channel 1 when it is in its original position.
- When it moves within the cell to a new position, it is impossible to operate at this frequency due to interferences.
- Therefore the BSC changes its carrier frequency to 2 to reduce the interference.
- Thus the intracell handover procedure is performed either to optimize the traffic load in the cell or to improve the quality of a connection by changing the carrier frequency.

2. **Inter-cell, Intra BSC handover :**

- The intercell intra BSC handover has been shown in Fig. 5.14.1(b).

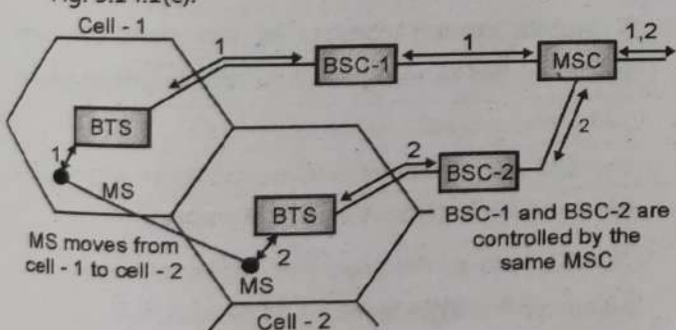


(GT-34) **Fig. 5.14.1(b) : Intercell intra-BSC handover in GSM**

- This type of handover takes place when a mobile station (MS), moves from one cell to the other (cell-1 to cell-2) but remains under control of the same BSC.
- The BSC will carry out the handover by assigning a new radio channel in the new cell to the MS and then release the old one.
- In Fig. 5.14.1(b) the MS is operating on channel-1 when it is in cell-1.
- As it moves to cell-2, the BSC will assign a new channel i.e. channel-2 to it when it enters into cell-2.

3. **Inter BSC, Intra-MSC handover :**

- The inter BSC intra MSC handover has been shown in Fig. 5.14.1(c).

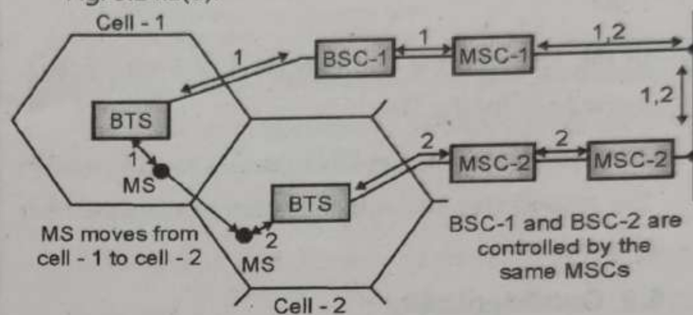


(GT-35) **Fig. 5.14.1(c) : Inter-BSC intra-MSC handover in GSM**

- This type of handover takes place when a mobile station (MS), moves from one cell to the other (cell-1 to cell-2) controlled by different BSCs but same MSC.
- Such a handover is controlled by the MSC. The MSC will carry out the handover by assigning a new radio channel in the new cell to the MS and then release the old one.
- In Fig. 5.14.1(c) the MS is operating on channel-1 when it is in cell-1.
- As it moves to cell-2, the MSC will assign a new channel i.e. channel-2 to it when it enters into cell-2.

4. **Inter-MSC handover :**

- The inter MSC handover has been shown in Fig. 5.14.1(d).



(GT-36) **Fig. 5.14.1(d) : Inter MSC handover in GSM**

- This type of handover takes place when a mobile station (MS), moves from one cell to the other (cell-1 to cell-2) controlled by different BSCs and different MSCs as well.
- Such a handover is performed by two MSCs together.
- This type of handover sets particularly high requirements on the cellular network.

5.15 Security in GSM :

- In the second generation digital cellular systems like GSM, the provision of security is relatively easy as compared to the first generation analog systems.
- It is possible to use the methods like encryption, scrambling, FEC etc. to ensure security in the system.
- GSM offers different security services with the help of the personal information stored in AuC and in the SIM.

Types of security services :

- GSM offers the following security services :
  1. Access control and authentication.
  2. Confidentiality.
  3. Anonymity.

5.15.1 Access Control and Authentication :

Definition :

- Authentication is the process of ensuring that the communication over the wireless radio medium is secured.
- The authentication of a user is the process of ensuring and verify that the user is really the person who claims he is.
- There are two steps in authentication process of GSM.
- In the first step the authentication of a valid user is carried out for the SIM.
- The user needs a secret PIN to access the SIM. And in the second step the authentication of the subscriber is done.

5.15.2 Confidentiality :

- The confidentiality of all the user related data is ensured by encrypting it.
- The BTS and MS apply **encryption** to voice, data and signaling information, once the authentication is done.
- Due to encryption, it is possible to apply confidentiality only between MS and BTS but not over the entire end to end GSM network.

5.15.3 Anonymity :

- In order to provide anonymity to the user, all data is first encrypted.
- The user identifiers (the information which could reveal the user's identity) is not transmitted.
- Instead a temporary identifier (TMSI) is transmitted by GSM.
- The VLR assigns this identifier newly after each location update.
- Additionally the TMSI can be changed anytime by the VLR.

5.15.4 Authentication in GSM :

Definition :

- The authentication of a user is the process of ensuring and verifying that the user is really the person who claims he is.
- Authentication is essential to ensure that the communication over the wireless radio medium is secured.
- The authentication process involves two functional entities :
  1. The SIM card in mobile phone
  2. The Authentication Center (AUC)
- An important element that ensures security in the GSM system is the Subscriber Identity Module **(SIM) card**, which is an intelligent plastic card with a microcontroller.
- SIM is an inherent part of a mobile terminal.
- The user receives the SIM card from the network operator, which contains a list of individual user data, encryption programs and keys.
- Because it is possible to separate the SIM and the mobile phone, the SIM card provides an additional security means against an unauthorized usage of the stolen or lost phone.
- A **mobile station** consists of two parts that are strictly related to each other : a mobile phone and a SIM card.
- The SIM card contains a microcontroller with ROM, RAM and **NVM (Non-Volatile Memory).**
- The ROM stores the programs implementing A3 and A8 encryption algorithms.
- The capacity of the ROM is 4 to 6 kbits and cannot be copied.
- The RAM is very small and its storage capacity can be up to 256 bytes.
- The size of **NVM** is about 2 to 3 kB and it contains the following individual user's parameters and data :

  Ki is user's authentication key.

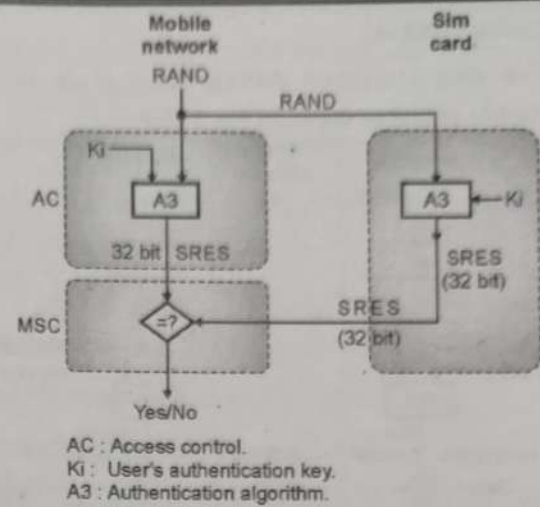
1. IMSI (International Mobile Subscriber Identity) : It is a 15-bit long user's individual identification number which consists of the country code, network code and number of the user,
2. TMSI (Temporary Mobile Subscriber Identity) : It is a temporary identification number assigned to the user after each registration in a new VLR,
3. LAI (Location Area Identifier),
4. PIN (Personal Identification Number); It is a 4 or 8-digit code identifying the user with respect to the SIM card,
5. The personal telephone book : It is a list of telephone numbers entered by the user,
6. The list of foreign cellular networks where roaming is allowed,
7. The received short messages (SMS)

- A specially designed algorithm A3 is used for carrying out authentication.
- After carrying out the authentication, a key is generated for encryption, with the help of another specially designed algorithm A8.
- GSM provides the security services by using three algorithms called **A3, A5 and A8.**
- Their functions are as follows :

Sr. No.	Algorithm	Function
1.	A3	Used for Authentication
2.	A5	Used for Encryption
3.	A8	Used for generation of cipher key.

5.15.5 Authentication Algorithm A-3 :

- Authentication is done with the help of SIM. SIM stores authentication key K_i and the user IMSI.
- During the authentication process the Mobile Switching Center (MSC) or MTSO challenges the Mobile Station (MS) with a random number (RAND) which is generated by the AC (Access control) as shown in Fig. 5.15.1.



(GT-37) **Fig. 5.15.1 : Verification of the user authenticity**

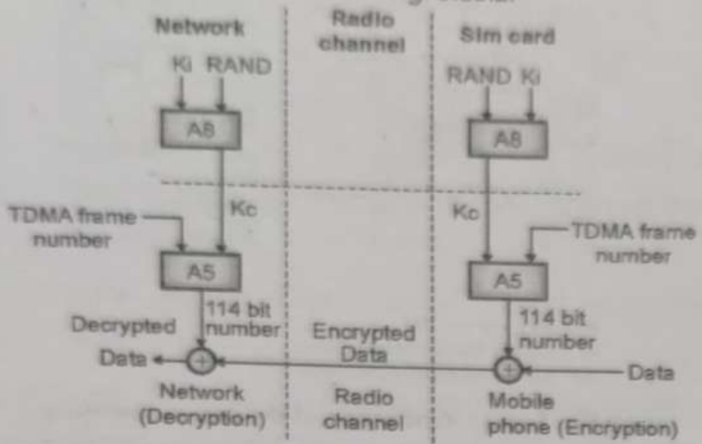
- The SIM card makes use of this RAND received from the MSC along with a secret key k_i stored within the SIM as input.
- Both RAND and k_i are basically 128 bit digital numbers.
- The A3 algorithm works on the RAND and k_i inputs to produce a 32 bit output called as the signature response (SRES).
- The SRES is then sent back to MSC from MS as the answer to the challenge. Using the same algorithm the AUC also generates a SRES.
- Then the SRES generated by MS (SIM) and AUC are compared.
- If they are identical then it is an indication that MS is an authentic user.
- That means it is concluded that SIM card is genuine.

5.15.6 Data Encryption Process using A-5 and A-8 Algorithm :

- Fig. 5.15.2 shows the data encryption process in GSM using A5 and A8 algorithm.
- In GSM, the A5 algorithm is used for the data encryption.
- Only manufacturers of the cellular devices have an access to this algorithm.
- The A5 algorithm is more secure because the secret key K_c is never transmitted over the air. Initially the network activates the A5 algorithm.

Encryption Process :

– The data encryption process takes place at the Mobile phone as shown in Fig. 5.15.2.



(GT-38) **Fig. 5.15.2 : Data encryption process using A5 and A8**

– The SIM card initially obtains the data encryption key K_c by applying the RAND number sent by the mobile network during the process of authentication and the individual secret key K_i, to algorithm A8.

– The A8 algorithm is present inside the SIM card.

– Then the A5 algorithm generates a 114-bit number by using the encryption key K_c and the current 22-bit TDMA frame number.

– These 114-bits are modulo-2 added with the information (i.e. data) bits of the normal burst to produce the encrypted data.

– This encrypted data is then transmitted over the radio channel.

Decryption process :

– The data decryption process takes place at the network as shown in Fig. 5.15.2.

– The same process of generation of the encryption key Kc from the RAND and Ki and then generation of 114 bit number from Kc and the current TDMA frame number, is carried out on the network side as well using A8 and A5 algorithms.

– The received encrypted data is applied to a modulo-2 adder alongwith this 114 bit number at the network site.

– If the received data has no errors during the transmission, the modulo 2 addition of the received data and the generated encrypted data results in the original data sequence.

– This is the process of decryption.

– The block diagram representation of the encryption and decryption processes are as shown in Fig. 5.15.2

Ex. 5.15.1 : The channel data rate is 270.833 kbps in GSM standard that is 40 % (say) of theoretical maximum data rate that can be supported in a 200 kHz channel bandwidth. Calculate the corresponding theoretical S/N required.

Soln. :

Given : GSM system, channel data rate R_b = 270.833 kbps, Channel BW = 200 kHz.

To find : Required (S/N).

Step 1 : To calculate theoretical maximum data rate, C :

– We know that,

$$R_b = 270.833 \text{ kbps}$$

– And R_b is 40 % of theoretical maximum data rate, i.e. channel capacity C.

$$\therefore \; R_b = 0.4 \times C$$

$$\therefore \; C = R_b / 0.4 = 270.833 \text{ kbps} / 0.4 = 677 \text{ kbps}$$

Step 2 : To calculate the corresponding theoretical S/N required :

– The maximum possible theoretical data rate, i.e. C channel capacity given by Shannon's channel capacity formula as follows :

$$C = B \times \log_2 (1 + S/N)$$

$$\therefore \; 677 = 200 \log_2 (1 + S/N)$$

$$\therefore \; \log_2 (1 + S/N) = 677 \text{ kbps} / 200 \text{ kHz} = 3.385$$

$$\therefore \; S/N = 2^{3.385} - 1 = 9.447 \quad \textbf{...Ans.}$$

– Calculate S/N in decibels as follows :

$$S/N \text{ (dB)} = 10 \log_{10} (9.447) = 9.75 \text{ dB} \quad \textbf{...Ans.}$$

5.16 GSM Services :

– The GSM services can be classified into three types of services :

1. Teleservices
2. Data services / Bearer services
3. Supplementary services.

5.16.1 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.

1. Digital telephony :

- The main service of GSM is to provide a high quality digital voice transmission, with a minimum bandwidth of 3.1 kHz.
- Special codecs (combination of coder and decoder) are used for transmission of voice digitally.

2. Emergency calling :

- With this GSM service the same emergency number can be used throughout a country.
- This is a mandatory but free service with the highest connection priority.
- If this number is dialled, then the call with the nearest emergency center is set up automatically.

3. Short Message Service (SMS) :

- With this service the user can send messages upto 160 characters. SMS messages are not transmitted over the standard data channels of GSM.
- Instead they are sent over the unused capacity of signaling channels.
- Hence SMS sending and receiving is possible even when the voice or data is being transmitted.
- SMS can transfer logos, ring tones, horoscopes alongwith the text messages.
- It is also possible to update the software of a mobile phone via SMS.

4. Enhanced Message Service (EMS) :

- EMS is the successor of SMS which offers a message size of upto 760 characters.
- It is possible to send text, ring tones, small images, animated pictures in a standard way using EMS.
- But EMS service never took off commercially.

5. Multimedia Message Service (MMS) :

- With this service, it is possible to transmit large pictures (GIF, JPEG) and short video clips.
- MSS is integral part of mobile phones with an inbuilt camera.

6. Group 3 FAX :

- This is one more non-voice tele-service in which fax data is transmitted as digital data over the network of analog telephone lines.

5.16.2 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.

5.16.3 Bearer Services :

- In GSM, there are different mechanisms for the data transmission.
- The **bearer services** supports the data transmission of transparent and non-transparent, synchronous or asynchronous types.
- Bearer services are of two types :
  1. Transparent bearer services.
  2. Non-transparent bearer services.

1. Transparent bearer services :

- These services use the functions of only the **physical layer** for the data transmission.
- The delay and the throughput of the data transmission is constant if there is no transmission error.
- The transmission quality can be improved only by using the Forward Error Correction (FEC).
- The data rates of 2.4, 4.8 or 9.6 kbps are possible depending on the FEC.
- These services do not try to recover the lost data irrespective of the cause.

2. Non-transparent bearer services :

- These services use the functions of the first three layers of the OSI model i.e. physical, data link layer and network layer.
- They use protocols in the DLL and network layer to add error correction and flow control.
- Due to this, a special mechanism of **selective reject** gets added to facilitate retransmission of lost or erroneous data.
- This reduces the error rate remarkably. But delay and throughput do not remain constant.
- They depend on the transmission quality.

Features of bearer services :

- The important features of bearer services are as follows :
  1. Full duplex data transmission.
  2. Synchronous transmission data rates : 1.2, 2.4, 4.8 and 9.6 kbps.
  3. A synchronous transmission data rates : 300 to 9600 bps.

5.16.4 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 :

- This service allows a mobile subscriber to start a conference call i.e. a simultaneous conversation takes place between three or more mobile subscribers.

2. Call Waiting :

- During a conversation this service informs a mobile subscriber about an incoming call. The user can answer, reject, or ignore the incoming call while conversation.

3. Call Hold :

- This service allows a user to put an incoming call on hold and after a while call can be resumed.

4. Call Forwarding :

- To divert calls from the original recipient to another number call forwarding service is used. The user himself can set up this service on his/her mobile.

5. **Call Barring :**

- To restrict some type of calls such as outgoing calls like ISD or incoming calls from unwanted numbers call Barring service is useful.

6. **Caller Identification :**

- On your mobile screen, this service displays the telephone number of the person who is calling.
- It displays telephone number of a person to whom you are connected.

7. **Suggestion of Charge :**

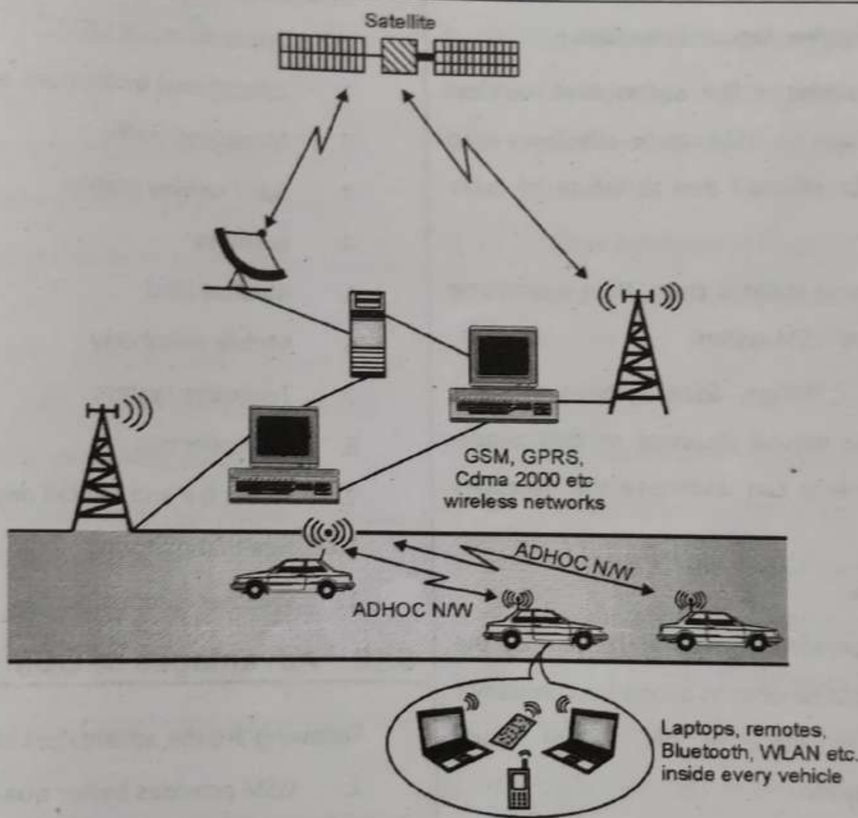
- This service informs the user about the cost of the services used by them.

8. **Closed User Groups :**

- This service is intended for the group of subscribers who want to call only each other in the group.

5.17 Applications of GSM :

- There are various applications of GSM network. We will discuss some of them in this section.
- Refer Fig. 5.17.1 to understand the scope of GSM applications.



(GT-2) **Fig. 5.17.1 : Typical scenario of GSM applications in road traffic**

1. **Providing help to accident victims :**

- This is typical road traffic scenario. The road is assumed to have the vehicles, that are equipped with wireless devices.
- The wireless networks among cars and inside the cars are of ad-hoc type.
- In this situation if there is an accident on this road, immediately the wireless devices communicates with the nearby hospital, ambulance, home devices of the person etc. so that help could be arranged immediately.
- In such a scenario many other telecommunication systems such as satellite links alongwith GSM are used.
- It is possible to build a similar system for the rail traffic or air traffic as well.

2 **Monitoring seriously ill patients :**

- This is the another possible application of the GSM network.
- We can have the emergency services like ambulance equipped with GSM modems, so as to transmit the real time information about the patient immediately to the hospital.
- Doctors can use the SMS service provided by the GSM to track the patient's health by continuously and provide their support and consultation to the patients in the serious conditions.

3. **Communication during natural calamities :**

- In the natural calamities like earthquakes, wireless communication base on GSM can be effectively used because, it is not affected due to failure of cable systems.
- However if the base stations crash, then it won't be possible to use the GSM system.
- It is possible to design GSM systems to give intimations of the natural disasters, so that people and the governments can undertake the necessary preparations.

4. **GSM for business :**

- When a businessperson is travelling, he can use the GSM and GPRS data services to access his company's database to keep track of his routine work, employees, salaries etc.
- The GSM mobile network always provides a good connectivity and keeps him connected to all his database.
- He can also get information about current trends in business by using GSM/GPRS services to access the Internet.

5. **GSM for home / office security :**

- We can use the GSM technology in home automation systems.
- A person can control his home electrical appliances by using his mobile phone, even when he is away from his home.
- It is now possible to connect different sensors used in home, like smoke sensor etc. to the GSM network and control them using a GSM mobile.
- We can also control or watch the live footage recorded by the CCTV cameras installed in home, offices etc connected to mobile IP network so as to resolve the security issues.

5.17.1 Other applications of GSM :

- In addition to these applications, following are a few other applications of GSM :
  1. Educational institutions and organizations
  2. Managing traffic
  3. Bus / railway station
  4. Business
  5. Medical field
  6. Mobile telephony
  7. Telemetry system
  8. Toll collection
  9. Forest fire and rainfall detection systems
  10. Health monitoring
  11. Weather forecasting.

5.18 Advantages of GSM :

- Following are the advantages of GSM :
  1. GSM provides better quality of speech.
  2. Data transmission is supported in the GSM system.
  3. International roaming is possible in the GSM.
  4. New services are provided due to ISDN compatibility.
  5. There is a large variety of mobile phones, which operate on GSM.
  6. The working of phone is based on a SIM card and hence user can change the different variety of phones.

7. The power consumption is less in GSM mobiles.
8. It is more cost effective.

5.19 Disadvantages of GSM :

Following are the disadvantages of GSM :

1. Main disadvantage of GSM is that many users share the same bandwidth, which may result in the transmission interference.
2. As compared to CDMA, the per-unit charge on roaming calls is higher in GSM.

Review Questions

Q. 1 What is GSM ?

Q. 2 What are the services provided by GSM ?

Q. 3 State and explain important features of GSM.

Q. 4 Explain various subsystems in the GSM system architecture.

Q. 5 Draw the block diagram and explain GSM architecture in details indicating all the interfaces.

Q. 6 Explain GSM Network architecture in detail.

Q. 7 Draw neatly and explain the role played by various entities in the GSM architecture.

Q. 8 Give a complete functional account on NSS.

Q. 9 Explain features of GSM.

Q. 10 GSM provides 'on the air privacy' security features during voice calls justify.

Q. 11 List and explain specifications of radio transmission in GSM system.

Q. 12 State and explain the basic radio transmission parameters of GSM.

Q. 13 State the GSM radio interface.

Q. 14 Explain in detail signaling protocol architecture used in GSM.

Q. 15 Explain GSM protocol architecture in detail.

Q. 16 Discuss in detail GSM logical channels.

Q. 17 Why are so many logical channels used in the GSM ? Explain GSM channel structure.

Q. 18 Explain various interfaces in GSM.

Q. 19 Explain the SS7.

Q. 20 Write a note on : functions and features of GSM.

Q. 21 State and explain different identifiers in GSM.

Q. 22 Explain the frame structure of GSM.

Q. 23 Write a note on : Classification of GSM channels.

Q. 24 Explain the logic channels in GSM.

Q. 25 What is meaning of traffic channel w.r.t GSM ?

Q. 26 Explain traffic channel in GSM.

Q. 27 What is meaning of signaling channel.

Q. 28 What is meaning of broadcast channels w.r.t. G. S. M ?

Q. 29 Explain broadcast channel in GSM.

Q. 30 What is meaning of common control channels w.r.t. G. S. M ?

Q. 31 Explain frame structure used in GSM.

Q. 32 Describe GSM frame structure.

Q. 33 Explain signal processing in GSM.

Q. 34 Explain GSM speech processing in detail.

Q. 35 Explain signal processing in GSM.

Q. 36 What is the use of interleaver ?

Q. 37 Write note on : Call procedure in GSM.

Q. 38 Write short note on : Hand off in GSM.

Q. 39 State different types of handovers in GSM.

Q. 40 What are the reasons for intra-cell handover ? Discuss different possible handover scenarios in GSM.

Q. 41 Explain security algorithm in GSM.

Q. 42 Write short note on : Authentication in GSM.

Q. 43 Write short note on : Security and authentication in GSM.

Q. 44 Explain the data encryption process using A5 and A8 algorithms in GSM.

Q. 45 Describe algorithms used for authentication and security in GSM with diagrams.

Q. 46 State and explain different GSM services.

Q. 47 Explain the bearer services in GSM.

Q. 48 Explain the supplementary services in GSM.

Q. 49 Write a short note on : applications of GSM.

Q. 50 State the advantages and disadvantages of GSM.

□□□

Syllabus : Concept of spread spectrum, Architecture of IS-95 CDMA system, Air interface, CDMA forward channels, CDMA reverse channels, Soft handoff, CDMA features, Power control in CDMA, Performance of CDMA System, RAKE Receiver, CDMA 2000 cellular technology, GPRS system architecture.

Chapter **6**

Wireless Systems-IS-95

Syllabus

Concept of spread spectrum, Architecture of IS-95 CDMA system, Air interface, CDMA forward channels, CDMA reverse channels, Soft handoff, CDMA features, Power control in CDMA, Performance of CDMA System, RAKE Receiver, CDMA 2000 cellular technology, GPRS system architecture.

Chapter Contents

6.1 Introduction to 2G Cellular Systems :

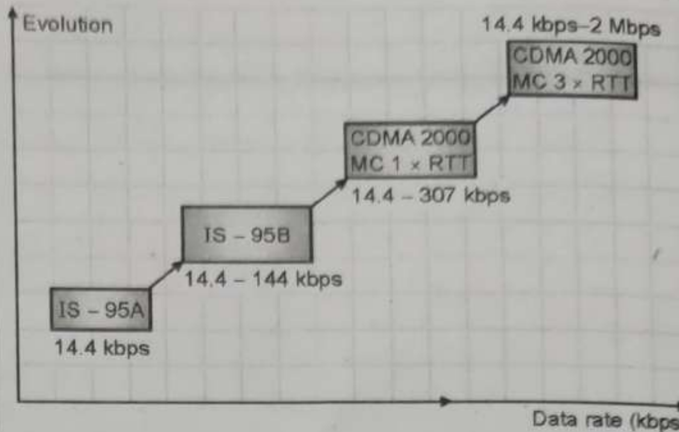
- The second generation of cellular telephony was developed in order to improve the quality of communication.
- The second generation was designed for digital voice.
- 2G networks began to emerge around 1980's but their actual implementation started by 1990's.
- The second generation mobile systems are digital voice systems and they can be classified as follows :
  1. IS-54 (TDMA) in 1991.
  2. IS-95 (CDMA) in 1993.
  3. IS-136 PDC in 1996.
  4. GSM (TDMA).
- Out of these the GSM (Global system for mobile communications) is by far the most consistent 2G standard.
- In this chapter we will discuss the IS-95 standard which uses CDMA as its multiple access technology.

6.1.1 Evolution from 2G to 3G Cellular Networks : GTU : S-18

University Questions

Q. 1 Illustrating the upgrade paths briefly describe 2G and 3G cellular network. **(S-18, 4 Marks)**

- An evolution from the present 2G technology to 3G technology takes place in two steps based on GSM and IS-95 CDMA respectively.
- Next to GSM, CDMA is popular mobile communication standard.
- Evolution of CDMA began in 1991 as IS-95A CDMA-one 2G technology for data and multimedia services as well as for voice communication as it allows communication of multiple users within the spectrum which avoids jamming and interference between users.
- Fig. 6.1.1(a) shows an evolution path from 2G technology CDMA to third generation technology.



(G-2546) **Fig. 6.1.1(a) : Evolution path from CDMA to 3G**

- For system operation, IS-95A explains structure of wideband 1.25 MHz CDMA channels, hand-offs, call processing, registration techniques, power control etc.
- At 14.4 kbps, many IS-95A operators provides circuit switched data connections.
- IS-95B is also known as CDMAone is 2.5 G technology which offers up to 144 kbps packet switched data, and defines well suited standard for 1.8 to 2.0 GHz CDMA PCS systems.
- Over 2G systems, CDMA 2000 multi-carrier (MC) system delivers spectrum efficiency and improved system capacity.
- In mobile (outdoor), CDMA 2000 supports data services at the data rate of 144 kbps and in fixed (indoor) environment the data rate will be 2 Mbps.

6.2 Interim Standard CDMA IS-95 :

GTU : W-12

University Questions

Q. 1 Explain IS-95 CDMA System. **(W-12, 7 Marks)**

Definition :

- **Interim Standard 95 (IS-95)** was the first ever CDMA -based digital cellular technology. The proprietary name for IS-95 is **cdmaOne**.
- It is a 2-G mobile telecommunications standard that uses doge division multiple access (CDMA), as the multiple access technology for digital radio.
- Code division multiple access (CDMA) is much superior to FDMA and TDMA, used by the GSM systems.

- IS – 95 stands for Interim Standard 95.
- It is a CDMA based system developed in United States.
- Code Division Multiple Access (CDMA) has many advantages over TDMA and FDMA including increased system capacity.

Principle :

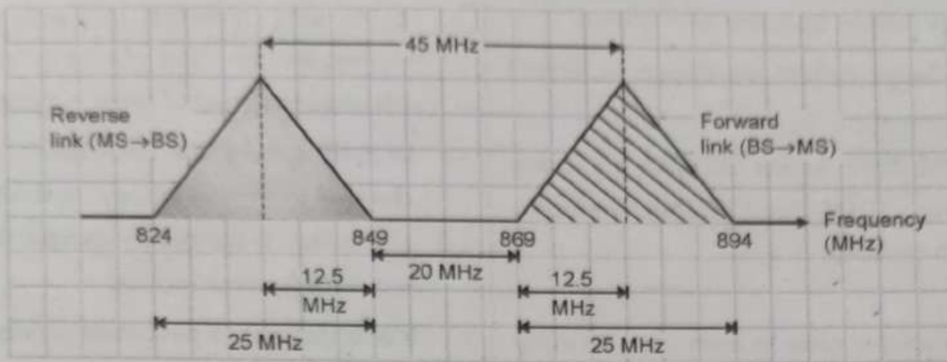
- CDMA assigns a unique code to each user. So every user is allowed to access the channel fully (entire bandwidth) all the time.
- Thus there is no restriction on bandwidth usage or time usage. CDMA operates on the principle of spread spectrum modulation.
- In an IS-95 system based on the direct sequence spread spectrum CDMA each user within a cell is allowed to use the same radio channel, and users in adjacent cells also use the same radio channel.
- Thus, in CDMA there is no need for frequency planning within a market.
- There are 15 channels in an IS-95 system and each one occupies 1.25 MHz of spectrum on forward as well as reverse link.

6.2.1 Types of Channels in IS-95 System :

- IS-95 system has two channels as follows :
  1. Forward channel and
  2. Reverse channel.
- The **forward channel** is defined as the wireless communication channel that is set to carry information from a base station (BS) to a mobile station (MS).
- The **Reverse channel** is defined as the wireless communication channel that is set to carry information from a mobile station (MS) to the base station (BS).
- In practice, there is a 270 kHz guard band on each side of the spectrum dedicated for IS-95.
- A distinct feature of IS-95 is that the users data rate changes in real time depending on the voice activity and requirements of the network.
- IS-95 uses different modulation and spreading techniques for the forward and reverse links (channels) in order to avoid interference.
- In IS-95 system, the base station uses the **forward channel** to simultaneously transmit the user data for all mobiles in the cell by using a different spreading sequence for each mobile.
- It also transmits a pilot code simultaneously and at a higher power level, that allows all mobiles to use the coherent carrier detection while estimating the channel conditions.
- All mobiles send their responses on the **reverse link,** in an asynchronous fashion and they have ideally a constant signal level because of the power control applied by the base station.
- The type of **speech coder** used in the 15-95 system is the Qualcomm 9600 bps Code Excited Linear Predictive (QCELP) coder.
- The function of the original implementation of this vocoder is to detects voice activity, and to reduce the data rate to 1200 bps during silent periods.
- Intermediate user data rates of 2400, 4800 and 9600 bps are also used for special purposes.

6.3 Frequency and Channel Specifications of CDMA IS-95 :

- The IS-95 uses two frequency bands of 25 MHz each for forward and reverse links.
- The 824-849 MHz band is used for the reverse link operation and 869-894 MHz band is used for the forward link as shown in Fig. 6.3.1.
- A PCS version of IS-95 designed for international market uses the 1800-2000 MHz band.
- As shown in Fig. 6.3.1 the forward and reverse channels have a 45 MHz separation between them.
- That means the difference between the center frequencies of the forward and reverse channels is 45 MHz with a guard band of 20 MHz.
- Many users use the same channel for transmission due to the use of CDMA.



(OT-48) **Fig. 6.3.1 : IS-95 frequency bands**

- The user data rate can be at the most (maximum) equal to 9.6 kb/s, which is very low.
- User data in IS-95 is spread to a channel chip rate of 1.2288 Mchip/s (a total spreading factor of 128) using a combination of techniques.
- The IS-95 uses spread spectrum technology along with CDMA.
- The spreading techniques used for forward link and the reverse link are completely different from each other.

6.3.1 Frequency Specifications of IS-95 :

1. Frequencies used : 800 MHz, 1900 MHz
2. Frequency band for forward link : 869-894 MHz
3. Frequency band for reverse link : 824-849 MHz
4. Guard band : 20 MHz
5. Data bit rate : 9.6 kbps
6. Channel chip rate : 1.2288 Mchip/s

6.3.2 Features of CDMA IS-95 : GTU : S-20, W-20

University Questions

Q. 1 Explain salient features of CDMA. **(S-20, W-20, 4 Marks)**

- Important features of IS-95 are as given below :
  1. IS-95 system is based on the direct sequence spread spectrum CDMA.
  2. Each user within a cell is allowed to use the same radio channel, and users in adjacent cells also use the same radio channel.
  3. It used specific modulation and spreading techniques for forward and reverse links. These techniques are different for forward and reverse links.
  4. Frequencies used : 800 MHz, 1900 MHz
  5. Uplink frequency : 824 – 849 MHz
  6. Downlink frequency : 869 – 894 MHz
  7. Frequency separation : 45 MHz
  8. Guard band : 20 MHz
  9. Channel bandwidth : Total 12 MHz with 1.25 MHz for spread spectrum.
  10. Data bit rate : 9.6 k bits
  11. Voice codec : 8 kbps or 13 kbps
  12. SMS service : Upto 120 characters
  13. Type of radio interface : CDMA
  14. Multipath does not create any interference
  15. Type of hand off : Soft
  16. High system capacity
  17. Less expensive than GSM.
  18. Transmit rate of one channel : 192 Kbps
  19. Number of time slots in one CDMA channel : 64
  20. Power updates of mobile user : every 1.25 mS
  21. Modulation method : QPSK / BPSK

6.3.3 Forward Link :

- On the **forward link** the user data is first encoded with a rate 1/2 convolutional encoder.
- Then interleaving and spreading is employed on the encoded data.
- For spreading, one of sixty-four orthogonal spreading sequences (Walsh functions) is used.
- Due to the spread spectrum technique each user in a given cell is assigned a different spreading sequence.
- This provides a perfect separation among signals from different users even though all of them operate in the same band all the time.

Interference on forward link :

- In the CDMA systems, interference takes place between the mobiles present in different cells, which use the same spreading sequence.
- This interference can be reduced if all signals in a particular cell are scrambled using a PN sequence of length chips.
- It is necessary to preserve the orthogonality among all forward channel users within a cell because their signals are scrambled synchronously.
- A pilot channel (code) is provided on the forward link, in order to enable each subscriber within the cell to determine the channel characteristics and react to them while employing coherent detection.
- The pilot channel is transmitted at higher power than the user channels.

6.3.4 Reverse Link :

- A different spreading technique is used for the reverse link (mobile to base station) than the one used for forward link because each received signal on the reverse path will arrive at the base station via a different path.
- The reverse channel data is encoded using a convolutional encoder with a rate equal to 1/3.
- This signal then undergoes interleaving and spreading, thereafter..
- After interleaving, each block of six encoded symbols is mapped to one of the 64 orthogonal Walsh functions This provides sixty-four-ary orthogonal signaling.
- The result of the rate 1/3 coding and the mapping onto Walsh functions is a greater tolerance for interference as compared to that obtained with traditional repetition spreading codes.
- This added robustness is important on the reverse link, because the type of detection is non-coherent detection and due to the in-cell interference received at the base station.

Transmitter power control :

- The transmitter power of each subscriber is controlled tightly to reduce the **near-far** problem, which occurs due to the varying received power from users.
- This is an essential element of the reverse link.
- The transmitter power of each in cell subscriber is controlled automatically by using a combination of open loop and closed loop control to ensure that the received signals from different subscribers at the base station have the same power.
- The closed loop control is exercised by sending commands at a rate of 800 b/s and bits from the speech frames are used for accommodating the command signals.
- At the base stations and subscribers, special receivers called the **RAKE** receivers are used, in order to reduce the effect of fading.
- A RAKE receiver makes use of the multipath time delays in a channel and combines the delayed versions of the transmitted signal for improvement in the link quality.
- In IS-95, **a three finger RAKE** is used at the base station.
- The IS-95 makes use of the "soft" handoffs, in which a mobile making the transition between cells maintains links with both base stations during the transition.
- While doing so, the mobile receiver combines the signals from the two base stations in the same manner as it would combine the signals received from two different multipath components.

6.3.5 Interferences in CDMA IS-95 System :

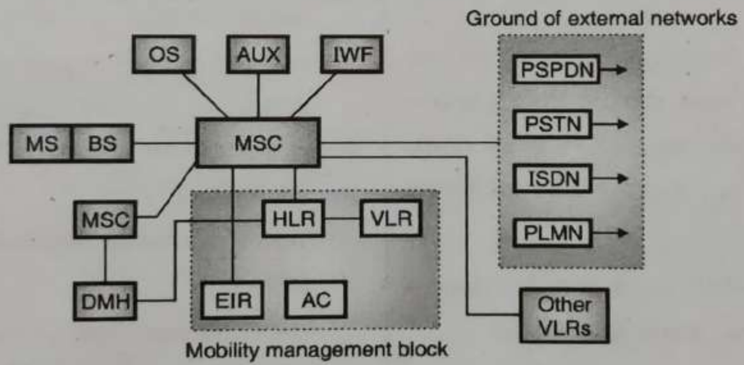
- Hence in CDMA system a new type of interference called **multiple-access interface (MAI) occurs.** This interference occurs when the spreading codes are not perfectly orthogonal.
- Another problem which is related to MAI is called as the **near far problem.**

- This problem arises if the received signals from mobile units do not have equal power at the base station.
- In the near far problem, the strongest signal will capture the demodulation process.
- This problem can be overcome by exercising a power control at the base station in order to control the power level of the transmitted signal from every mobile which is coming under that base station.
- There is one more reason for which the power control in CDMA is important. Every multiple access system is supposed to maximize the **system capacity**.
- The system capacity can be defined as the maximum number of users that can be served reliably by a system.
- It can be maximized if the transmitter of each mobile is under control of the serving base station.
- The IS-95 system has been designed to be compatible with the existing US analog cellular system (AMPS) frequency **band**.

6.4 CDMA IS-95 System Architecture :

Block diagram :

- Fig. 6.4.1 shows the system architecture of IS-95 CDMA system. Some of the important elements of the reference model are as follows :
  1. Mobile Station (MS)
  2. Base Station (BS)
  3. Mobile Switching Center (MSC)
  4. Home Location Register (HLR)
  5. Data Message Handler (DMH)
  6. Visited Location register (VLR)
  7. Authentication Center (AC)
  8. Operating System (OS)



MS : Mobile station
MSC : Mobile Switching Center
VLR : Visitor Location Register
EIR : Equipment Identity Register
BS : Base Station Controller
HLR : Home Location Register
AC : Authentication Center

(G-1577) **Fig. 6.4.1 : IS-95 system architecture**

1. Mobile Station (MS) :

- Mobile unit or handset of the subscriber is called as mobile station MS.
- The user can make use of this MS so as to access various services from the network.
- The MS can be is single unit (standalone) or it can be connected to other devices such as computer, Fax machine etc.

2. Base Station (BS) :

- A separate base station is installed for every cell. It communicates with all the mobile stations belonging to that cell.
- The BS communicates with the mobile switching center (MSC) or MTSO. The BS is divided into two units namely BTS and BSC.
- The Base Transceiver Station (BTS) consists of one or more transceivers whereas Base Station Controller (BSC) acts as the control and management system for one or more BTS.

3. **Mobile Switching Center (MSC) :**

- It is the heart of the IS-95 system. It is the main and centralized switching center connected to various blocks as shown in Fig. 6.4.1.
- MSC is equivalent to the telephone exchange in the conventional telephone system.
- MSC is there to automatically interface the users from the wireless network to either a wired network or to the other wireless networks.
- Following are some of the important functions of MSC :
  1. To provide a radio contact to a call.
  2. To control BTSs.
  3. To accept a call or a hand off.
  4. To initiate and manage an intersystem call.
  5. To provide all the required services to a call.
  6. To provide trunk connection.
  7. To provide services to the mobile stations.

4. **Home Location Register (HLR) :**

- HLR is a unit which maintains all the subscriber related information that is required for the management of mobile subscribers.
- HLR can have a separate existence or it can be an integral part of MSC.

5. **Data Message Handler (DMH) :**

- The DMH has been assigned the job of collecting the billing data.

6. **Visited Location Register (VLR) :**

- This unit stores subscribers information dynamically which is obtained from the subscribers HLR data.
- VLR can be attached to one or more MSCs. When a roaming MS enters into a new service area the MSC informs the corresponding VLR.

7. **Authentication Center (AC) :**

- It is essential to authenticate each subscriber. This is managed by the AC.
- The AC can have an independent identity or it can be a part of MSC of HLR.

8. **Equipment Identity Register (EIR) :**

- The EIR provides information about the mobile devices which is used for preparing the record.
- The EIR can be located separately or it can be located with the MSC.

9. **Interworking Function (IWF) :**

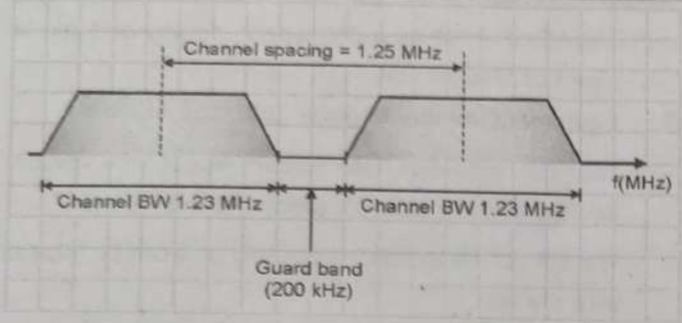
- The MSC can communicate with other networks only with the help from IWF.

10. **External Networks :**

- The other communication such as those listed below are called as external networks :
  1. Public Switched Telephone networks (PSTN).
  2. Integrated Service Digital Network (ISDN).
  3. Public Switched Packet Data Network (PSPDN).
  4. Public Land Mobile Network (PLMN).

6.5 CDMA Air Interface :

- The air interface in CDMA systems is the most complex of all systems because it is not symmetrical on the forward and reverse channels as in TDMA systems.
- The means of applying spread spectrum modulation and error-control coding techniques on the forward and reverse channels are totally different from each other.
- The definition of CDMA channels comes in terms of an RF frequency and code sequence.
- The forward channels are identified by sixty-four Walsh functions, whereas the reverse channels are identified by 64 long PN codes.
- The IS-95 standard defines different communication channels for both forward-channel and reverse-channel transmission and all of them use the CDMA multiple access technique.
- Each carrier of the IS-95 occupies a 1.25-MHz band as shown in Fig. 6.5.1 which shows the frequency spacing for two adjacent CDMA channels.



(OT-47)**Fig. 6.5.1 : CDMA channel bandwidth, guard band, and channel spacing**

- As shown in this figure, the bandwidth of each CDMA channel is 1.23 MHz wide and the channel spacing between adjacent carrier channels is 1.25-MHz.
- A guard band of 200-kHz is provided between two adjacent CDMA channels to ensure that the CDMA carrier channels do not interfere with one another.
- A direct-sequence spread spectrum (DSSS) is used by each RF channel at a cell-site to support 64 orthogonal CDMA channels.
- The CDMA system a PN sequence is used for spreading of the spectrum.
- In IS-95 standards, the rate of this PN sequence which is also called as the **chip rate** is 1.2288 Mega-chips per second (or Mcps).
- In IS-95 standard multiple mobile users are allowed to share common transmit and receive channels with a baseband data rate of 9.6 kbps.
- The user information data (which is at 9.6 kbps rate) is spread by a factor of 128 to a channel chip rate of 1.2288 Mcps (note that 128 × 9.6 kbps = 1.2288 Mbps).
- The bandwidth of this spread signals is about 1.25 MHz.
- Table 6.5.1 lists the modulation and coding features of the IS-95 CDMA system.
- These parameters have different values for the forward and reverse channels.

(G-2797) **Table 6.5.1 : Modulation and coding features of the IS-95 CDMA system**

Sr. No.	Parameter	Value
1.	Channel bandwidth	1.23 Mhz
2.	Chip rate	1.2288 Mcps
3.	Modulation scheme	QPSK
4.	Nominal date rate	Rate set 1 : 9600 bps Rate set 2 : 14,400 bps
5.	Coding type	4 to 6
6.	Interleaving procedure	2 to 3

- In the IS-95 CDMA system voice activation and power-control features are used to minimize system interference.
- Out of these the voice activation is achieved by using a variable-rate decoder.
- The voice coder operates at a variable rate from 8 kbps to 1 kbps for Rate Set 1 (RSI), depending on the level of voice activity.
- IS-95 system also supports a coding algorithm at 13.3 kbps for Rate Set 2 (RS2).
- The power control feature is used to reduce the transmitter power to achieve the same bit-error rate (i.e. the same error performance) at the reduced data rate.
- It is important to note that an excessive transmitter signal power is responsible for increase in the overall interference in the system.
- Hence it is necessary to have a precise power control as well as voice activation to avoid the overall interference in the system.
- In IS-95 CDMA, it is possible to overcome the effects of rapid multipath fading and shadowing, by using a time interleaver with error-control coding and with a 20-ms time span.
- This time span is same as the time frame of the voice compression algorithm, is used with error-control coding.

The PN Sequences :

- The maximal-length sequences (M-sequences) are widely used for single-user spread-spectrum systems in military applications as they are the most suitable and best-described PN sequences.

- However in the multi-user cellular CDMA systems, they use the Walsh sequences, Gold sequences, or Kasami sequences due to their cross-correlation properties.
- The PN-spreading codes are nothing but M-sequences that are generated by linear feedback shift registers of length 15 with a period of 32,768 chips.

Types of PN codes :

- In the IS-95 A system, two different types of PN codes are used :
  1. The short PN code 2. The long PN code
- The **short PN code** is a periodic binary PN sequences with a period of 2^{15} that are used for spreading and de-spreading signals into in-phase and quadrature components.
- Multiple base stations use the same short PN code and the same frequency band by using different timing offsets in the code cycle.
- The **long PN code** is a PN sequence with a period of 2^{42}-1 which is really a very long period.
- It is used for spreading signals on the reverse channel.
- The **long PN code** is also used for power control burst randomization and data scrambling.
- The PN sequences are used to differentiate between several base stations in the service areas employing the same frequency.
- The same PN sequence is used in all base stations, but the PN sequence of each base station is offset from those of other base stations by some value.
- For this reason, base stations in IS-95 have to be synchronised on the forward channel.
- Such synchronisation is achieved using GPS.

Importance of PN codes :

- Several base stations operating in the service areas and employing the same frequency are differentiated from one another by using the PN sequences.
- It is interesting to note that the same PN sequence is used in all base stations, but the PN sequence of each base station is offset from those of other base stations by some value.
- For this reason, it necessary to synchronize all base stations in IS-95 on the forward channel.
- Such synchronization can be achieved using GPS.
- IS-95 CDMA uses a set of 64 mutually orthogonal codes called the Walsh codes, in addition to the PN codes stated earlier.
- The Walsh codes are used to ensure orthogonality between the signals that are being received by different users from the same base station.
- The Walsh code is also used for modulation on the reverse channel of IS-95A.
- Thus, one can determine the logical channel on the forward channel with the help of, the short PN code offset, the Walsh code assigned, and the assigned frequency of operation.
- Similarly on the reverse channel, we can determine the logical channel by the short PN code offset, the long code offset, and the assigned frequency of operation.

Operation on forward channel :

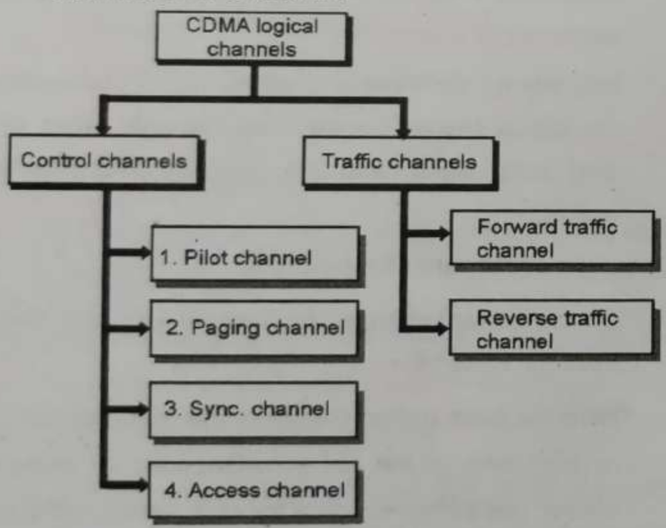
- On the forward channel the transmission takes place from the BS to MS.
- Here the base station transmits the user data for all mobile users in the cell simultaneously by using a unique spreading sequence for each mobile station.
- The base station also transmits a pilot code simultaneously at a higher power level, so as to allow all mobile users to use coherent carrier detection for estimating the channel conditions.
- In this way, on the forward channel, all the transmissions originating at a single base station transmit for all mobile users are synchronized.
- This makes it possible, to employ orthogonal spreading codes to minimize the interference between mobile users.

Operation on reverse channel :

- On the reverse channel, the transmission takes place from mobile users to base station.
- The mobile uses transmit whenever they have to transmit the data.
- The transmissions from various mobile users in a cell are not synchronized.
- Therefore the spreading is employed in such a way that we can use the same orthogonal codes for orthogonal modulation to reduce the error rate.
- On the reverse channel, all mobile users operate in an asynchronous manner and all of them ideally have a constant signal level because of the power control applied by the base station.

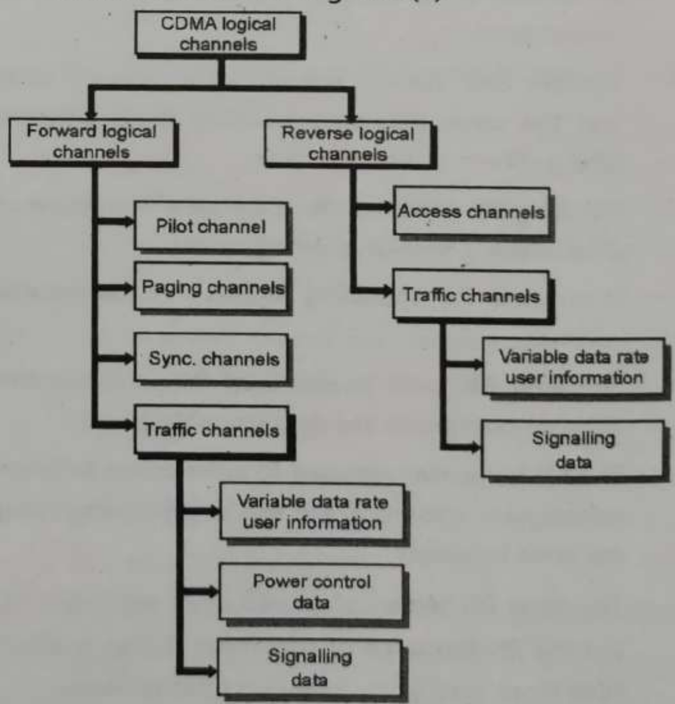
6.5.1 Classification of CDMA IS-95 Channels :

- Fig. 6.5.2(a) shows the classification of the logical channels of IS-95 CDMA.



(OT-35) **Fig. 6.5.2(a) : Classification of IS-95 CDMA channels**

- We may classify the logic channels of IS-95 CDMA in different ways
- One way is to classify them as the **control** and **traffic channels**.
- The control channels are further classified into the pilot channels, paging channels, sync channels, and access channels.
- The traffic channels are of two types namely the forward and reverse traffic channels.
- The traffic channels are used to carry user data along with signaling traffic between the BS and the MS.
- The traffic channels carry a variable-data-rate user information.
- If the complete user information is replaced by the associated signaling and control data, then it is called **blank and burst.**
- However if only a part of the user information is replaced by signaling and control data, then it is called **dim and burst.**
- Both the reverse channel and forward channels have a power control subchannel for allowing the mobile phones to adjust their transmitted power by ±1 dB after every 1.25 mS.
- The other way to classify the logical channels in IS-95 CDMA is to classify them as the **forward** and **reverse** channels as shown in Fig. 6.5.2(b).



(OT-34) **Fig. 6.5.2(b) : Classification of logical channels in IS-95**

- The forward channels are further classified into the pilot channels, paging channels, sync channels, and traffic channels. access channels.
- The reverse channels are further classified into the traffic channels and access channels as shown.

- In CDMA, all channels can be used in all sectors of all cells.
- Therefore CDMA is spectrally more efficient as compared to the other systems (typically ten to twenty times that for GSM).
- Another important aspect of CDMA is that the signal quality in CDMA system degrades gracefully and not suddenly, with increasing traffic.
- Therefore it is difficult to obtain a definite maximum value for its capacity.

6.5.2 IS-95 Air interface Standards :

- The list of important IS-95 CDMA air interface standard specifications has been given in the Table 6.5.2.

(OT-46) **Table 6.5.2 : IS-95 CDMA air interface standard specifications**

Sr. No.	Parameter	Specification/value
1.	Frequency band	IS - 95 A : 800MHz band IS - 95 B : 1900MHz band
2.	Bandwidth	Total BW : 2.46MHz Forward channel BW : 1.23MHz Reverse channel BW : 1.23MHz
3.	Forward and reverse channel duplex spacing	IS 95A : 45MHz IS 95B : 60MHz
4.	Multiple access method	DS 55. CDMA
5.	Modulation technique	Uplink : Digital OQPSK Downlink : Digital QPSK
6.	Total CDMA channels	64
7.	Voice channels	55
8.	Voice bandwidth	8 kHz
9.	Assignment of frequency	Dynamic
10.	Number of simultaneous voice channels per carrier	Up to 20

6.6 IS - 95 CDMA Channel Structure :

- The communication from base station to mobile station is known as **Forward Link** or Down Link and frequency band of 824 to 849 MHz which amounts to 25 MHz is used for forward link.
- The communication from mobile station to base station is known as **Reverse Link** or up link and the frequency band of 869 to 894 MHz which amounts to 25 MHz is used for the reverse link.

6.6.1 The IS-95 CDMA Forward Channels :

GTU : W-13

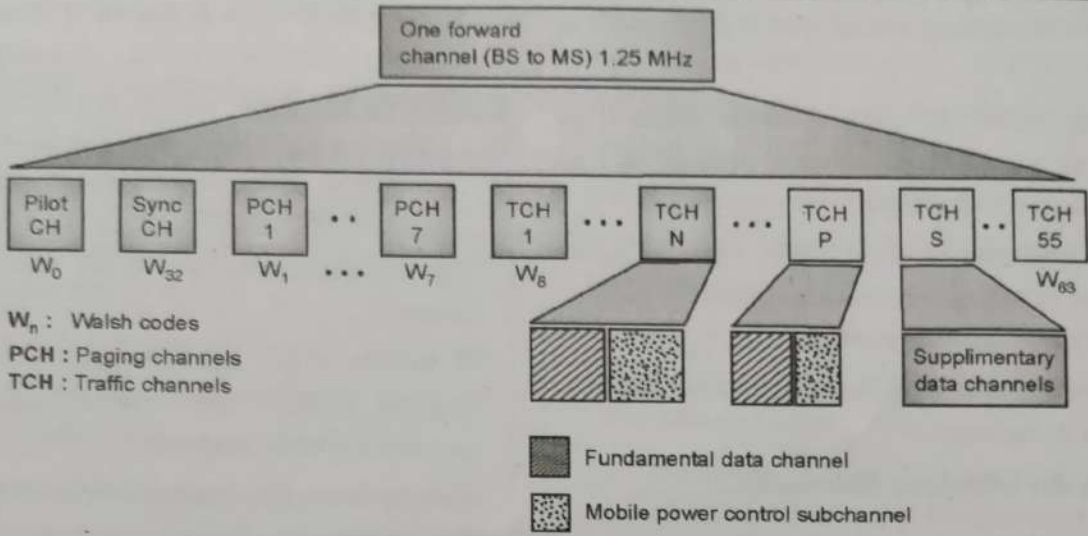
University Questions

Q. 1 With the aid of block diagrams, explain in detail the IS-95 CDMA forward and reverse channels and compare the two. **(W-13, 7 Marks)**

- Fig. 6.6.1(a) shows the IS-95 forward channel structure.
- It consists of four types of logical channels - pilot channel, synchronization channel, paging channel, and forward traffic channels.
- Each forward carrier channel consists of the following four types of logical channels to transmit information.
- These channels are as given below :
  1. One pilot channel
  2. A synchronization channel
  3. Up to seven Paging channels (PCH) and
  4. Up to sixty three forward traffic channels
- As shown in Fig. 6.6.1(a), based on the nature of signaling and traffic data carried by them, some of the traffic channels are designated as fundamental data channel, supplementary data channel and mobile power control subchannel.
- Different forward and reverse channels, their bit rates, applications and spreading codes have been listed in Table 6.6.1.

(OT-42) **Table 6.6.1 : IS-95 CDMA channels**

Forward channels (Downlink)			
Type of channel	**Application**	**Bits/s**	**Spreading code**
1. Pilot	System monitoring	NA	Walsh 0
2. Synchronization	Synchronization	1200	Walsh code 32
3. Paging	Signalling	9600	Walsh code 1-7
4. Traffic	Voice/data	9600/14,400	Walsh 8-31, 32-63
Reverse channels (Uplink)			
Type of channel	**Application**	**Bits/s**	**Spreading code**
1. Access	Signalling	4800	Access channel long code mask
2. Traffic	Voice / data	9600/14,400	Walsh code + access channel long code mask



(OT-39) **Fig. 6.6.1(a) : IS - 95 forward channel structure**

- The pilot channel W_0 is always required. The four different types of forward channels are separated from one another using different spreading codes.
- Different Walsh codes (W_0 through W_{63}) are assigned to various logical channels as shown in Fig. 6.6.1(a).
- The pilot channel is followed by the synchronization channel, seven paging channels (PCH_1 to PCH_7) and then the forward traffic channels denoted by TCH_1 to TCH_N, TCH-P and TCH-S.

Processes of forward channel :

- The processes that are carried out on the forward channel are as follows :
  1. Encoding of the user data.
  2. Interleaving.
  3. Blocks of 6 bits are converted to one of the 64 Walsh codes.
  4. Data is spread using a 42 bit user specific code. This code is known as the channel identifier. This code is different for each user.

1. Pilot channel :

- The Base Station (BS) transmits the pilot CDMA signal which acts as a reference for all the Mobile Stations (MS).
- The Walsh code W_0 (all zeros) has been assigned to the pilot channel.
- The power level of pilot signal is higher by 4 to 6 dB as compared to the traffic channel.
- The same PN sequence is used for the pilot signals from all the base stations.
- But each base station is identified using a unique time offset assigned to that station.
- Pilot channel acts as a downlink reference channel for the purpose of synchronization and tracking.
- The base station uses this channel as a reference for all mobile stations.
- This channel does not carry any information. Its function is to compare the signal strength and to lock onto other channels on the same RF carrier.
- It also provides the capability for soft handover and coherent detection.
- In IS-95 system there is only one pilot channel and it carries the phase reference for the other channels.
- In IS-95, different Walsh codes are used for spreading various logical channels.
- The Walsh code W_0 comprising of all 0s is used for spreading the pilot channel.

2. Synch. channel :

- The next logical forward channel after the pilot channel is the synchronization or sync channel.
- As shown in Fig. 6.6.1(a), it is a single channel which uses the Walsh code W_{32} for its spreading.
- It's function is to provide synchronization and configuration information to the mobile phones by carrying the accurate timing information that is synchronized to the GPS satellite system.

- The mobile users use this information to decode the other channels.
- The sync channel also provides the system information such as the PN short sequence offset, the system time, the PN long code state, to the mobile users.
- Various message parameters for the synch. channel are as follows :
  1. System Identification (SID)
  2. Network Identification (NID)
  3. System time
  4. Long code state
  5. Offset of local time
  6. Daylight saving time indicator
  7. Paging channel data rate

3. **Paging channel :**

- The next logical forward channels after the sync channel are the paging channels that are basically the control channels.
- As shown in Fig. 6.6.1(a), there can be up to seven paging channels.
- A paging channel is used for control information and sending paging messages to the mobile users in the system.
- These channels transmit control information to the terminals which are not engaged in call processing.
- The seven paging channels are assigned the Walsh codes W_1 to W_7 for their spreading.
- This channel is also used for sending short messages of the following types :
  1. The broadcast messages
  2. The messages containing details of registration procedures
  3. Pages for the mobile users that are being called
  4. The messages containing traffic channel information
  5. The temporary mobile subscriber identity
  6. The response message to access requests
  7. The lists of neighbouring cell-sites and their parameters
  8. Various other short messages for individual mobile users.

Forward Traffic Channel :

- Refer Fig. 6.6.1(a). The logical forward channels seen after the paging channels are the traffic channels marked TCH_1 ....TCH_N, TCH_P, TCH_S etc.
- A forward traffic channel is the main forward traffic-carrying channel.
- It provides a dedicated link between the cell-site and the mobile user. A forward channel is supposed to carry the voice or user data.
- We know that there is a pilot channel a sync channel and up to seven paging channels i.e. nine channels out of total 64.
- Hence the remaining fifty-five logical channels are used for traffic channels.
- The Walsh codes W_8 to W_{31} and W_{33} to W_{63} are assigned to the forward traffic channels for spreading their information.
- There are supplement traffic channels, that are added dynamically to meet the data rate requirement.
- The forward channel uses QPSK as the modulation scheme for transmission of spread signal.
- In the forward channel, all logical channels that are transmitted by the same cell-site together can be synchronized.

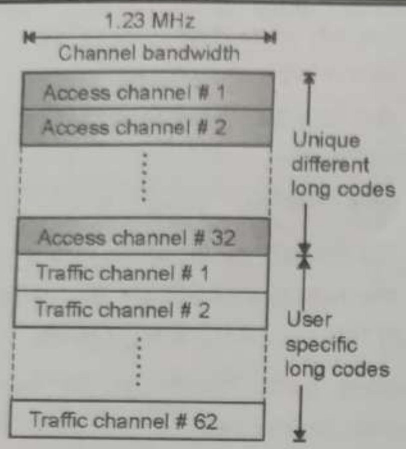
6.6.2 The IS-95 CDMA Reverse Channels :

GTU : W-13

University Questions

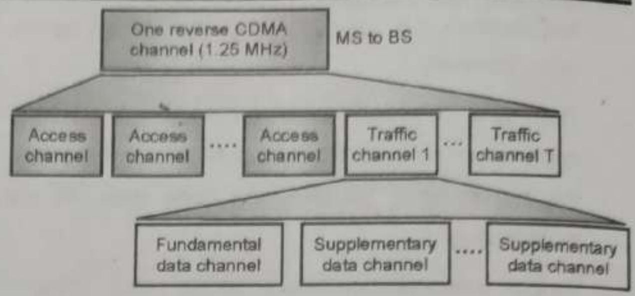
Q. 1 With the aid of block diagrams, explain in detail the IS-95 CDMA forward and reverse channels and compare the two. **(W-13, 7 Marks)**

- The CDMA reverse channel is totally different from the forward channel.
- The structure of reverse channels is as shown in Fig. 6.6.1(b) which shows that a reverse link can support upto 32 access channels and up to 64 traffic channels.



(OT-32)**Fig. 6.6.1(b) : IS-95 channel structure for reverse channels**

- The modulation scheme used by the CDMA reverse channel is OQPSK (offset QPSK) rather than QPSK used by the forward channel because OQPSK provides for a more power-efficient implementation of the transmitter at the mobile phone.
- On the other hand the QPSK modulation used by the forward channel is easy to demodulate at the mobile phone.
- Fig. 6.6.1(b) shows that the number of logical channels supported by the reverse CDMA link can be upto 94 including the access channels that are control channels and reverse traffic channels to carry the voice and data produced by MSs to the base station.
- Each of these 94 logical channels occupies a bandwidth of 1.23-MHz.
- Note that there is no spreading of the data symbols using orthogonal codes in the reverse channel.
- Instead, the orthogonal codes are used for waveform encoding.
- That means that the reverse channel uses an orthogonal modulation scheme for waveform coding but reduces the error rate performance of the system as the spreading is not used.
- Fig. 6.6.2 demonstrates the IS-95 reverse channel structure.



(OT-33)**Fig. 6.6.2 : IS - 95 reverse channel structure**

- As shown, the reverse channel structure consists of two types of logical channels - the access channel and reverse traffic channels.
- These logical channels help the mobile users to access the system and transfer user data.

Access channel :

- The access channel is basically a control channel. It is used by a free terminal (one for which a call is not in progress) for sending messages to the base station.
- Such messages can be sent for the following purposes :
  1. For originating a call.
  2. As a response to a paging message.
  3. For registering its location.
- There can be upto 32 access channels corresponding to each base station.
- An access channel is supposed to carry the information for signaling and control.
- The mobile users communicate on the access channel, various short messages consisting of information on registration, call originations, and responses to pages, or providing other data to the cell-site.
- When any mobile user initiates a call, it uses the access channel to inform about the call to the serving base station.
- The mobile users also use the access channel to respond to a page received from the base station.
- The access channel uses a prearranged long-code offset.
- The data rate of this channel is 4,800 bps and each access channel message is composed of many access-channel frames that last for 20 ms.

- Therefore the length of an access-channel frame is 96 bits.
- In an access channel frame a preamble always precedes an access-channel message, and it consists of multiple 96-bit frames with all bits in the frame equal to zero.
- The actual message itself is fragmented into 96-bit frames that have 88 bits of data and 8 tail bits set to zero.
- Important parameters of access channels are as shown in Table 6.6.2.

(G-2798) **Table 6.6.2 : Access channel parameters**

Sr. No.	Parameter	Value
1.	Date rate	4800 bps
2.	Code rate	1/3
3.	Symbole rate before repetition	14,400 sps
4.	Code symboles per modulation symbol	6
5.	PN chips per modulation symbol	256

Reverse Traffic Channel :

- Reverse traffic channel are used by the mobile stations to send the primary (voice) and secondary (data) or signalling (control) data to the base station.
- In this way it is similar to the forward traffic channel, and is intended to transfer dedicated user data.
- The reverse traffic channel supports the operation at variable-data-rates.
- The traffic-channel data rates are divided in to two sets namely : Rate Set 1(RS1) has a maximum data rate of 9.6 kbps, whereas Rate Set 2 (RS2) has a maximum data rate of 14.4 kbps.
- Both these rate sets support full, half, quarter, and one-eighth data rates with respect to the maximum data rate for example RS1 supports the data rates of 9600, 4800, 2400 and 1200 bps.
- Each mobile user has a unique traffic channel in the reverse channel and each mobile user also has a unique long-code mask based on its electronic serial number.
- The long code mask is a 42-bit number. Therefore we can have 2^{42}-1 different masks.
- A mobile uses the access channel for the following purpose :
  1. To initiate a call.
  2. To respond to a paging channel message from the base station, and
  3. For a location update.
- As stated earlier, the reverse traffic channel uses 9600 bps, 4800 bps, 2400 bps, or 1200 bps data rates for transmission, for Rate Set 1.
- The duty cycle for transmission varies proportionally with the data rate.
- It is equal to 100% at 9600 bps and 12.5% at 1200 bps.
- The data /signal processing on the reverse traffic channel is similar to that on the access channel except for the fact that the reverse channel uses a data burst randomizer.
- In the reverse channel, the mobile phone transmitters are not synchronized with each other or with the cell sites.
- They will transmit whenever they wish to. This results in to more multiple-access interference.
- The frames used on the reverse CDMA channel in IS-95, are all 20 ms frames.
- They use a more robust error-control system.

Types of messages :

- The reverse traffic channel can typically carry the following messages :
  1. Order messages.
  2. Authentication challenge response message.
  3. Pilot strength measurement message.
  4. Data burst message.
  5. Hand off completion message.
  6. Parameter response message.

6.6.3 Comparison of Forward and Reverse IS-95 CDMA Channels : GTU : W-13

University Questions

Q. 1 With the aid of block diagrams, explain in detail the IS-95 CDMA forward and reverse channels and compare the two. **(W-13, 7 Marks)**

– Table 6.6.3 gives the comparison between the forward and reverse CDMA IS-95 channels.

Table 6.6.3

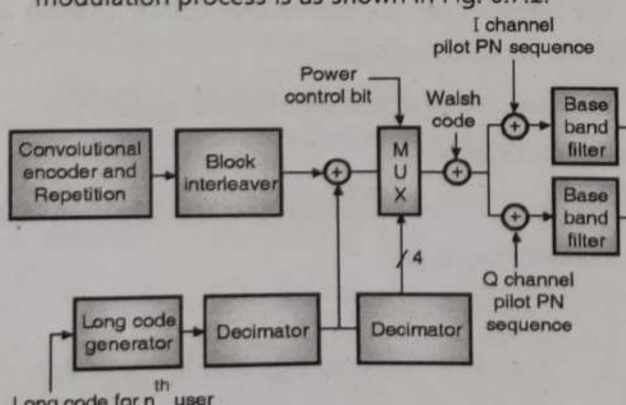
Sr. No.	Parameter	Forward channel	Reverse channel
1.	Direction of transmission	Downlink (BS to MS)	Uplink (MS to BS)
2.	Power level	High	Low
3.	Number of supported channels	It supports four channels	It supports two channels
4.	Types of supported channels	Pilot, synch. ,paging and traffic	Access and traffic
5.	Modulation scheme	QPSK	OQPSK
6.	Use of orthogonal codes	For the spreading of data symbols	For waveform coding

6.7 Forward and Reverse Channel Modulation Process :

6.7.1 Forward Channel Modulation Process :

Block diagram :

– The block diagram of forward CDMA channel modulation process is as shown in Fig. 6.7.1.



(G-1575) **Fig. 6.7.1 : Forward CDMA channel modulation process**

– The data on the forward channel is grouped into 20 ms frames.

– The following processes are carried out on the user data :

1. Convolutional encoding.
2. Formatting.
3. Interleaving.
4. Signal spreading using the Walsh code and long PN sequence.

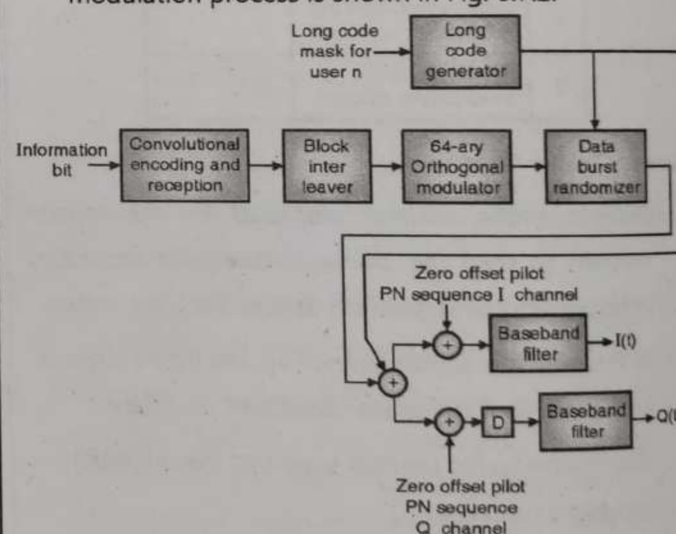
6.7.2 Reverse Channel Modulation Process : GTU : S-20, W-20

University Questions

Q. 1 State the reason(s) for the IS-95 CDMA system to use rate 1/2 convolution encoding in the forward channel and rate 1/3 convolution encoding in the reverse channel. **(S-20, W-20, 4 Marks)**

Block diagram:

– The block diagram of reverse traffic channel modulation process is shown in Fig. 6.7.2.



(G-1576) **Fig. 6.7.2 : Reverse IS-95 channel modulation process for a single user**

– User data on the reverse channel are grouped into frames with a duration of 20 ms each.

– The following processes are carried out on the reverse channel user data :

1. Convolutional encoding.
2. Block interleaving.
3. Modulation by 64-ary orthogonal modulation.
4. Spreading and transmission.

- The convolutional coder used in the reverse traffic channel has the rate 1/3 and a constraint length of K = 9 generates three code symbols for each data bit input to the encoder.
- Rate 1/3 code is a more powerful error correction code as compared to the rate 1/2 code. Therefore it requires quite sophisticated circuitry at the base station receiver.
- Such a sophisticated circuitry cannot be used at the mobile stations.
- Hence instead of rate 1/3 code, a rate 1/2 convolutional code is preferred for the forward channel.
- Rate 1/3 code is used for the reverse channel because at the CDMA base station multiple signals arrive with approximately the same power.
- Due to multipath delay spreads and synchronization errors, these user signals cause mutual interference.
- The stronger the error control code, the more signals can be tolerated on the channel, so the higher the user capacity of the system.

6.8 IS-95 CDMA Call Processing :

- In order to set up a call or transmit data, it is necessary to establish a data path through the traffic channel.
- A mobile station in IS-95 goes through the following states, in order to establish such a transmission channel :
  1. System initialization
  2. System idle state
  3. System access
  4. Traffic channel state

1. **System initialization state :**

- In this state, the mobile acquires a pilot channel by searching all the PN offset possibilities.
- Ultimately it selects the strongest pilot signal. Then it acquires the sync. channel and detects the pilot channel.
- After this the mobile gets the system configuration and timing information.

2. **The idle state :**

- The next state is called system idle state. The mobile enters into this state and it monitors the paging channel.

3. **Access state :**

- In the idle state the mobile monitors the paging channel and if a call is being placed or received, it enters into the access state.
- In this state it exchanges the necessary parameters.
- The mobile and base station transmit their responses on the access channel and the paging channel respectively.

4. **Traffic state :**

- If the access is successfully done then the mobile enters into the last state i.e. traffic state in which the transactions of voice and data takes place.

6.9 IS-95 CDMA Packet and Frame Format :

- In IS-95 system, the forward logical channels are of four types - the pilot, the sync, the paging, and the traffic channels whereas the reverse channels are either access channels or traffic channels.
- IS-95 defines two rate sets namely Rate Set 1 and Rate Set 2 depending on the data rates used for the encoded data or encoded voice.
- The data rates in RS1 are lower than those in RS2.
- The forward traffic channels carry user data (either encoded data bits or encoded voice) at the bit rates of 9600, 4800, 2400, or 1200 bps in **Rate Set 1** and 14400, 7200, 3600, or 1800 bps in **Rate Set 2**.
- The forward traffic frame is 20 ms long in duration.
- Table 6.9.1(a) demonstrates the number of information bits, tail bits and CRC bits used in a forward traffic channel frame for different data rates.
- Note that the number of information bits increases with increase in the data rate.

- Each frame consists of these fields, but their lengths are different depending on the data rate.

(G-2799) **Table 6.9.1(a) : Forward traffic channel frame contents for RS 1**

Data rate (bps)	Number of bits		
	Information bits	Tail bits	CRC bits
1200	16	8	0
2400	40	8	0
4800	80	8	8
9600	172	8	12

6.9.1 IS-95 Forward Channels Frame Format :

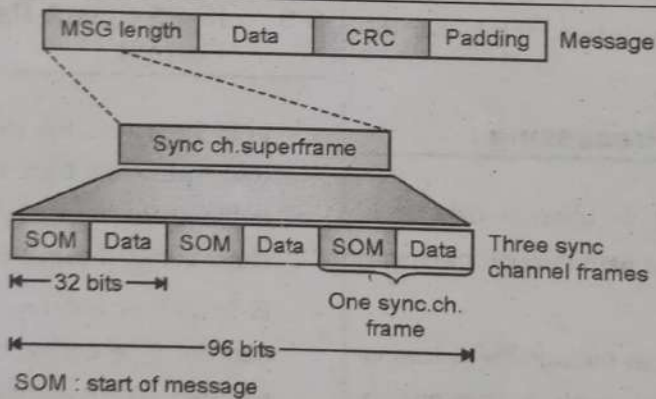
- The information related to the system identification (SID), PN, short sequence offset, PN long code state, Network ID (NID) and the system time etc is provided to the mobile station (MS) by the sync channel.
- Such messages can have a long length and therefore they are fragmented into synch frames of 32 bits as shown in Fig. 6.9.1(a).

(G-2800) **Table 6.9.1(b) : Forward traffic channel frame contents for RS 2**

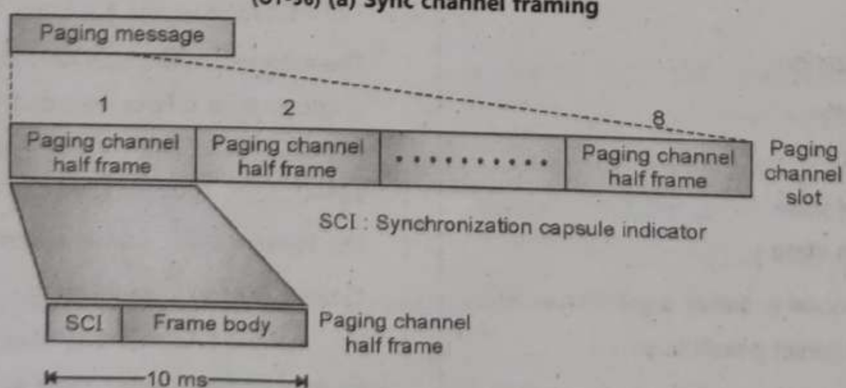
Data rate (bps)	Number of bits		
	Information bits	Tail bits	CRC bits
1200	21	9	6
2400	95	9	8
4800	125	9	12
9600	267	9	12

Sync Channel Framing :

- Fig. 6.9.1(a) shows the sync channel framing in IS-95.
- It shows that each sync channel frame is 32 bit long and consists of two fields namely :
- SOM and DATA where SOM stands for Start Of Message.
- Three such sync channel frames are combined together to form a sync channel superframe.
- Therefore its length is of 96 bits.



(OT-36) **(a) Sync channel framing**



(b) Paging channel framing

(OT-37)**Fig. 6.9.1 : IS-95 forward channel framing**

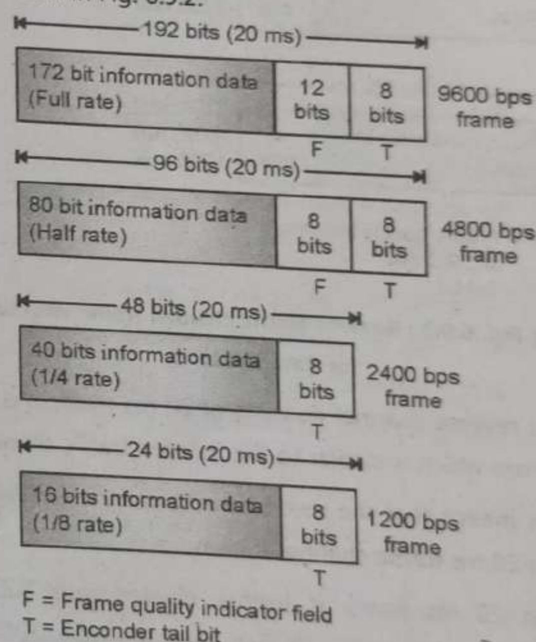
- The value of SOM is 1 for the first sync channel frame and zero for the subsequent ones the belong to the same message.
- As shown in Fig. 6.9.1(a), the message itself consists of four fields namely: the message length, the data, and error checking code (CRC) and some padding.
- Padding is necessary to ensure that every new message starts in a new superframe. Note that the padding bits are all zeros.
- The frame length of access channel is 96 bits with a duration of 20 ms.

Paging Channel Framing :

- Fig. 6.9.1(b) shows the paging channel framing in IS-95.
- The paging channel is used to provide a variety of parameters to a MS such as the traffic channel information, the temporary mobile subscription identity, response to access request and list of neighboring base station along with their parameters.
- Paging can be either slotted or unslotted.
- The slotted paging which enables the MS to save its battery power. Such channel is divided into 80 ms slots.
- The structure of the paging channel message is similar to that of the sync channel message.
- However it is too long for transmission in one slot.
- Therefore it is fragmented into 47 or 95 bits (for data rate of 9600 or 4800 bps respectively) and transmitted over a paging channel half frame (10 ms).
- As shown in Fig. 6.9.1(b) a paging channel half frame consists of two fields namely SCI and frame body.
- The synchronization capsule indicator (SCI) bit in the paging channel half frame has a similar functionality to the SOM bit.
- In this case however, a message can start anywhere (not necessarily in a half frame) and if SCI = 0 then it indicates that one paging message has ended and another is starting within the same half frame.
- Eight paging half frames are combined to form one paging slot. Hence its length is 80 ms.
- The number of bits carried per half frame depends on the data rate for example if data rate is 9600 bps, then the number of bits carried by a 10ms half frame will be 96 bits (one bit in a SCI).
- On the other hand it would carry 48 bits if the data rate is 4800 bps.

Forward Traffic Channel Framing :

- Table 6.9.1(a) shows the number of information bits, frame error control check (CRC) bits and tail bits in Rate Set 1.
- The forward traffic channel frame is 20 ms long. The forward channel frame structure for Rate Set 1 is shown in Fig. 6.9.2.



(OT-31) **Fig. 6.9.2 : Forward traffic channel frame structure for Rate Set 1**

6.9.2 Frame Formats of Reverse Channel :

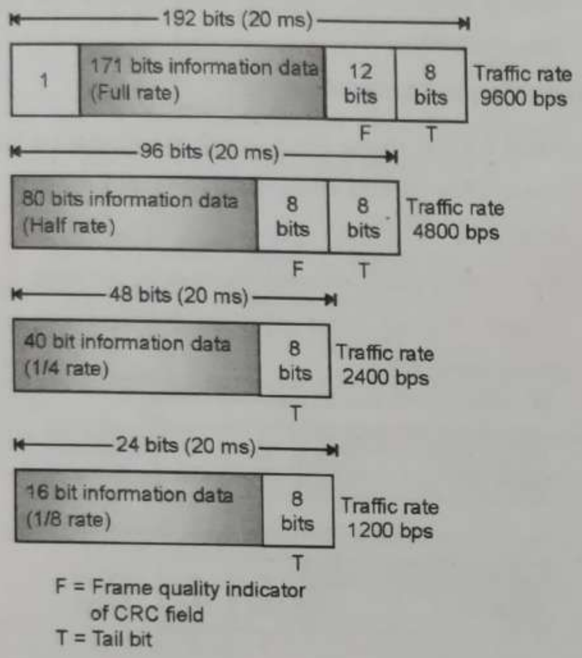
Access channel frame :

- The access channel data rate is 4800 bps and each access channel message consists of multiple access channel frames which last 20 ms.
- Thus the length of an access frame is 96 bits. An access channel message consists of several 96 bits frames with all bits in the frame equal to Zero.

- The actual message itself is fragmented into 96-bit frames that have 88 bits of data and 8 tail bits set to zero.

Reverse traffic channel :

- The reverse traffic channel frame is 20 ms long. The reverse channel frame structure for Rate Set 1 is shown in Fig. 6.9.3.



(OT-43) **Fig. 6.9.3 : Reverse traffic channel frame structure for Rate Set 1**

- The reverse channel consists of 20 ms traffic channel frames which is similar to the forward traffic channel.
- This means that the reverse traffic channel is divided into 20 ms traffic channel frames.
- Each 20 ms frame is further divided into 1.25ms power control groups (PCGs). There are thus 16 PCGs in one frame.
- In order to ensure less interference on the reverse channel, a data burst randomizer is used to randomly masks out individual PCGs depending on the data rate.
- For example, at half the data rate (4.8kbps), eight of the total sixteen PCGs are masked.
- In addition to voice traffic, the traffic channel can also be used to transfer signalling or secondary data.
- The entire frame carries data in the blank and burst case.
- The frame structure for the reverse traffic channels is very similar to that of the forward traffic channel.

6.10 Handoffs in IS-95 CDMA :

- We have discussed the principle of hand offs. It is called as handover in GSM and handoff in IS-95.
- There are three possible types of handoffs in IS-95 as follows :
  1. Soft handoff
  2. Hard handoff
  3. Softer handoff
- As shown in Fig. 6.10.1, each CDMA cell is divided into 3 equal sectors (α, β and γ).
- Each sector corresponds to one third of the total cell area or 120° as shown in Fig. 6.10.1.

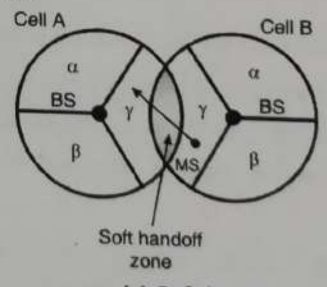
6.10.1 Soft handoff : GTU : W-14, S-17, S-18

University Questions

Q. 1 Explain the following term with reference to CDMA
1. Power control
2. Soft hand-off
3. Frequency hopping **(W-14, S-17, 7 Marks)**

Q. 2 Explain three types of soft handoffs in IS-95 standard. **(S-18, 3 Marks)**

- Refer Fig. 6.10.1(a). The soft handoff takes place when the mobile station MS moves from one cell to the other.



(a) Soft handoff

(G-1578) **Fig. 6.10.1 : Handoffs in IS-95**

- In the soft handoff, the control of a Mobile Station (MS) is transferred to an adjacent cell or an adjacent sector without disconnecting its connection with the original B.S.
- Thus the MS keeps talking to its old and new BSS simultaneously.

- As soon as the new communication link with a new BS is fully established the older connection is terminated.
- This process is a make before break process which ensures that there is no loss of service when the handoff is taking place.
- Fig. 6.10.1(a) shows the soft handoff taking place when an MS moves from cell B to cell A.
- In the Soft handoff the MS communicates with two (or three) sectors of different cells at the same time.
- A three-way soft hand-off can end by first dropping one of the sectors of any base station.
- Then it becomes a two-way soft hand-off.
- As compared to softer hand-off, a soft hand-off uses considerably more network resources.

6.10.2 Hard handoff :

- The handoff is known as hard handoff if a MS moves between two base stations having different operating frequencies.
- In the hard handoff, the MS first terminates the original connection before establishing the connection with a new B.S.
- The voice is muted for a very short time when the handoff is taking place.
- The handoff is completed very fast so the break in voice is not even noticed.

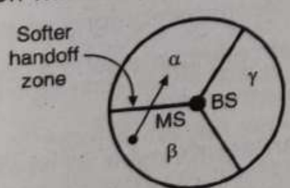
6.10.3 Inter-sector or Softer handoff :

GTU : S-18

University Questions

Q. 1 Explain three types of soft handoffs in IS-95 standard. **(S-18, 3 Marks)**

- If a MS moves from one sector to the other within the same cell as shown in Fig. 6.10.1(b), then the softer handoff will take place.



(b) Softer handoff

(G-1578) **Fig. 6.10.1 : Handoffs in IS-95**

- The softer handoff is a logical handoff and uses the signals from all other base stations.

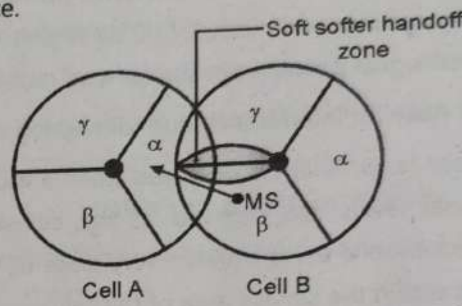
6.10.4 Soft-softer handoff :

GTU : S-18

University Questions

Q. 1 Explain three types of soft handoffs in IS-95 standard. **(S-18, 3 Marks)**

- If a MS communicates with two sectors of one cell and one sector of another cell as shown in Fig. 6.10.1(c), then the Soft-softer handoff will take place.



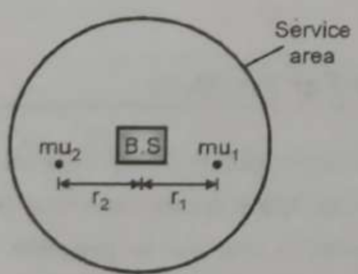
(OT-58) **Fig. 6.10.1 (c): Soft-softer handoff**

- As shown in Fig. 6.10.1(c), the candidate sectors for hand-off include two sectors from the cell B and a third sector from a neighbouring cell A.
- For this type of handoff, the network resources required includes the resources for a two-way soft handoff between cell A and B and the resources for a softer handoff of the cell involving two sectors of cell B.

6.11 Near-Far Problem :

- In CDMA IS-95 system a new type of interference related to **multiple-access interface (MAI) occurs** which is called as the **near far problem**.
- This problem arises if the received signals from various mobile units do not have equal power at the receiving base station.
- In the near far problem, the strongest signal will capture the demodulation process.
- This problem can be overcome by exercising a power control at the base station in order to control the power level of the transmitted signal from every mobile which is coming under that base station.

- The problem of near-far interference can be illustrated with a scenario in which a nearby and a far-off mobile user transmit with the same power(say +30dBm).
- Let the respective propagation-path loss be 35 dB and 95 dB.
- Therefore, the received power at base station from these two mobile users will be (+ 30 dBm– 35 dB) = – 5 dBm. and (+30 dBm – 95 dB) = – 65 dBm.
- Thus, there is an in-band interference power, caused by the near-in mobile user, of 60 dB higher than the received signal power from the far-end mobile user.
- This is near-far interference due to masking effect.
- The near-far problem is observed when a wide range of signal levels are received at the cell-site from different mobile users situated very close or far away from it within the service area of the cell.
- In order to prevent the signal from one mobile user (operating nearer to the cell-site) overtaking that of another mobile user (operating far away from the cell-site at the same time), strict power control at the mobile-transmitter end needs to be implemented.
- Consider a cellular system of Fig. 6.11.1 in which two Mobile Users (MUs) are communicating with a base station.



(G-2739) **Fig. 6.11.1 : Illustration of near-far problem**

- It is assumed that the transmission power of each MU to be the same.
- Then the received signal levels at the BS from the MU_1 and MU_2 are very different due to the difference in the propagation signal path-lengths.
- If $r_1 < r_2$ then the received signal level from MU_1 will be much larger than that received level from MU_2 at the base station.

6.12 Mobility and Radio Resource Management :

6.12.1 Mobility Management :

- The purpose of mobility management function is to support the registration and deregistration of a MS when it is on the move.
- In addition to this, the other tasks of mobility management are authentication and voice privacy.
- IS-95 uses spread spectrum technology. This makes the standard a bit complex.

6.12.2 Concept of Resource Management :

- Radio resource management (RRM) is the management of co-channel interference, radio resources, and other radio transmission characteristics at the system level in different wireless communication systems such as cellular networks, wireless local area networks, wireless sensor systems etc.
- The objective of resource management (RM or RRM) is to utilize the limited radio-frequency spectrum resources and radio network infrastructure as efficiently as possible.
- The radio resource management (RRM) involves strategies and algorithms to control various parameters such as :

  1. Transmit power,
  2. User allocation,
  3. Beam forming,
  4. Data rates,
  5. Handover criteria,
  6. Modulation scheme,
  7. Error coding scheme.

- RRM is used to improve the multi-user and multi-cell network capacity, rather than in improving the point-to-point channel capacity.
- Traditional telecommunications research is focused on the channel coding and source coding techniques with a single user in mind.
- However in an environment in which, several users and adjacent base stations share the same frequency channel, the traditional approach may not achieve the maximum channel capacity.

- Instead new and efficient dynamic RRM schemes are used that increase the system spectral efficiency to a great extent as compared to what is possible by introducing advanced channel coding and source coding schemes.
- RRM is especially important in the systems limited by co-channel interference rather than by noise, for example cellular systems and wireless networks consisting of many adjacent access points, that are operating on the same channel frequencies.
- The cost for deploying a wireless network mainly depends on the costs related to the base station sites (real estate costs, planning, maintenance, distribution network, energy, etc.) and also by frequency license fees.
- Therefore, the objective of radio resource management is to maximize the system spectral efficiency in bit/s/Hz/area unit or Erlang/MHz/site, with a constraint that the grade of service should be above a certain level.
- Provision of grade of service of an adequate level involves covering a certain area and avoiding outage due to multiple possible reasons such as the co-channel interference, noise, attenuation due to path losses, fading due to shadowing and multipath, Doppler shift and distortion.
- The grade of service is also affected by blocking due to admission control, scheduling starvation or inability to guarantee quality of service that is requested by the users.
- The **classical RRM techniques** primarily considered the allocation of time and frequency resources (with fixed spatial reuse patterns).
- However due to the recent multi-user MIMO techniques, it is possible to employ the adaptive resource management in the spatial domain as well.
- An example of RRM in cellular networks is that the fractional frequency reuse in the GSM standard has been replaced by a universal frequency reuse in LTE standard.

Static radio resource management :

- Static RRM involves manual as well as computer-aided fixed cell planning or radio network planning, which involves the following aspects :
  1. Frequency allocation band plans decided by standardization bodies, by national frequency authorities and in frequency resource auctions.
  2. Deployment of base station sites (or broadcasting transmitter site)
  3. Antenna heights
  4. Channel frequency plans
  5. Sector antenna directions
  6. Selection of modulation and channel coding parameters
  7. Base station antenna space diversity
  8. Circuit mode communication using FDMA and TDMA.
  9. Fixed channel allocation (FCA)
  10. Static handover criteria
- Static RRM schemes are used in many traditional wireless systems, for example 1G and 2G cellular systems.

Dynamic radio resource management :

- The dynamic RRM schemes are adaptive in nature.
- They adaptively adjust various radio network parameters based on the traffic load, user positions, user mobility, quality of service requirements, base station density, etc.
- Dynamic RRM schemes are considered in the design of wireless systems, so as to minimize expensive manual cell planning and achieve "tighter" frequency reuse patterns.
- This results in improved system spectral efficiency.
- Some of the dynamic RRM schemes are centralized, in which, multiple base stations and access points are controlled by a Radio Network Controller (RNC).
- Others dynamic RRM schemes are distributed in nature and in the form of autonomous algorithms in mobile stations, base stations or wireless access points.

- Otherwise these schemes are coordinated by exchanging information among these stations.
- Examples of dynamic RRM schemes are as follows :
  1. Power control algorithms
  2. Pre coding algorithms
  3. Link adaptation algorithms
  4. Dynamic Channel Allocation (DCA) or Dynamic Frequency Selection (DFS) algorithms, allowing "cell breathing"
  5. Traffic adaptive handover criteria, allowing "cell breathing"
  6. Re-use partitioning
  7. Adaptive filtering
  8. Dynamic diversity schemes, for example Soft handover
  9. Phased array antenna with beam forming, multiple-input multiple-output ommunications (MIMO), space-time coding
  10. Admission control
  11. Dynamic bandwidth allocation using resource reservation multiple access schemes or statistical multiplexing, for example Spread spectrum and/or packet radio
  12. Channel-dependent scheduling, for instance
  13. Mobile ad hoc networks using multihop communication.

6.13 Security and Authentication in IS-95 CDMA :

- The Electronic Serial Number **(ESN)** is a 32 bit binary number is used in the IS-95 system to identify a mobile.
- This number is set in the factory and it cannot be changed by anyone else.
- Every mobile is assigned a unique ESN number by the manufacturer.
- A mobile station also has a different 15-digit number called as Mobile Identification Number **(MIN).**
- This number is nothing but the mobile's 10 digit directory number.
- When we turn on a mobile, it gets registered with the network.
- During the process of authentication the network throws a challenge to the mobile to prove its identify.
- The Authentication Center (AC) transmits a random number to the mobile station.
- The MS encrypts this message and sends it back to AC.
- The AC checks this message with a message it has produced using the same encryption.
- If both messages match, then the mobile is authenticated.
- After successful authentication, the VLR assigns **TMSI** (Temporary International Mobile Subscriber Identity).
- TMSI provides anonymity because this identity is known only by the mobile and the network.
- The CDMA traffic in IS-95 is fully secure and if someone wants an access to this encrypted traffic he should know the PN sequence used for encryption and spreading.

6.14 Output Power Control in CDMA :

GTU : W-14, S-15, S-17

University Questions

Q. 1 Explain the following term with reference to CDMA

1. Power Control
2. Soft hand-off
3. Frequency hopping. **(W-14, S-17, 7 Marks)**

Q. 2 Explain how power control is achieved in CDMA. **(S-15, 7 Marks)**

- The power control is especially important for CDMA systems because they allow every user in every cell to share the entire bandwidth all the time.
- So as to minimize the Bit Error Rate (BER) for each user, the IS-95 makes every effort to force each user to provide the same power level to the Base Station (BS) receiver.
- The base station reverse traffic channel receiver estimates and responds to the signal strength of a Mobile Station (MS).

- The signal strength and interference are varying continuously.
- Therefore a dynamic power control is exercised by the BS by sending update signals to the MS after every 1.25 ms.
- These power control commands are sent to each mobile subscriber unit on the forward control subchannel.
- It tells the MS to increase or decrease their output power in steps of 1 dB.
- If the received signal at the BS receiver is low then a 0 (Zero) is transmitted over the power control subchannel.
- This tells the MS to increase its output power by 1 dB.
- On the other hand, if the received signal at the BS receiver is high, then a 1 (One) is transmitted to instruct the MS to reduce its output power by 1 dB.
- This type of power control is called as the **closed loop** power control because it is continuously measuring and adjusting the output power of a MS.
- If the output power of MS is controlled with taking into consideration, the received signal power at BS then the control is called as the **open loop control**.

6.14.1 Performance of the CDMA System :

- The parameter that determine the performance of a CDMA digital cellular system are as given below :

1. Processing gain $\left(\text{ratio of spreading code to information data rate } \frac{W}{R}\right)$
2. Voice activity factor
3. Ratio of energy per bit to noise power $\left(\frac{E_b}{N_0}\right)$
4. Frequency reuse efficiency
5. Number of sectors in the cell-site antenna.

- The capacity of a CDMA system is,

$$N_p = \frac{(W/R)\ v\ S}{(E_b/N_0)\ F}$$

- Where N_p is capacity in terms of number of calls / 1.25 MHz channel cell.

W/R : ratio of spreading code (1.2288 Mcps) to maximum information rate (9.6 kbps)

v : Voice activity gain (approximately 2)

S : sectors per cell

$\frac{E_b}{N_o}$: minimum ratio of bit energy to noise power (6 dB or factor of 4)

F : frequency reuse efficiency factor (approximately 32)

- Hence, the theoretical capacity of CDMA channel is of the order of 128 calls per 1.25 MHz channel per cell.
- The effects of thermal noise are neglected.
- Practically the CDMA systems are operated at maximum capacity loading such that about half the receiver noise is from mutual interference and other is thermal noise that reduces the system capacity to half.

6.15 Comparison of GSM and IS-95 :

- The comparison of GSM and CDMA IS-95 is as given in Table 6.15.1.

Table 6.15.1 : Comparison of GSM and IS-95

Sr. No.	Parameters	GSM system	IS-95 system
	Frequency band	900 MHz, 1800 MHz, 1900 MHz.	900 MHz, 1900 MHz.
2.	Number of full duplex channel	125	20
3.	BW of each channel	200 kHz	1250 kHz (1.25 MHz)
3.	Type of multiple access technique used	TDMA	CDMA
4.	Number of users per channel	8	20 to 35
5.	Type of modulation	GMSK	QPSK
6.	Data rate	9.6 kbps	9.6 or 14.4 kbps

Sr. No.	Parameters	GSM system	IS-95 system
7.	Frame duration	4.615 ms	20 ms
8.	Multipath phenomenon	Causes fading and interference	No problems due to RAKE receiver
9.	SIM card	Yes	No
10.	Hand off type	Hard	Soft
11	System capacity	Fixed and limited	Flexible
12	Cost	High	Low
13.	SMS length	160 characters or 140 octets	120 Octets

6.16 Advantages of CDMA IS-95 :

GTU : S-12, W-17

University Questions

Q. 1 Explain the advantages of CDMA over GSM system in terms of Multipath characteristics, Privacy features, Security and Quality degradation. **(S-12, 8 Marks)**

Q. 2 List advantages and disadvantages of CDMA compared to GSM. **(W-17, 4 Marks)**

- The CDMA systems have the following advantages over the 2G GSM systems and other 2G systems.

1. **Higher capacity :**

- One main advantage of CDMA is its higher capacity. CDMA can accommodate more users per MHz of bandwidth than any other system of the same generation.
- Therefore the IS-95 has the capacity that is 4 to 5 times higher than that of GSM.

2. **Better quality calls :**

- The CDMA call quality is better with more consistent sound as compared *-to that of the GSM.
- The handoff features reduces call dropping in IS-95 CDMA.
- The interference is less than that in GSM.

3. **Better coverage :**

- CDMA system gives better coverage and needs few antenna sites and consumes less power.

4. **Easy management of frequency reuse :**

- CDMA uses one frequency per cell. Hence, the frequency reuse plan is easier to manage.

5. **Better multi-path performance :**

- When the radio signal is transmitted to a receiver, it can take direct route or it can take reflected path.
- It leads to multipath effect causing interference. The multipath performance of CDMA is better than that of the GSM.

6. **Higher security :**

- It is not possible to decode the CDMA messages easily because it uses DSSS-CDMA.
- Hence, it offers increased cellular communications security.

7. **Better privacy features :**

- There is an inherent higher privacy in the CDMA technology due to the encryption is inherent to CDMA.
- Hence the CDMA phone calls will be secure from the casual eavesdropper.

8. **Increased efficiency** because it can serve more users.
9. Low power requirements.
10. CDMA phones are smaller in size as compared to the GSM phones.

6.17 Disadvantages of CDMA IS-95 :

GTU : W-17

University Questions

Q. 1 List advantages and disadvantages of CDMA compared to GSM. **(W-17, 4 Marks)**

- The CDMA systems have the following disadvantages :
  1. CDMA is relatively new. The network is not as mature as the GSM.
  2. CDMA cannot offer international roaming, a large GSM advantage.

3. The CDMA system performance degrades with increase in the number of users.

Ex. 6.17.1 : In an IS-95 system, calculate the processing gain in dB if the baseband data rate is 9.6 kbps, 4.8 kbps, 2.4 kbps and 1.2 kbps in rate set 1 (RS1). If the error correction codes increase the data rate to 19.2 kbps, recalculate the processing gain. Comment on the results obtained.

Soln. :

Given : IS – 95 system, Baseband rate R_b = 9.6, 4.8, 2.4 and 1.2 kbps.

- Note that the processing gain, G_p is given by,

$$G_p = \frac{B_C}{R_b}$$

- Where B_C = Channel bandwidth and R_b is the baseband (before spreading) bandwidth or baseband data rate.
- In IS-95, the standard RF bandwidth, B_c = 1.2288 Mcps

Step 1 : To calculate the processing gain G_p at 9.6 kbps :

Given : R_b = 9.6 kbps and B_c = 1.2288 Mcps

$\therefore$ Processing gain, $G_p = B_c / R_b = \dfrac{1.2288 \times 10^6}{9.6 \times 10^3}$

$$\therefore \quad G_p = 128 \quad \text{...Ans.}$$

$$\text{And} \quad G_p\,(\text{dB}) = 10 \log 128 = 21 \text{ dB} \quad \text{...Ans.}$$

Step 2 : To calculate the processing gain, G_p at other values of R_b :

- Using the same formula of G_p we can calculate the processing gain for different values of R_b.
- These values have been given in Table P. 6.17.1.

Table P. 6.17.1 : Processing gain for different values of R_b

Sr. No.	R_b kbps	B_c Mcpc	G_p	G_p (dB)
1.	4.8	1.2288	256	24
2.	2.4	1.2288	512	27
3.	1.2	1.2288	1024	30

Step 3 : To calculate the processing gain, G_p at 19.2 kbps:

- The increased data rate after error correction is

$$R_b = 19.2 \text{ kbps}$$

$$\therefore \quad G_p = B_c / R_b = 1.2288 \text{ Mbps}/ 19.2 \text{ kbps} = 64 \quad \text{...Ans.}$$

$$\therefore \quad G_p\,(\text{dB}) = 10 \log 64 = 18 \text{ dB} \quad \text{...Ans.}$$

Comment :

- The processing gain decreases with increase in the value of R_b.
- Due to error correction, redundant bits are added, which increases the value of R_b and reduces the processing gain.

6.18 Rake Receiver :

GTU : S-17, S-18, W-19, S-20, W-20

University Questions

Q. 1 Describe a Rake receiver in CDMA. **(S-17, 7 Marks)**

Q. 2 Explain the concept of RAKE receiver in CDMA. **(S-18, 7 Marks)**

Q. 3 Describe the Rake receiver in CDMA. **(W-19, 7 Marks)**

Q. 4 Explain briefly how a RAKE receiver improves the received signal strength. **(S-20, W-20, 3 Marks)**

Definition :

- A rake receiver is a radio receiver that is designed to counter the effects of multipath fading.
- It does this by using several "sub-receivers" called **fingers**, that is, several correlators each assigned to a different multipath component.

Function of a RAKE receiver :

- In the environment of a multipath propagation, the direct and reflected versions of the transmitted signal reach the destination with different path delays.
- At the mobile receiver signal fading is observed due to multipath propagation.
- In CDMA cellular mobile phone DSSS receivers, RAKE receivers are commonly used, to provide a strong

signal reception in a hostile mobile radio environment.

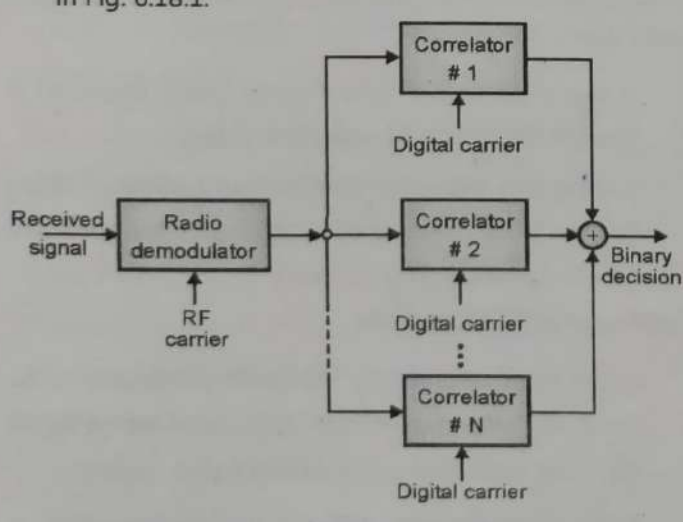
- The mobile receiver recovers the signal by **correlating** the chip sequence with the dominant received signal.
- The remaining signals are treated as noise.
- No pilot channel available for the reverse channel transmission.
- In order to obtain high-quality carrier-channel estimation, a pilot channel is useful.
- It makes Coherent detection and combining of multipath components possible.
- By combining direct and reflected signals in the receiver, the effect of multipath interference can be reduced.

Principle of RAKE Receiver :

- This is operating principle of the RAKE receiver used in CDMA systems is as follows:
- The receiver tries to recover the signals that it receives from multiple paths and then combine them with suitable delays to obtain a good quality output signal.

Block diagram :

- The block diagram of the RAKE receiver is illustrated in Fig. 6.18.1.



(OT-38) **Fig. 6.18.1 : Principle of RAKE receiver**

Operation :

- The Rake receiver processes several multipath signals components.
- The original information signal is in the binary form is spread with the help of XOR operation with the PN spreading code.
- This spread spectrum signal is then modulated and transmitted over the wireless channel.
- The wireless channel generates multiple copies of the same signal due to multipath effects, each with a different amount of time delay and attenuation factors (a_1, a_2 etc.).
- The multiple copies of the transmitted signal combine together and this combined signal is applied to the receiver.
- The combined signal is demodulated at the receiver and the demodulated chip stream is applied to multiple correlators, each delayed by a different amount.
- These signals are then combined using weighting attenuator factors (a_1 , a_2 etc.) estimated from the channel characteristics.
- The outputs of the correlators are then brought together in a diversity combiner whose output is the estimate of the transmitted information symbol.
- This is done to achieve better reliability and communication performance.
- In a DSSS system, a RAKE receiver optimally combines the multipath components as part of the decision process.
- A RAKE receiver can combine the received signal paths using any standard diversity combiner technique such as a selective, equal-gain, square-law, or maximal-ratio combiner.
- A maximal-ratio technique is widely used which resolves all the paths and does not introduce any inter symbol interference to provide optimum system performance in the presence of time diversity.

Improvement in S/N ratio :

- Each finger in a rake receiver independently decodes a single multipath component.

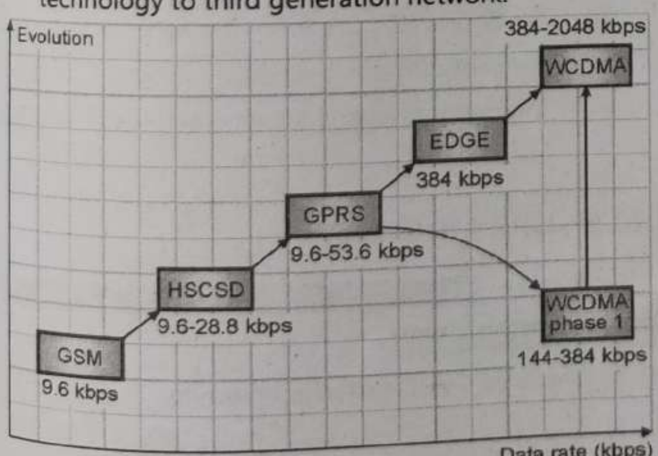
- at a later stage the outputs of all fingers are combined in order to make the most use of the different transmission characteristics of each transmission path.
- This could very well result in higher signal-to-noise ratio (or E_b/N_0) in a multipath environment than in a "clean" environment.

6.18.1 Advantages of RAKE Receiver :

- Some of the important advantages of a RAKE receiver are as follows:
  1. Better reliability
  2. Higher performance
  3. It makes the reception of a multipath signal possible in the hostile mobile environment.
  4. It improves the S/N ratio of the mobile system.
  5. It provide a better estimate of the transmitted signal.

6.19 Evolution from GSM to 3G Networks :

- An evolution from the present 2G technology to 3G technology takes place in two steps based on GSM and IS.95 CDMA respectively.
- Fig. 6.19.1(a) shows an evolution path from GSM 2G technology to third generation network.



(G-2545) **Fig. 6.19.1(a) : Evolution path from GSM to 3G**

- GSM is cellular technology which is open and supports data transfer and voice calls with speeds up to 9.6 kbps simultaneously with the transmission of the SMS (Short message service).
- In Europe GSM operates in the range of 900 MHz and 1.8 GHz frequency bands and in US GSM operates in the range 850 MHz-1.9 GHz.
- Roaming capability is also provided by GSM so that when travelling abroad users can access the seamless services.
- **HSCSD** is a high speed circuit switched data which allows data transfer rapidly as compared to standard GSM using multiple channels.
- Widely used wireless data service is **GPRS** which has now become available with GSM networks.
- The data rate offered by GPRS is of up to 53.6 kbps, so that users can have access speed similar to dial-up modem with convenient access from anywhere.
- EGPRS is a technology which offers the data capacity three times more as that of GPRS.
- It provides data services such as high speed internet access, email and multimedia messaging etc.
- With simple software up gradation it is possible for EDGE to overlay directly onto existing GSM.
- For 3G system WCDMA is the air interface which supports to services such as text, voice and MMS.
- UMTS provide data speed of 2.048 Mbps when it is stationary and when moving it provides speed of 384 kbps.

6.20 GPRS - General Packet Radio Service : GTU : W-12

University Questions

Q. 1 Explain briefly GPRS. **(W-12, 3 Marks)**

- GPRS is a packer based technique which could be the next step in evolution of GSM as well as IS-136 and PDC standards (all the TDMA based 2G standards).

Principle :

- GPRS operates by supporting a multiple user network sharing of individual channels and time slots.

- This is different than the principle of HSCSD. Due to this technique. GPRS can support many more users than HSCSD but in a burst manner (non-continuous manner).
- The GPRS standard provides a packet network on dedicated GSM or IS-136 radio channels.

Air interface :

- The modulation formats specified in the original 2G TDMA standards (GSM and IS-436) are retained in GPRS.
- But it uses a completely redefined air interface (as compared to GSM or IS - 136) for better handling of data.
- GPRS has dedicated radio channels and particular time slots that allow an **always on** access to the network.
- The GPRS subscribers are instructed automatically, to tune to the above mentioned channels and time slots.

Data rates :

- If all the eight time slots of a GSM channel are dedicated to GPRS, it is possible for an individual user to achieve a data rate of 171.2 kbps.
- However these data rates decrease with increase in the number of users trying to use the GPRS network.
- The data rate specified by GPRS (dedicated peak) i.e. 21.4 kbps per channel operates well with both GSM and IS-136 and has been successfully implemented.
- There are eight time slots of a GSM radio channel.
- When all of them are dedicated to GPRS, a user can achieve a data rate of $8 \times 21.4 = 171.4$ kbps.

Error correction :

- In GPRS the applications are required to provide their own error correction schemes.

GPRS implementation :

- For implementation of GPRS, the GSM operator needs to install only the new routers and gateways at the base station.
- A new software that redefines the base station air interface and time slots, is also needs to be installed at standard the base station.
- A new RF base station hardware is also required.

6.20.1 Features of GPRS :

- Some of the most important features of GPRS are as follows :
  1. Channel bandwidth : 200 kHz.
  2. Duplex : FDD.
  3. No new spectrum is required.
  4. Old GSM handsets cannot be used. Needs new GPRS handsets.
  5. It is built on the existing GSM network to provide high-speed data service.
  6. GPRS has dedicated radio channels and particular time slots that allow an **always on** access to the network.
  7. High data rate up to 171.2 kbps for a single user.
  8. GPRS supports both point-to-point and point-to- multipoint packet service.
  9. GPRS is designed to support bursty applications like email, traffic telematics, telemetry, broadcast services and web browsing.
  10. GPRS provides the following security services : Authentication, access control, user information confidentiality and user identity security.

6.20.2 GPRS Architecture :

GTU : W-13, S-14, S-15, S-16, S-17, W-19

University Questions

Q. 1 Describe GPRS system architecture. **(W-13, 7 Marks)**

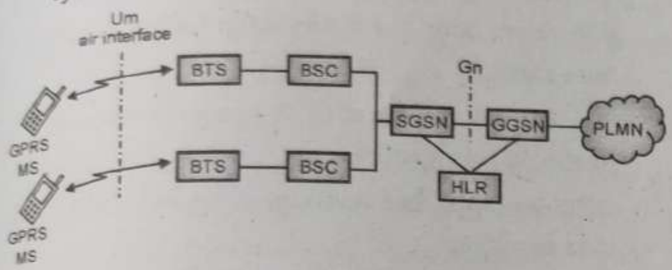
Q. 2 Draw the architecture of GPRS system and explain in brief about each block. **(S-14, 7 Marks)**

Q. 3 With the help of a neat sketch, describe GPRS architecture. **(S-15, 7 Marks)**

Q. 4	What is the difference between 2G, 2.5G and 3G? Describe GPRS architecture. **(S-16, 7 Marks)**
Q. 5	With the help of a neat sketch, describe GPRS architecture. **(S-17, W-19, 7 Marks)**

Block diagram :

- Fig. 6.20.1 shows the architecture of the GPRS system.



(GT-48) **Fig. 6.20.1 : Architecture of GPRS system**

- In GPRS two new network elements are introduced, which are known as GSN (GPRS support nodes).
- Fig. 6.20.1 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. 6.20.1, 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. 6.20.1.
- 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.

6.20.3 GPRS Radio Interface :

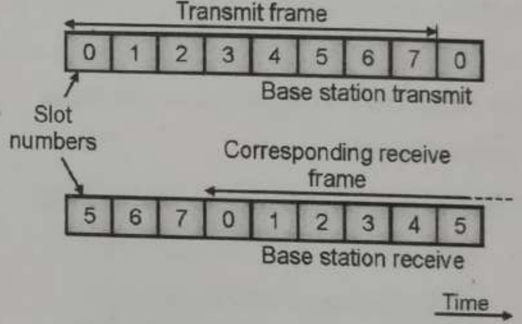
- The GPRS radio interface has to accommodate GSM voice as well as packet data and this requires updates including to the slot & burst.
- One requirement for GPRS was that it would be able to operate alongside the GSM system with mobiles for both types being able to access the radio access network.

GPRS modulation scheme :

- GPRS builds on the basic GSM structure. It uses the same signal format having 200 kHz channel bandwidths.
- It also has the same modulation scheme and using GMSK modulation.
- Retaining the same modulation scheme means that the level of upgrade required to be able to support GPRS in addition to GSM is minimized.
- GMSK modulation was chosen for GSM originally because it offered a number of advantages including good spectral efficiency, resilience to interference, low levels of interference outside the wanted bandwidth, and the ability to use a non-linear RF power amplifier.
- This last point is of great importance because the use of a non-linear power amplifier brings greater levels of efficiency and this results in longer battery life - an important factor for mobile phones.

GPRS frame and slot structure :

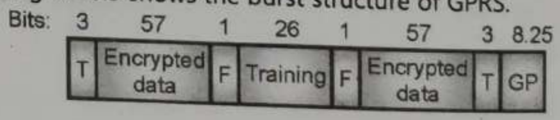
- Again the GRPS air interface employs the same basic structure as that adopted for GSM.
- The overall slot structure for this channel is the same as that used within GSM, having the same power profile, and timing advance attributes to overcome the different signal travel times to the base station dependent upon the distance the mobile is from the base station.
- This enables the burst to fit in seamlessly with the existing GSM structure.
- GPRS employs four levels of error correction in its data encoding.
- The level of error correction used depends upon a number of variables and it is defined as four levels, CS1, CS2, CS3, and CS.
- Fig. 6.20.2 shows the frame structure of GPRS.



(G-2730)**Fig. 6.20.2 : Frame structure of GPRS**

GPRS burst structure :

- Fig. 6.20.3 shows the burst structure of GPRS.



(G-2731) **Fig. 6.20.3 : Burst structure of GPRS**

- Each GPRS burst of information is 0.577 ms in length and is the same as that used in GSM.
- The GPRS burst carries two blocks of 57 bits of information in line with a GSM burst, giving a total of 114 bits per burst.
- It therefore requires four GPRS bursts to carry each 20 ms block of data, i.e. 456 bits of encoded data.
- Slots can be assigned dynamically by the BSC to GPRS dependent upon the demand, the remaining ones being used for GSM traffic.

- Where : T = tail bit and F = coding flag
- The BSC assigns PDCHs to particular time slots, and there will be times when the PDCH is inactive, allowing the mobile to check for other base stations and monitor their signal strengths to enable the network to judge when handover is required.
- The GPRS slot may also be used by the base station to judge the time delay using a logical channel known as the Packet Timing Advance Control Channel (PTCCT).
- The GPRS radio interface is very similar to that of GSM and this enables both GSM and GPRS to operate via the same radio access network.
- They can operate together on the same carrier, bursts of GSM and GPRS occupying the same frame.
- This enabled GPRS to be an evolution of GSM and base stations to steadily have GPRS incorporated into them.

6.20.4 Advantages of GPRS :

- 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.

6.20.5 Disadvantages of GPRS :

- 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.

6.20.6 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).

6.20.7 Comparison of GSM and GPRS :

- Table 6.20.1 gives the comparison between GSM and GPRS.

Table 6.20.1 : 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

6.21 Need of 3G Technology :

- The existing mobile networks such as 2G and 2.5G are not compatible around the world as worldwide devices need contain many technologies into a single device.
- In order to develop a single standard, which will be accepted all over the world, is, the 3G technology was introduced in 2001.
- Existing technologies (GSM/CDMA) were designed for handling mainly the voice traffic and voice oriented services.
- After introduction of 2G and 2.5G technologies into the market, people wanted to have more services other than voice services (such as data based services).
- The requirement of data transmission through mobile networks has been gradually growing due to the popularity of Internet.
- Therefore, some up gradation needs to be introduced to existing networks, to increase the capability, as they do not provide variable data speed, flexibility, supporting quality of service solutions etc.
- For all these reasons, 3G is needed. It provides higher bandwidth, video streaming, video calls, gaming for customers and high speed tele-working, video conferencing, real time financial information etc. for the business, as well as for the domestic users.

6.21.1 Advantages of 3G Wireless Networks :

- Some of the major advantages of 3-G technology are as given below :
  1. The users get high-speed network for their communication, which is better than the 2G technology, particularly for data communication.
  2. The user get wireless broadband.
  3. Using 3G technology customers can see video or satellite based programs like TV programs.
  4. The 3G networks can provide many services in one package, due to the use of DTH and 3G technologies simultaneously. This makes it easy to keep records for different service providers and saves time.
  5. 3G provides uninterrupted video streaming on phones.
  6. Video calls and large MMSs can be sent.
  7. 3G services are cheaper for network providers.
  8. 3G enables video calls, video-conferencing etc.
  9. The 3G networks allow people to access music, picture and videos.
  10. These are much faster than previous networks.

6.21.2 Disadvantages of 3G Wireless Networks :

- Some of the major disadvantages of 3-G technology are as given below :
  1. Due to the cut, throat competition in telecommunication sector, the companies have a very marginal profit for their services.
  2. The companies, that will not get a license from the spectrum distribution authorities will haver to use only 2G, which will badly affect their business.
  3. Due to the combined use of the DTH and the 3G technology, everyone will use these multipurpose services to avoid time loss and keeping records for different service providers. So, the traditional cable business will be badly affected.
  4. With the increased use of the wireless systems the radiation of magnetic waves generated will affect our life too. The radiation of the magnetic waves is dangerous to our life. Long use can affect our brains.

6.21.3 Applications of 3G Networks :

- Some of the important applications of 3G networks are as follows :
  1. Mobile TV.
  2. Mobile internet connectivity.
  3. Downloading various applications.
  4. Multimedia services.
  5. Improved music on your mobile.

6.21.4 Various 3G Standards :

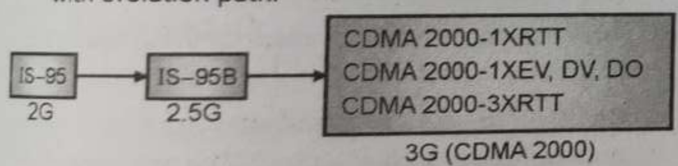
- Different 3-G standards are as follows :
  1. CDMA 2000.
  2. WCDMA - UMTS.
  3. 3GTD – SCD 4. IMT 2000.

6.22 CDMA 2000 Technology :

- The CDMA 2000 is updated technology of 2G and 2.5G CDMA technology.
- As compared to 2G and 2.5G systems, 3G systems supports much higher data rates.
- The structure of CDMA 2000 and 2G CDMA system is same with a channel bandwidth of 1.25 MHz per radio channel.
- CDMA 2000 provides high data rate internet access in existing systems.
- The standards of CDMA 2000 are based on IS-95, IS-95 A and 2.5G IS-95 B standards.
- The drawbacks in the existing CDMA or IS-9 B can be overcome in the 3G technology. CDMA 2000 is designed for forward and backward compatibility in mobile phones.
- The existing CDMA operators can add the improved capabilities of 3G CDMA 2000 at each cell.
- This is an advantage over the W-CDMA system.
- There is no need to change the base stations entirely is an advantage of 3G CDMA 2000.

6.22.1 Advanced Versions of CDMA 2000 :

- Fig. 6.22.1 shows advanced versions of CDMA 2000 with evolution path.



(G-2552) Fig. 6.22.1 : 3G CDMA Evolution path

- Following are the advanced versions of CDMA 2000 :
  1. CDMA 2000-1XRTT (CDMA 2000 1XMC),
  2. CDMA 2000-1XEV, DV, DO
  3. CDMA 2000-3XRTT

1. CDMA 2000-1XRTT (1XMC) :

- The first CDMA 2000 air interface is called as CDMA 2000-1XMC (multicarrier) or CDMA 2000-1XRTT (radio transmission technology) which involves a single 1.25 MHz radio channel.
- This needs new hardware in base station controllers but no need of new radio interface.
- CDMA 2000-1XRTT supports an instantaneous throughout up to 307 kbps and per mobile user it supports typical throughput of up to 144 kbps.
- The number of voice users supported by 3G CDMA 2000 is almost twice the users supported by the 2G IS95 CDMA system.
- Through multi-level keying and incremental redundancy this system uses fast acceptable PN code rates and baseband signaling rates for each and every mobile user.
- By doing appropriate changes in software and adding new channel cards at the base station the performance of CDMA 2000 can be improved.
- By using CDMA technology multicarrier modulation is applied to 3G voice oriented cellular networks.
- To support variety of data channels and more reliable voice, CDMA 2000 uses multicarrier operation where user is agreed to use 1, 3, 6, or 9 of the CDMAONE channel.

Advantages of multicarrier modulation :

1. Higher data rates for data application.
2. Better voice quality.
3. Wide bandwidth.
4. Backward compatibility with existing CDMA systems.

2. CDMA 2000-1XEV :

- For high data rate applications CDMA 2000-1XEV is evolutionary system.
- In this technology with the help of 16 QAM (16-Quadrature) amplitude modulation, on the downlink maximum data rate is increased to 2.4 Mbps and on the downlink it is increased to 307.2 kbps.
- On a single 1.25 MHz channel the system can uses QPSK, 8-PSK or 16-QAM modulation.
- As 16-QAM requires a better signal quality capacity of 1XEV is lowered in case of large interference.
- The modulation level drops down to 8-PSK / QPSK as the signal becomes weaker.
- By using TDMA as well as CDMA the uplink becomes more flexible.
- There is option in CDMA 2000-1XEV that it can provide the mobile users with services which are dedicated like CDMA 2000-1XEV-DO or both data and voice (CDMA 2000-1XEV-DV).
- In the CDMA 2000-1XEV–DO system individual 1.25 MHz channels may be installed which dedicates base station radio channels to mobile users.

- On a particular CDMA channel CDMA 2000-1XEV provides greater than 2.4 Mbps high speed packet throughput per user.
- CDMA 1XEV-DV support data and voice users and they may offer data rate upto 144 kbps with improved quality of service.

3. CDMA 2000-3XRTT :

- In this version three adjacent 1.25 MHz radio channels are used in combination which can provide packet data throughput in excess of 2 Mbps / user though actual throughput in dependent on vehicle speed, propagation conditions and cell loading.
- Non-adjacent channel can be operated in parallel as single 1.25 MHz channel or three non-adjacent radio channels can be simultaneously operated.
- Adjacent channels can be combined into one 3.75 MHz channel.

6.22.2 Specifications of CDMA 2000 :

- Table 6.22.1 gives the specification of CDMA 2000.

Table 6.22.1

Sr. No.	Parameter	Value
1.	Frequency band	Any
2.	Chip rate	1X : 1.2288 Mcps 3X : 3.6864 Mcps
3.	Frame length	5 MS, 10 MS, 20 MS
4.	Minimum required frequency band	1X : 2 X1.25 MHz 3X : 3 X3.75 MHz
5.	Power control rate	800 Hz
6.	Spreading factors	4.....256 uplink
7.	Maximum user data rate	1X : 144 Kbps – 307 Kbps 1XEV – DO : 384 Kbps – 2.4 Mbps 1XEV-DV : 4.8 Mbps

6.22.3 Forward and Reverse Channels :

- As compared to W-CDMA, Cdma2000 uses multiple carriers to offer a higher data rate.
- CDMA 2000 uses N carriers (N = 1, 3, 6, 9, 12) for an overall chip rate of N times 1.2288 Mcps. E. g. For N= 6 the chip rate is 7.3728 Mcps.
- Over existing IS-95 systems, this mode of operation is suitable for overlaying Cdma2000.
- To provide variable spreading and processing gains in CDMA2000, Walsh codes from 128 chips to 4 chips are used.
- The same single code is used by all N carriers for scrambling.
- The cell-site synchronization in is needed in CDMA2000 and the PN-code offsets are used for differentiation.
- In CDMA2000, Pilot channels are used for rapid acquisition and hand-off.
- Auxiliary pilot channels can be used in order to supply beam-forming information in addition to the pilot, synch, and paging channels, if smart antennas are used.
- A fundamental channel for signaling and a supplemental channel for traffic can be made available in order to support QoS at different rates.
- On the forward supplemental channels, Turbo codes are used for high data rates.
- The reverse link in the cdma2000 is made more symmetrical with the forward link in many aspects.
- For example a reverse pilot channel is used between each mobile user and the cell-site.
- A reverse pilot channel is used for initial acquisition, time tracking, and power control measurement.
- On the reverse supplementary channels, more powerful codes such as a rate 1/2 convolutional code with a constraint length of 9 Turbo codes are used.
- In order to enable better error-correction ability and a variety of data rates, variable rate spreading is supported in CDMA 2000.

6.22.4 Handoff and Power Control :

- The hand-off procedures and power control in Cdma2000 and IS-95 are similar.
- Different pilot sets are maintained in CDMA 2000.
- On order to complete the call, CDMA 2000 uses active sets corresponds to the pilot channels.
- Instead of absolute instantaneous samples, relative threshold values are used.
- Relative threshold values are based on average signal strength levels.

- In IS-95 and CDMA 2000,power control scheme is used at 800 bps whereas in W-CDMA, a fast power control scheme is used at 1500 bps.
- The implementation of closed loop power control in W-CDMA and IS-95 are similar with the power control bits transmitted 1500 times a second.
- This provides significant capacity gain and allows a very fast power control in W-CDMA.
- In CDMA 2000 uses both inner and outer loop power control mechanisms.

6.22.5 Features of CDMA 2000 :

- The following are the features of CDMA 2000 :

1. **Very good performance :**
   - As compared to other technology the performance of CDMA 2000 is very good in terms of data speeds, voice capacity and latency etc.
2. **Support for advanced mobile services :**
   - CDMA 2000-1XEV-DO allows the delivery of broad range of services like high performance video telephony, VoIP, multimedia messaging, multicasting etc.
3. CDMA 2000 are compatible with IP which have higher bandwidth efficiency more flexibility.
4. **Efficient use of spectrum :**
   - By using maximum frequency spectrum CDMA 2000 offers highest voice capacity and data throughput.
5. **Selection of device :**
   - CDMA 2000 has significant cost advantage as compared to other 3G networks. It offers wide selection of mobile devices.
6. **Evolution path :**
   - CDMA 2000 provides seamless evolution path based on the principle of forward and backward compatibility.
7. **Flexible :**
   - CDMA 2000 systems have been designed for rural and urban areas for WLL, fixed wireless, limited and full mobility applications in different frequency spectrum bands which 450 MHz, 800 MHz, 1700 MHz, 1900 MHz and 2100 MHz etc.

6.22.6 Advantages of CDMA 2000 :

- Advantages of CDMA 2000 are as follows :

1. End to end latency (delay) is low.
2. Good voice clarity.
3. High speed broadband data connectivity.
4. Increased throughput capacity of data and voice.
5. Long term robust and evolutionary path with forward and backward compatibility.
6. Flexible network architecture.
7. User, application and flow based quality of service.
8. Flexible spectrum allocation.
9. Multimode, global, multi-band roaming features.
10. Improved privacy with security.
11. Total cost of ownership is lowered.

6.22.7 Disadvantages of CDMA 2000 :

1. **Pollution of channel :**
   - In subscribers phone there are many signals from cell sites but none of these is dominant which results in degradation of call quality.
2. **International roaming :**
   - In CDMA 2000 there is lack of international roaming ability.
   - CDMA 2000 device which have to be used internationally should have GSM radio.6.14

6.22.8 Comparison of IS-95 and CDMA 2000 :

- Table 6.22.2 gives the comparison between CDMA 2000 and IS-95.

Table 6.22.2 : Comparison of IS-95 and CDMA 2000

Sr. No.	Parameter	IS-95	CDMA 2000
1.	Channel bandwidth	1.25 MHz	1.25 MHz
2.	Chip rate	1.2288 M	3.68 Mcps
3.	Frame size	20 ms	20 ms
4.	Number of carriers	20	48

Sr. No.	Parameter	IS-95	CDMA 2000
5.	Channel coding	Convolutional code, block code	Convolution code, turbo code
6.	Inter cell site operation	Synchronous	Synchronous
7.	Modulation	QPSK/BPSK	Uplink : QPSK Downlink : BPSK
8.	Channels/Carrier	64	64
9.	Data rate	14.4 Kbps (15 – 95A) 115 Kbps (15 – 95B)	1X : 144 Kbps – 307 Kbps 1XEV – DO : 384 Kbps – 2.4 Mbps 1XEV-DV : 4.8 Mbps
10.	Handover	Seft Handoff	Soft handoff
11.	Generation	2G	3G

Review Questions

Q. 1 Explain the CDMA digital standard IS-95.

Q. 2 Explain the system architecture of CDMA IS-95.

Q. 3 Explain the call processing in IS – 95.

Q. 4 Write a note on : Security and authentication in CDMA IS-95.

Q. 5 Compare GSM and IS-95.

Q. 6 State important features of IS-95 CDMA.

Q. 7 Compare GSM with CDMA with respect to following points :

1. Hand off used
2. Modulation used
3. Number of user
4. Channel bandwidth
5. Access method
6. Error control technique used.

Q. 8 What type of handoff is used in IS-95 ? Describe it with diagram.

Q. 9 Describe frequency and channel specifications of IS-95.

Q. 10 Describe key features of IS-95.

Q. 11 List various features and services of IS – 95 and also write the various services offered by a GSM system.

Q. 12 Describe radio aspect and security aspects of IS-95 system.

Q. 13 Explain closed loop and open loop power control for reducing interference.

Q. 14 Describe radio aspect and security aspects of IS-95 system.

Q. 15 Describe the call processing in IS-95 CDMA.

Q. 16 Draw system architecture of IS-95. Explain its working.

Q. 17 Draw and explain forward and reverse link channel structure of IS-95.

Q. 18 With the help of neat sketches explain the forward link and reverse link channel structure used in IS-95.

Q. 19 Explain IS-95 forward and reverse channel structure in detail.

Q. 20 Sketch the block diagram of reverse traffic channel of IS-95. Explain function of each block.

Q. 21 Explain concept and importance of power control in CDMA.

Q. 22 Explain mobile assisted soft handoff procedure in a CDMA based secular system.

Q. 23 Write short note on Rake receiver.

Q. 24 What is soft handoff ?

Q. 25 Explain RAKE Receiver in CDMA system.

Q. 26 How RAKE receiver improves S/N ratio in CDMA also explain why power control on the reverse channel is essential ?

Q. 27 Discuss GPRS technology.

Q. 28 Write short note on : GPRS technology.

Q. 29 Give the 3G CDMA evolutionary path.

Q. 30 Draw the architecture of GPRS.

Q. 31 Draw and explain the GPRS protocol stack.

Q. 32 Write the characteristics of GPRS.

Q. 33 State advantages, disadvantages and applications of GPRS.

Q. 34 Compare : GSM and GPRS.

Q. 35 Write advantages of CDMA digital cellular system.

Q. 36 Write short note on CDMA 2000.

Q. 37 State the features of CDMA 2000.

Q. 38 Explain 3G CDMA 2000.

Q. 39 What are the advantages of CDMA 2000 over W-CDMA ?

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Chapter 7 : Recent Trends 7-1 to 7-54

Syllabus : Introduction to Wi-Fi, WiMAX, ZigBee Networks, MIMO, Software Defined Radio, UWB Radio, Wireless Adhoc Network and Mobile Portability, Security issues and challenges in 5-G and above Wireless networks.

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7

Recent Trends

Syllabus

Introduction to Wi-Fi, WiMAX, ZigBee Networks, MIMO, Software Defined Radio, UWB Radio, Wireless Adhoc Network and Mobile Portability, Security issues and challenges in 5-G and above Wireless networks.

Chapter Contents

7.1 Introduction to WLAN/Wi-Fi :

- We all know wired local area networks (LANs) very well.
- In order to get rid of the wiring associated with the interconnections of PCs in LANs, researchers have tried to use radio waves or infrared light as a replacement to the wires.
- This is how the wireless LANs i.e. WLANs got evolved.

Why Wireless LANs :

- Standard LAN protocols such as Ethernet can operate at high speed using inexpensive connection hardware.
- However, the problem with these LANs is that they are limited to the physical, hard-wired infrastructure of the building and the network nodes are limited to access only through wired landline connections.
- Many mobile users of the network in businesses find many advantages from the added capabilities of wireless LANs.
- The WLANs are gaining popularity because they have certain advantages over the wired LANs such as : increased mobility and flexibility, cost effectiveness, ease of installation, ease of adding new members etc.
- Earlier the wireless LANs were costly, they could support only low data rates and a license was required to build and operate them.
- Hence there were limitations on the practical utility of wireless LANs.
- But all these problems are being addressed now which is increasing the popularity of wireless LANs day by day.

7.1.1 IEEE Standards :

- The Institution of Electrical and Electronics Engineers (IEEE) has developed the layered architecture and other standards of LAN, under their project 802 set up in 1980.
- The IEEE 802.3 standard is for the wired LAN whereas the IEEE 802.11 standard is for the wireless LANs.

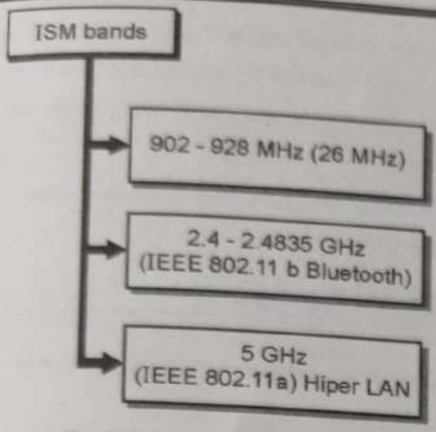
7.1.2 Wi-Fi :

Definition :

- Wi-Fi is a popular technology which allows an electronic device to exchange data or to connect to the Internet using radio waves.
- We can define **Wi-Fi** as any wireless local area network **(WLAN)** product that are based on the IEEE 802.11 standards.
- The devices which can use Wi-Fi are personal computers, video game consoles, smart phones, some digital cameras, Tablet computers etc.
- Wireless communication is one of the fastest growing technologies.
- The wireless LANs are used in following applications :
  1. Office buildings
  2. Colleges
  3. Public areas
- In this chapter we are going to discuss about IEEE 802.11 wireless LAN.

7.1.3 ISM Band :

- Internationally the ITU has designated some frequency bands called as ISM bands for unlimited usage.
- The long form of ISM is Industrial, Scientific, Medical band.
- These frequency bands are located around 2.4 GHz and used for the wireless LAN and PAN applications.
- The wireless networks use the ISM frequency bands for their operation.
- These bands are as follows :
  1. 902-928 MHz,
  2. 2.4-2.4835 GHz and
  3. 5.725-5.85 GHz.
- No license is required for operating in this band. Fig. 7.1.1 shows the three ISM bands along with the corresponding technologies operating in them.
- Most of the wireless LAN products operate within the unlicensed ISM bands.



(O-897) **Fig. 7.1.1 : The various ISM bands**

- Table 7.1.1 lists various frequency bands in the ISM band along with their bandwidth, power level and spread spectrum techniques suitable to them.

Table 7.1.1 : Various frequency bands in ISM band

Sr. No.	Band (GHz)	Bandwidth (MHz)	Power level	Spread spectrum
1.	0.902 – 0.928	26	1 W	FHSS, DSSS
2.	2.4 – 2.4835	83.5	1 W	FHSS, DSSS
3.	5.725 – 5.850	125	1 W	FHSS, DSSS
4.	24.0 – 24.5	250	50 mW/m @ 3 m	Not applicable

7.2 Architectural Comparison of Wired and Wireless LANs :

- In this section we will compare the architectures of wired and wireless LANs on the basis of the following points :
  1. Medium.
  2. Hosts.
  3. Isolated LANs.
  4. Connection to other networks.
  5. Moving between environments.

1. Medium :

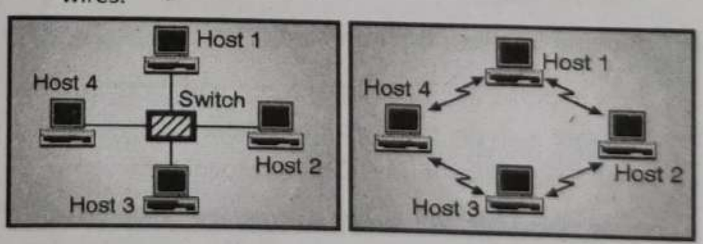
- The wires (shielded or coaxial) are used to connect the hosts in a wired LAN.
- But the medium used by the wireless LANs is air.
- In the wired LANs the type of communication is point to point and full duplex i.e. bidirectional. But in wireless LANs the signal is generally broadcast.
- The hosts in a WLAN share the same medium i.e. air (it is called as multiple access). In WLANs a point to point communication between the wireless hosts is extremely rare.

2. Hosts :

- A host in a wired LAN is always connected at a point to its network.
- Each host will have a fixed link layer address related to its network interface card (NIC).
- If the host moves from one point to the other in the Internet its link layer address remains the same but the network layer address will change.
- A host in a wireless LAN can move freely as it is not connected physically to the network at all.
- It can still use all the services provided by the network.
- In short the mobility issue in the wired and wireless LANs is entirely different.

3. Isolated LANs :

- The meaning of the word isolated is different for the wired LANs and wireless LANs.
- Refer Fig. 7.2.1(a) which shows an isolated wired LAN.
- As shown it consists of hosts which are interconnected via a link layer switch with connecting wires.



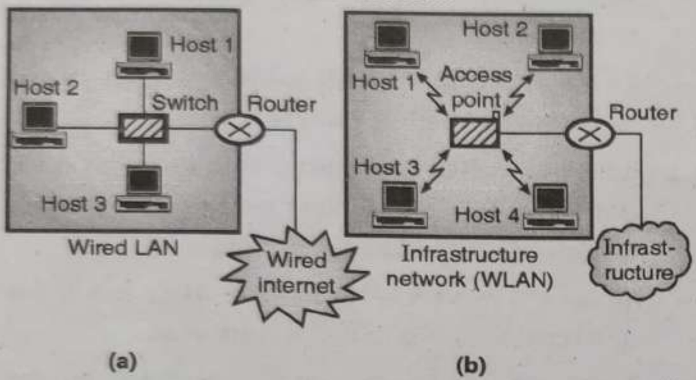
(a) Isolated wired LAN **(b) Ad hoc network**

(G-2096) **Fig. 7.2.1**

- A wireless isolated LAN is as shown in Fig. 7.2.1(b). It is also known as the **Ad hoc Network** in the terminology used for wireless LANs.
- Here a group of wireless hosts communicate with each other directly and freely without using any switch or wired links.

4. Connection to Other Networks :

- Refer Fig. 7.2.2(a), which shows the manner in which a wired LAN is connected to some other network such as the Internet through a **router.**
- It is possible to connect a wireless LAN either to a wired infrastructure network or a wireless infrastructure network, or to another wireless LAN.
- Fig. 7.2.2(b) shows the connection of a wireless LAN to a wired infrastructure network.



(G-2097) **Fig. 7.2.2 : Connection of wired LAN and wireless LAN to the other network**

- Consider Fig. 7.2.2(b). In this case the wireless LAN is called as **infrastructure network.**
- It is connected to the wired infrastructure such as the Internet through a special device called as **Access Point (AP).**
- The communication between the wireless hosts and AP is wireless in nature whereas that between the AP and the wired infrastructure is a wired communication.

5. Moving between Environments :

- It is important to that both wired and wireless LANs operate only in the two lowest layers (physical and data link layers) of the TCP/IP protocol suite.
- Now suppose we want to replace a wired LAN connected to Internet via a router or a modem with a wireless LAN.
- Then we need to make the following changes :
  1. Replace the network interfacing card (NIC) designed for wired environment by a NIC designed for the wireless environment.
  2. Use an Access Point (AP) in place of the data link switch.
- When we change the NIC of each host, the link layer address will change for each host but there won't be any change in the network layer address i.e. the IP address of each host.
- In this way we can move from wired LAN to a wireless LAN.

7.3 WLAN Equipment :

- The three main equipment used in WLAN are :
  1. LAN adapter.
  2. Access point (AP) and
  3. Outdoor LAN bridges.

7.3.1 LAN Adapter :

- The wireless adapters are made in the same basic form as their wired counterparts including PCMCIA, card bus, PCI and USB.
- The function of wireless adapters is also same as that of the wired LAN adapters that is to enable the end-users to access the network.
- A wired LAN adapter provides an interface between the network operating system and the wire.
- A WLAN adapter provides the interface between the network operating system and an antenna in order to create a transparent connection to the network.

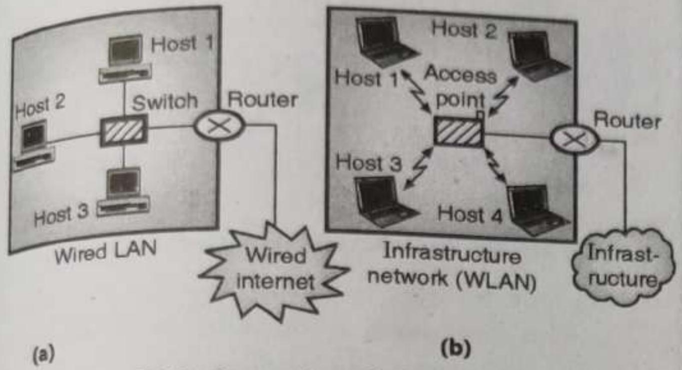
7.3.2 Access Point (AP) :

- The access point AP is the wireless equivalent of a LAN hub.
- Its functions are to receive, buffer and transmits data between a WLAN and the wired network, supporting a group of wireless user devices.

Definition :

- In computer networking an Access Point (A.P.) is a device that allows a Wi-Fi device to connect to a wired network.
- Refer Fig. 7.3.1(a), which shows the manner in which a wired LAN is connected to some other network such as the Internet through a **router.**
- It is possible to connect a wireless LAN either to a wired infrastructure network or a wireless infrastructure network, or to another wireless LAN.

- Fig. 7.3.1(b) shows the connection of a wireless LAN to a wired infrastructure network.



(G-2097) **Fig. 7.3.1 : Connection of wired LAN and wireless LAN to the other network**

- Consider Fig. 7.3.1(b). In this case the wireless LAN is called as **infrastructure network.**
- It is connected to the wired infrastructure such as the Internet through a special device called as **Access Point (AP).**
- The communication between the wireless hosts and AP is wireless in nature whereas that between the AP and the wired infrastructure is a wired communication.
- An AP is typically connected with the backbone network through a standard Ethernet cable and communicates with wireless devices by means of an antenna.
- The AP or antenna connected to it is generally mounted on a high wall or on the ceiling.
- An access point contains a radio card which communicates with the individual user devices as well as the wired NIC.
- Access Point (A.P.) is a station that transmits and receives data.
- Each A.P. can serve multiple users within a specified network area.
- As a user moves beyond this area, it is automatically handed over to the next A.P.
- Thus multiple APs can support handoff from one AP to another.
- A small WLAN may require only one A.P but their number increases with the increase in the size of the wireless network.
- APs have a range from 20 to 500 meters. A single AP can support between 15 to 250 users, depending on technology, configuration and use.
- Generally the adjacent APs use different frequencies to communicate with their clients to avoid interference between the nearby wireless networks.
- Access points can have major security issues.
- If an A.P. is connected to a wired network, then anybody within the range of that A.P. can get connected to the network.
- Therefore every wireless A.P. must be protected with a password.
- We can easily scale up a WLAN by adding more APs to reduce network congestion and increase the coverage area.
- In large networks multiple APs are deployed in such a way that overlapping cells are connected to ensure a constant connectivity to the network.

7.3.3 Outdoor LAN Bridges :

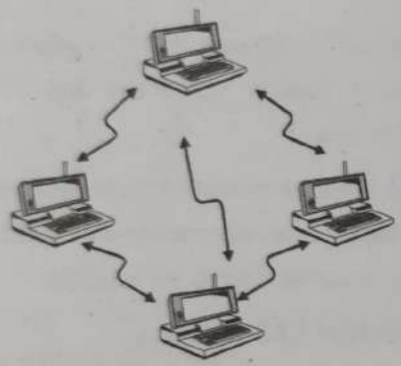
- The outdoor LAN bridges are the WLAN equipment used for connecting LANs in different buildings to each other.
- We can connect LANs in different buildings with a fiber optic cable as well.
- But a fiber optic cable is a costly option, particularly if there are barriers such as highways or water bodies in the way.
- In such situations a WLAN can be an economical alternative to fiber optic cable to connect LANs in different buildings.
- An outdoor bridge can provide a less expensive alternative to the leased line as well.
- The WLAN outdoor bridges can support fairly high data rates and large ranges (typically of several miles) by using line-of-sight directional antennas.
- It is also possible to use APs as a bridge if the distance between the buildings is relatively small proximity.

7.4 WLAN Topologies :

- WLANs can be built with either of the following topologies :
  1. Peer-to-peer (ad hoc) topology.
  2. Access point-based topology.
  3. Point-to-multipoint bridge topology.

7.4.1 Peer-to-peer (ad hoc) Topology :

- The peer-to-peer topology is also known as ad-hoc network in which the client devices within a cell communicate directly to each other as shown in Fig. 7.4.1.

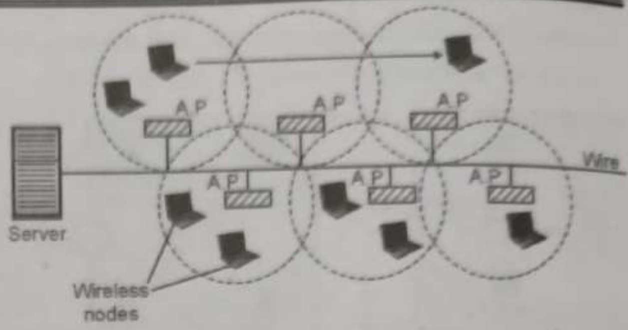


(G-376(a)) Fig. 7.4.1 : Peer-to-peer topology (Ad hoc network)

- These WLANs do not have any fixed architecture. They can be set up at any place.
- It is a peer-to-peer network without any centralized server.
- It is just a collection of few stations within range of each other dynamically configuring themselves into a temporary network.

7.4.2 AP Based Topology :

- The AP based topology is also known as an infrastructure network and it is shown in Fig. 7.4.2.
- These WLANs contain special nodes called Access Points (APs) which can interact with wireless nodes as well as wired networks. The other wireless nodes known as mobile stations (STAs) communicate via APs.
- The APs can also work as bridges to connect to other networks a wired (Ethernet or Token Ring) or a wireless backbone as shown in Fig. 7.4.2.



(O-922) Fig. 7.4.2 : Access point-based topology

- Thus the AP-based technology uses APs to enable a wireless client device to communicate with any other wired or wireless device on the network.
- AP-based topology is very commonly used and it demonstrates that the WLAN does not replace the wired LAN, instead it extends the connectivity to mobile devices.
- Another wireless network topology is the point-to-multipoint bridge.
- Wireless bridges connect LANs in one building to LANs in another building even if the buildings are miles apart.
- These conditions receive a clear line-of-sight between buildings.
- The line-of-sight range varies based on the type of wireless bridge and antenna used as well as environmental conditions.

7.5 Characteristics of WLANs :

- Several characteristics of wireless LANs are very different from those of the wired LANs.
- Some of the important characteristics of wireless LANs in connection with the wireless LAN protocols are as follows :
  1. Attenuation.
  2. Interference.
  3. Multipath propagation.
  4. Errors.

7.5.1 Attenuation :

- While travelling from transmitter to receiver, the electromagnetic signal tends to disperse in all the directions, due to which a very small portion of the transmitted signal actually reaches the receiver.

- Due to this the strength of the EM signal decreases very rapidly.
- The situation degrades further when the transmitter is actually a mobile sender which is battery operated and has a very low output (transmitted) power.
- The phenomenon of reduction in the strength of an EM signal is called as attenuation.

7.5.2 Interference :

- In mobile communication or FM transmission more than one users (senders) use the same frequency band.
- Due to this the receiver may receive signals from an unintended senders along with that from the intended sender.
- This will create an interference at the receiver.

7.5.3 Multipath Propagation :

- A signal sent by a sender can follow more than one paths to reach a receiver as discussed earlier in this chapter.
- This is called as the **multipath propagation** of an EM signal.
- Therefore, the receiver receives multiple versions (copies) of the same transmitted signal, with different phase shifts introduced by the different path lengths they had travelled.
- Due to this the received signal may sometimes become less recognizable.

7.5.4 Error :

- Taking into consideration the above characteristics of the wireless network, we can conclude that the presence of error and requirement of error detection mechanism should be taken more seriously than that in the wired networks.
- Thus in the wireless networks, the error detection, error correction and retransmission are more important in wireless networks than in the wired networks.
- The value of signal to noise ratio (SNR) is a very important parameter for a wireless network.
- A high value of SNR implies that the signal is stronger than noise and therefore it may be possible to convert the signal into data.
- But a low value of SNR implies that the signal is corrupted by the noise and therefore it may not be possible to recover the data at all.

7.6 Design Goals for WLANs : GTU : W-11

University Questions

Q. 1 Mention some of the advantages and disadvantages of WLANS ? Mention the design goals of WLANS ? **(W-11, 7 Marks)**

- Some of the important goals that should be achieved while designing WLANs are as follows :

1. Simplicity of operation :

- A WLAN should have features which will enable a mobile user to quickly set up and access network services.
- The access should be easy and efficient as well.

2. Power efficient operation :

- The mobile devices operate on battery hence their operation is power constrained one.
- Hence the WLANs also should operate on minimum amount of power.
- The design of WLAN should include the power saving features with the necessary technology and protocols.

3. Licence free operation :

- The wireless access licence free is an important factor which determines the cost of wireless access for the spectrum in which WLAN is operating.
- This cost should be as low as possible. Hence the design should consider using that portion of the spectrum (e.g. ISM band) which does not need any official licensing.

4. Tolerance to interference :

- There is a significant level of interference present in the entire radio spectrum.
- The design of WLAN should be such that it should be able to operate satisfactorily even in the presence of this interference.

- This can be achieved by selecting an appropriate technology and protocols for the WLAN.

5. **Global usability :**

- By selecting the technology and operating frequency spectrum and by taking into account the existing spectrum restrictions, in various countries across the world, we can make a WLAN which can used globally.

6. **Security :**

- Due to the inherent broadband nature of wireless medium, special features should be included in the design of WLAN to provide adequate security.

7. **Safety requirements :**

- The safety requirements that should be followed by a WLAN can be classified as follows :
  1. Interference to medical and other instrumentational devices.
  2. Increased power level of transmitter which can result in health hazards.
- WLAN design should be such that the transmitter power levels are restricted below the safe limits.

8. **QoS requirements :**

   WLAN should be designed to support a wide variety of traffic including the multimedia traffic.

9. **Compatibility with other technologies and applications :**

- Different wired and wireless LANs should be able to interact with each other.
- In addition, the interoperability with existing WAN protocols such as TCP/IP also is essential.

10. **Mobility :**

- Wireless networks provide mobility to its users.
- They provide access to Internet and contact with the other users without using any wires.

11. **Installation :**

- Installing a wireless network is simple. It eliminates the need of pulling connecting wires.

12. **Reliability :**

- In wireless systems, the EM waves are used to carry the information. But these waves undergo fading (loss of signals) due to various reasons.
- This will lead to reduced reliability. So some minimum level of reliability should be ensured.

13. **Scalability :**

- Wireless systems can be configured in different types of topologies depending on need of applications.
- It is possible to change the configuration easily right from peer to peer which is suitable for small networks to large infrastructural network used for large areas.

7.6.1 Factors Considered to Deploy WLAN :

- Various factors to be considered while deploying WLAN are as follows :

1. **Security:**

- Radio waves cannot penetrate through various obstructions such as walls or buildings.
- This creates a possibility of interference or eavesdropping.
- Therefore, it is necessary to use encryption to ensure the data privacy.

2. **Frequency allocation :**

- Different countries allocate different frequency bands within the ISM band for the operation of WLANs.
- All the subscribers need to operate in the allocated frequency band approved in their country.

3. **Power consumption :**

- WLANs involve the handheld wireless mobile devices like smart phones, tablets etc. which are operated on small batteries.
- Hence, these devices must be designed to have a higher energy efficiency and longer battery life.

4. **Throughput :**

- In order to improve the throughput of WLAN systems the spread spectrum methods are used which support multiple transmissions.

5. **Mobility :**

- Mobility and connectivity are two very important factors in the WLANs.
- In order to ensure mobility and continuous connectivity, the WLANs should provide hand off mechanism to the mobile devices.

6. **Interference and reliability:**

- The WLAN systems are more prone to signal interferences due to various reasons such as traffic errors, rains or transmitting data simultaneously etc.
- This could make the data transmission over WLANs unreliable.
- We can increase the WLAN system reliability, by using different error detection and error corrections techniques.

7.7 Technical Issues in WLANs :

- Here we discuss the technical issues related to design and engineering of WLANs.
- The differences between wireless and wired networks are also elaborated.

1. **Address is not equivalent to physical location :**

- In a wireless network, the address refers to a particular station.
- But it does not have any relation with the physical address of the device.
- This happens because the station need not be stationary at a particular physical address it can move.

2. **Dynamic topology and restricted connectivity :**

- As the mobile nodes can go out of reach of each other, the network connectivity is partial at times and not full as in case of the wired transmission.

3. **Medium boundaries are not well defined :**

- The exact range of a wireless signal cannot be accurately defined, because it is the function of various factors.
- Therefore it will never be possible to precisely define the boundaries or range of the medium.

4. **Medium is prone to errors :**

- In a wireless network, transmissions by a node are affected by simultaneous transmissions taking place from the neighbouring nodes, that are located in a close vicinity.
- Hence the error rates are high in the wireless communication as compared to those in the wired one.
- The bit error rate (typical) of a wireless channel is 10^{-4} while that of a fiber optic cable is 10^{-9}. This is a huge difference.

5. **Frequency allocation :**

- The operation of a wireless WLAN requires that all users operate in a common frequency band.
- The frequency band must be approved in each country.

6. **Interference and reliability :**

- In a WLAN, interference is caused by simultaneous transmission of information in the shared frequency band and by multipath fading.
- The reliability of a communication channel is measured in terms of bit error rate (BER). Automatic repeat request (ARQ) and forward error correction (FEC) techniques are used to increase reliability.

7. **Security :**

- As radio waves are not confined to the boundary of buildings.
- There is always a possibility of eavesdropping and intentional interference. Hence data privacy over is usually ensured by using data encryption.

8. **Power consumption :**

- WLANs are mostly used in mobile applications in which battery power is a scarce resource. Therefore, the devices must be designed to consume less power.

9. **Mobility :**

- In order to ensure mobility the devices should accommodate handoff at transmission boundaries so as to route data calls to mobile users.

10. **Throughput :**

- The need of multiple transmissions simultaneously is supported by using spread spectrum techniques.

7.8 Medium Access Control :

- Access control means how a wireless host in a wireless LAN can get access to the shared medium which is air.
- The access control is possibly the most important issue in a wireless LAN.

MAC for wired LANs :

- In the standard Ethernet the CSMA/CD algorithm is used for access control.
- In this technique each host is a contender to share the medium so that it can send its frame if the medium is found idle.
- In this mechanism, there is always a possibility of collision.
- If collision takes place, the CSMA/CD detects it and the frame is sent again.
- The collision detection is useful in two ways :
  1. In the event of collision, the sent frame is not received and hence it should be sent again.
  2. The absence of collision is a kind of acknowledgement that the frame was received.
  3. The third reason of not using the CSMA/CD for wireless networks is that the distance between the stations can be sometimes too large. Due to huge distance, the signal fading could occur and the station at one end could be prevented from hearing a collision at the other end.
- For the **wireless LANs** however, the CSMA/CD algorithm does not work properly.

Reasons for CSMA/CD not being suitable for WLANs :

- Following are the reasons why CSMA/CD algorithm does not work for wireless LANs :
  1. For a successful detection of a collision, a host should work in the **duplex** mode. That means it should send the frame and receive the collision signal at the same time. But the wireless hosts cannot do this. They can either send or receive at one time, because being battery operated they do not have enough power to do so.
  2. The Hidden station problem : We will discuss this problem shortly.
  3. The third reason of not using the CSMA/CD for wireless networks is that the distance between the stations can be sometimes too large. Due to huge distance, the signal fading could occur and the station at one end could be prevented from hearing a collision at the other end.

Which Access Control Algorithm for Wireless LAN ?

- The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is the access control algorithm used for the wireless networks because it overcomes all the problems of CSMA/CD discussed earlier.

7.9 MAC Protocol Issues :

- There are many issues that need to be addressed in order to design an efficient MAC protocol in a wireless ad hoc network environment.
- Several MAC protocols can be employed for adhoc networks such as IEEE 802.11 WLAN, Bluetooth and Hiper LAN.
- In this section, we discuss some important issues that are key to the design of MAC protocols for any wireless network. Some of these issues are :
  1. Hidden terminal problem
  2. Reliability
  3. Collision avoidance
  4. Congestion avoidance
  5. Congestion control
  6. Energy efficiency.
  7. Other MAC issues.

7.9.1 Hidden Terminal Problem :

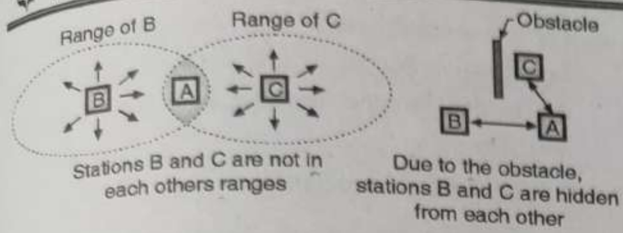
GTU : S-12, S-20, W-20

University Questions

Q. 1 Explain the terms :
1. Hidden- terminal
2. Exposed –terminal **(S-12, 4 Marks)**

Q. 2 Explain the hidden-node problem and exposed-node problem in context of mobile ad-hoc networks. **(S-20, W-20, 7 Marks)**

- 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. 7.9.1.
- Refer Fig. 7.9.1(a) which shows three wireless stations A, B and C.



(G-2098) **Fig. 7.9.1 : 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. 7.9.1(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. 7.9.1(b) which shows the hidden station problem occurring due to an obstacle.

Note : Due to hidden station problem, the possibility of collision increases and the capacity network will reduce.

7.9.2 Exposed Station Problem :

GTU : S-12, S-20, W-20

University Questions

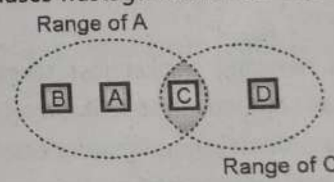
Q. 1 Explain the terms :

1. Hidden- terminal
2. Exposed –terminal

(S-12, 4 Marks)

Q. 2 Explain the hidden-node problem and exposed-node problem in context of mobile ad-hoc networks. **(S-20, W-20, 7 Marks)**

- Earlier in this chapter we have discussed the problem of hidden station. 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. 7.9.2 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. 7.9.2, station C is in the range of station A. In other words C is exposed to A.
- 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.



(O-918) **Fig. 7.9.2 : Exposed station problem**

Which Access Control Algorithm for Wireless LAN ?

- Note that the carrier sense (CSMA/CD) protocol can provide the information about potential collisions at the sender, but not at the receiver.
- Therefore this information can be misleading for a distributed configuration because all stations are not within range of each other.
- The Medium Access with Collision Avoidance (MACA) protocol proposes the solution to the hidden terminal problem.
- The solution suggested by this protocol is to transmit Request-to-Send (RTS) and Clear-to-Send (CTS) packets between the nodes that wish to communicate.
- These RTS and CTS packets contain information about the duration of the data transfer of the communicating nodes.

- For this duration the neighbouring stations that do not participate in communication but overhear either of these packets will keep quiet.
- The exposed terminal problem cannot be solved using any scheme in the IEEE 802.11 MAC layer.
- However the protocol named Medium Access with Collision Avoidance for Wireless (MACAW) which is based on MACA solves this problem.
- In MACAW protocol the source transmits a **data sending** control packet that will alert exposed nodes of the impending arrival of an ACK packet.

7.9.3 Reliability :

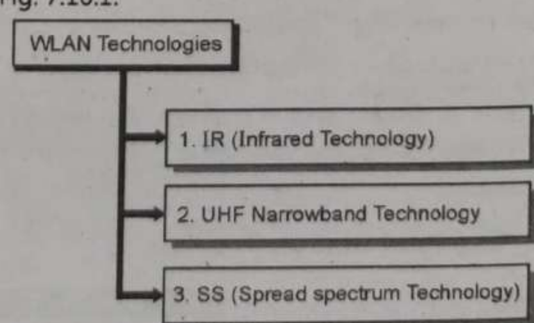
- Wireless links are vulnerable to errors. That means the packet error rates of wireless mediums are much higher than that of the wired mediums. Hence the reliability of wireless mediums is very low.
- Therefore some protocols like TCP which was originally designed for the networks suffer degradation in performance when used in a wireless environment.
- In wireless networks packet loss takes place on a regular basis due to effects like multipath fading, interference, shadowing, large distance between transmitter and receiver, etc.
- If we use TCP in the wireless network it will erroneously assume that the packet loss has occurred due to congestion and will start the congestion control mechanisms.
- There have been some proposals to find remedy of such TCP behaviour in wireless and mobile ad hoc networks.
- Coming back to the MAC protocol, they use a common approach to reduce packet loss rates experienced by upper layers by introducing the acknowledgment (ACK) packets.
- Thus use of an ACK packet increases the reliability.
- For example whenever node B receives a packet from node A, it sends an ACK packet to A. If node A does not receive the ACK from B, it will retransmit that packet.
- Many protocols have adopted this approach.
- For example, the IEEE 802.11 Distributed Coordination Function (DCF) uses RTS-CTS to avoid the hidden terminal problem and ACK to achieve reliability.

7.9.4 Collision Avoidance :

- The type of communication used in the wireless and mobile nodes is half-duplex.
- That means they are not able to transmit and receive at the same time. Therefore the collision detection is not possible.
- Therefore for minimizing collisions, the wireless MAC protocols, such as CSMA with Collision Avoidance (CSMA/CA), use the technique of collision avoidance along with a carrier sense (physical or virtual) scheme.
- The principle of collision avoidance is implemented by making it mandatory for the node, that, even when the channel is sensed idle, it has to wait for a randomly chosen time before attempting to transmit.
- This mechanism decreases the probability of more than one node attempting to transmit at the same time drastically and avoids collision.
- In cases where more than one node initiates transmission at the same time, the transmissions are corrupted and the corresponding nodes retry later on.

7.10 WLAN Technologies :

- WLANs can use different wireless technologies for transmitting the signals.
- The most important of them are as shown in Fig. 7.10.1.



(O-1460) **Fig. 7.10.1: Wireless technologies**

7.10.1 IR (Infrared) Technology :

- The electromagnetic waves having frequencies 300 GHz to 400 THz are called infrared waves.

- They use line-of-sight propagation.
- Infrared light cannot penetrate walls i.e. it is contained in a room.
- There are two types of IR WLANs. Diffused beam and direct beam.
- The direct beam IR WLAN uses line of sight propagation and has a faster data rate in comparison to the diffused beam WLAN.
- The diffused beam WLAN uses reflected waves for transmitting/receiving the data.

Advantages of IR Technology :

1. It support high data rates.
2. It does not have any government regulations for controlling its use.
3. This technology can be used with a reduced interference and possibility of reusing same frequency band in different rooms.

Disadvantages of IR Technology :

1. Signals cannot penetrate through walls or solid objects.
2. It is a short range technology.
3. The signal can be affected by parameters like light, ice, snow, fog etc.
4. Sun generates radiation in the infrared band. This can cause interference in IR communication.

Applications of IR Technology :

1. Development of high speed WLANs
2. Communication between keyboard, mouse, PCs and printers.

7.10.2 UHF Narrowband Technology :

- In this technology the signal is sent on narrowband of 12.5 or 25 KHz with power level being 1 to 2 W.
- These systems usually work in the frequency range 430-470 MHz. Where 430- 450 MHz is the unlicensed (unprotected) band and 450-470 MHz is the licensed(protected) band.
- The unlicensed band can be used by anyone whereas the licensed band can be used by the clients of that band only.
- Nowadays the newer UHF systems use synthesized radio technology, where a single standard crystal frequency drives the desired channel frequency. Moreover they are easy to install and do not have frequency drift problems.
- The modern UHF systems configure the Access points separately for working on different pre-programmed frequencies.

Advantages :

1. It has the longest range of communication.
2. It provides a cheap solution for large locations with low to medium throughput.

Disadvantages :

1. For operating in the licensed band, license is needed by the customers.
2. Large radio and antennas increase the size of the customer.
3. Low throughput
4. It has not have multivendor interoperability.

7.10.3 Spread Spectrum Technology :

- This technology is widely used in WLAN systems. It is a wideband radio frequency method where the entire spectrum is shared and the transmitted power is spread over the complete spectrum that can be used.
- The features of spread spectrum technology are as follows :
  1. Capability of multiple access.
  2. Resistant to jamming.
  3. Higher channel capacity.
  4. Ability to resist multipath propagation.
  5. It provides immunity to distortion.
  6. It cannot be interrupted by any unauthorized person.
  7. It can be operated at the same frequency at which the current narrow band systems are working.
  8. As signal is spread over wide bandwidth, interception, eavesdropping, jamming of the signal is tedious.
- Spread spectrum technology provides data rates up to 2 Mbps.

7.11 IEEE 802.11 Standard for WLAN :

- The 802.11 is the specifications for the wireless LANs, defined by IEEE.
- This specification defines the physical and data link layers. It is sometimes called as **Wireless Ethernet.**
- Generally the term **Wi-Fi** (Wireless fidelity) is used as a synonym for wireless LAN.
- However in reality, Wi-Fi is a wireless LAN which is certified by the **Wi-Fi Alliance** a global industry association.

7.11.1 Classification of WLANs :

- We can classify the WLANs into the following two categories :

  1. Infrastructure networks. 2. Ad-hoc LANs.

1. Infrastructure networks :

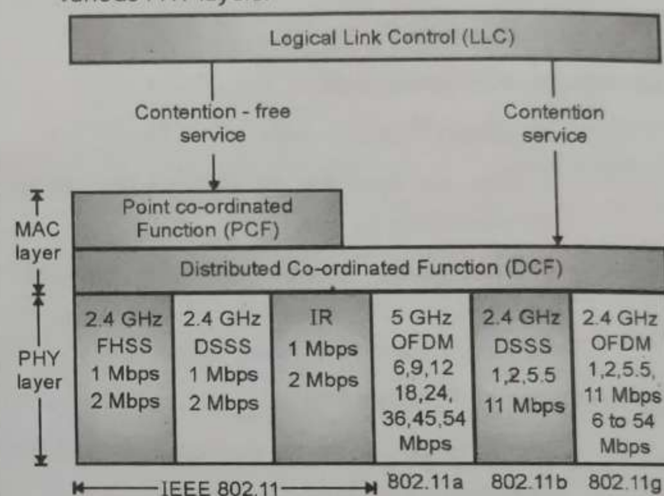
- These WLANs contain special nodes called Access Points (APs) via existing networks.
- APs can interact with wireless nodes as well as wired networks.
- The other wireless nodes known as mobile stations (STAs) communicate via APs. The APs can also work as bridges with other networks.

2. Ad-hoc LANs :

- These WLANs do not have any fixed architecture.
- They can be set up at any place. It is a peer-to-peer network without any centralized server.
- The Ad-hoc LAN is set up temporarily to meet some immediate requirements.
- Such as a group of people with laptops conferencing with each other in a room.
- The ad-hoc LAN does not have any infrastructure. It is just a collection of few stations within range of each other dynamically configuring themselves into a temporary network.

7.11.2 The IEEE 802.11 Protocol Stack :

- The IEEE approved the 802.11 standard (sometimes also referred to as Wi-Fi - for Wireless Fidelity) for WLANs in June 1997 and in July 1997, it was adopted as a worldwide International Standards Organization (ISO) standard.
- The WLAN standard defines three possible physical (PHY) layer implementations and one MAC layer for supporting data rates of 1 Mbps or 2Mbps.
- The IEEE 802.11 standard has different physical layer variants from 802.11a to 802.11g.
- In this chapter we concentrate more on the physical layer specifications of the IEEE 802.11 a/b standards.
- Fig. 7.11.1 shows the 802.11 protocol stack with various PHY layers.



(O-899) **Fig. 7.11.1 : 802.11 protocol stack**

- This shows that the MAC layer protocols are common for all standards while they are not always compatible at the PHY layer.
- Due to all the enhancements, alongwith ease of use and customer satisfaction, the IEEE 802.11 standard has become the most widely used WLAN standard.
- Table 7.11.1 enlists the six subgroups in IEEE 802.11 standard.

Table 7.11.1 : IEEE 802.11 subgroups

802.11a	High speed physical layer in 5 GHz band
802.11b	Higher speed physical layer extension of wireless in 2.4 GHz band
802.11d	Local and metropolitan area wireless
802.11g	Broadband wireless
802.11i	Security
802.11n	Wideband service

- The data rates of the indoor WLANs are in the range of 11 Mbps to 54 Mbps with the IEEE standards 802.11a and 802. 11g, that is considerably high.

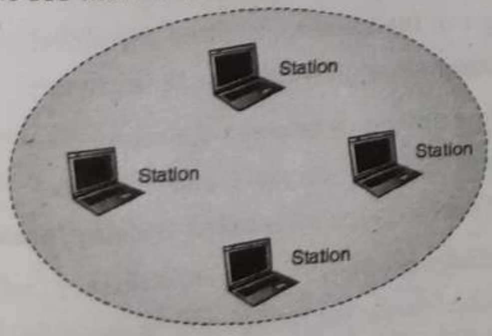
- A high throughput amendment to the IEEE 802.11 standard is currently in the final stages with the 802.11n task group working on it.
- It uses multiple-input multiple output (MIMO) techniques that can support data rates over 100 Mbps.
- The 802.11 MAC layer is considered as the "brains" of the network and it uses an 802.11 PHY layer, such as 802.11a/b/g etc to perform the tasks such as carrier sensing, transmission and receiving of 802.11 frames.
- The MAC layer functional specifications are essentially the same for all the PHY layer specifications with some minor differences.

7.11.3 802.11 Network Architecture :

- IEEE 802.11 is the most popular WLAN standard. It defines the specifications for the physical and MAC layers.
- We can use a WLANs to either replace a wired LANs, or as an extension of the wired LAN infrastructure.
- IEEE 802.11 defines two types of services :
  1. Basic Service Set (BSS)
  2. Extended Service Set (ESS)

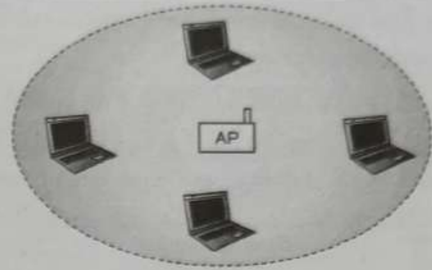
1. Basic Service Set (BSS) :

- As per IEEE 802.11 the BSS has been defined as the basic building block of wireless LAN.
- A BSS consists of stationary or moving wireless stations and a central base station which is optional called as the Access Point (AP).
- Thus a BSS can be either without AP or with AP as shown in Figs. 7.11.2(a) and (b).
- A BSS with AP is as shown in Fig. 7.11.2(b). It can however communicate with the other BSS via the access point AP.
- The BSS with AP is also called as **Infrastructure BSS.**



(a) BSS without AP

(Contd...)



(b) BSS with an AP

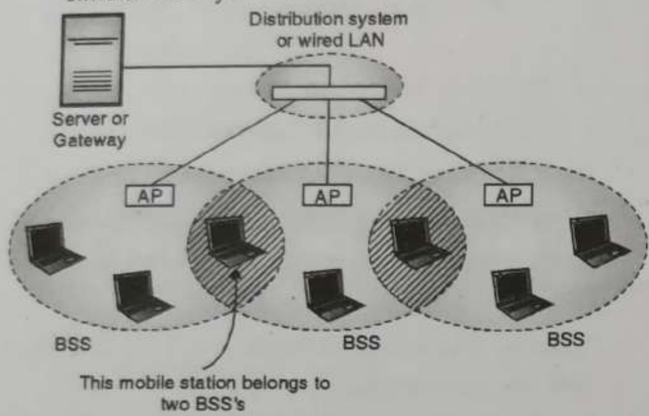
(G-380) Fig. 7.11.2 : Types of BSS

- The BSS without AP cannot send data to another BSS.
- So no data exchange can take place outside that BSS hence it is known as a standalone network or **ad hoc BSS.**
- However all the stations inside a BSS can exchange data among themselves.

2. Extended Service Set (ESS) :

- An Extended Service Set (ESS) consists of multiple BSSs with APs.
- The BSSs in this system are connected to each other via a **distribution system** or a wired LAN as shown in Fig. 7.11.3.
- The APs are connected to each other via the distribution system as shown.
- The distribution system can be any type of LAN such as Ethernet.
- The ESS contains two types of stations :
  1. Mobile stations which can move and change location.
  2. Stationary of non-moving stations.
- Out of these, the non-moving stations are the APs which are a part of the wired LAN.
- Whereas the mobile stations are those contained in the BSS. Fig. 7.11.3 shows the structure of an ESS.
- The BSSs are connected to each other to form a network called **infrastructure network.**
- In such networks the stations close to each other can communicate without taking help of AP.
- But if two stations located in two different BSS wish to communicate with each other, than they have to do so through APs.

- This type of communication is very similar to that in the cellular communication.
- The BSS acts as a cell and AP as base station.
- As shown in Fig. 7.11.3 it is possible that a mobile station can belong to more than one BSSs simultaneously.



(G-381) **Fig. 7.11.3 : ESS (Extended Service Set)**

7.11.4 Types of Stations :

- Three types of stations are defined by IEEE 802.11 depending on their mobility in the wireless LAN as :
  1. No transition
  2. BSS transition
  3. ESS transition

1. No transition mobility :

- It is defined as a station which is not moving at all (stationary) or moving inside a BSS only.

2. BSS transition mobility :

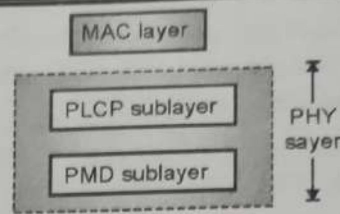
- A station having BSS transition mobility is the one which can move from one BSS to the other BSS but does not move outside one ESS.

3. ESS transition mobility :

- A station having ESS transition mobility is the one which can move from one ESS to any other ESS.
- But IEEE 802.11 does not guarantee a continuous communication when the station is moving.

7.12 The Physical Layer :

- The PHY layer acts as the interface between the MAC and wireless media, which transmit and receive data frames over a shared wireless media as shown in Fig. 7.12.1.



(O-900) **Fig. 7.12.1 : Sublayers within PHY**

- There are three important functions of the PHY as follows :
  1. To provide a frame exchange between the MAC and PHY that is controlled by the physical layer convergence procedure (PLCP) sublayer.
  2. To use signal carrier and spread spectrum modulation to transmit data frames over the media that is controlled by the physical medium dependent (PMD) sublayer.
  3. To provide a carrier sense indication back to the MAC to verify activity on the media.

Fading :

- Fading is defined as the phenomenon in which the signal strength at the receiver fluctuates.
- It is an important limiting factor for the high speed network performance.

Types :

- Fading can be classified into two types :
  1. Fast fading or small scale fading.
  2. Slow fading or large scale fading.

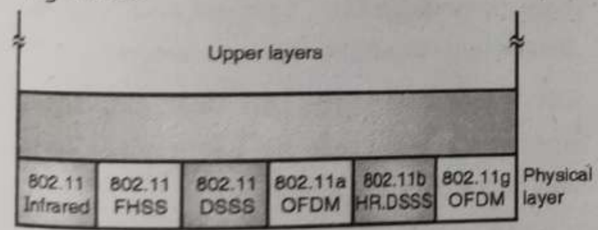
1. Fast fading :

- The rapid fluctuations in the amplitude phase or delay of the received signal is referred to as **fast fading,** or **small scale fading.**
- The fast fading takes place due to the interference that takes place at the receiver between the multiple versions of the same transmitted signal that arrive at the receiver at slightly different time instants.
- The time difference between the reception of the first version of the signal and its last version (most delayed version) is called as **delay spread.**
- The three propagation mechanisms i.e. reflection, diffraction and scattering are responsible for the multipath propagation of the transmitted signal which causes the fast fading.

- The variation in the received signal takes place because the multipath signals may sometimes add together to increase the signal power but they may subtract at some other time to reduce the signal power.
- Two commonly used techniques to overcome frequency selective fading are Spread Spectrum (e.g., FHSS or DSSS) and OFDM.
- The types of modulation schemes used by this standard are GFSK, DBPSK and DQPSK.
- Both the FHSS and DSSS modes are specified for operation in the 2.4 GHz ISM band, that is used by most electronic products.
- The third physical layer alternative is an infrared system using near-visible light in the 850 nm to 950 nm ranges as the transmission medium. But this is rarely used.

7.12.1 Various PHY Specifications :

- IEEE 802.11 has defined the specification for converting bits to a signal in the physical layer.
- One of them is in the infra-red frequency spectrum and the other five specifications are in RF range as shown in the partial 802.11 protocol stack of Fig. 7.12.2.



(G-382) **Fig. 7.12.2 : Part of 802.11 protocol stack**

- The five specifications in RF range are :
  1. FHSS - Frequency Hopping Spread Spectrum (802.11).
  2. DSSS - Direct Sequence Spread Spectrum (802.11).
  3. OFDM - Orthogonal Frequency Division (802.11 a).
  4. HR-DSS-High Rate-DSSS (802.11 b).
  5. OFDM (802.11 g).
  6. OFDM (802.11 n).

- In this section we are going to discuss the six specifications listed in Table 7.12.1.

Table 7.12.1 : Physical layer specifications

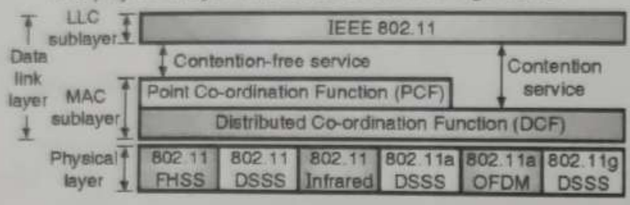
IEEE standard	Technique used	Frequency band	Modulation type	Data rate (Mbps)
802.11	FHSS	2.4 - 4.835 GHz	FSK	1 and 2
	DSSS	2.4 - 4.835 GHz	PSK	1 and 2
	None	Infrared	PPM	1 and 2
802.11 a	OFDM	5.725 – 5.85 GHz	PSK or QAM	6 to 54
802.11 b	DSSS	2.4 – 4.835 GHz	PSK	5.5 and 11
802.11 g	OFDM	2.4 – 4.835 GHz	Different	2.2 and 54
802.11 n	OFDM	5.725 – 5.85 GHz	Different	6000

- All these physical layer implementations except the infrared, work in the ISM frequency band.
- As defined earlier the ISM band is the industrial, scientific and medical band.
- Three unlicensed frequency bands are defined under the ISM band.
- They are as follows :
  1. 902 - 928 MHz
  2. 2.400 – 4.835 GHz
  3. 5.725 – 5.850 GHz

7.13 MAC Sublayer :

- MAC protocol has the responsibility to arbitrate the accesses to a shared medium among several end systems.
- The IEEE 802.11 standard does this via an Ethernet-like stochastic and distributed mechanism : CSMA/CA.
- According to IEEE 802.11 protocol a multiple access network is defined as the network where all the devices have to compete with each other to get access to the wireless channel.

- IEEE 802.11 specifies two medium access control protocols, Point Coordination Function (PCF) and Distributed Coordination Function (DCF).
- Out of these DCF is a fully distributed scheme which is suitable for the adhoc networking, whereas PCF is an optional centralized scheme.
- In IEEE 802.11 protocol stack these two protocols are represented by two MAC sublayers.
- The relation between DCF, PDF, the LLC sublayer and the physical layer has been shown in Fig. 7.13.1.



(G-2099) **Fig. 7.13.1 : MAC layers in 802.11 standard**

- We have already discussed the physical layer implementations.
- Now we will focus on the MAC sublayer.

7.13.1 RTS and 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 that are described later in the section on DCF.
- For avoiding faulty consecutive retransmissions, the **retry counters and timers** are employed to limit the lifetime of a frame.

Disabling RTS/CTS Mechanism :

- It is possible to disable the RTS/CTS mechanism by an attribute in the IEEE 802.11 management information base (MIB).
- The length of a frame that is required to be preceded by the RTS and CTS frames is defined by the value of the dot 11RTS threshold attribute.
- The RTS/CTS frames are employed if the frame size is larger than this threshold, otherwise, the frame can be transmitted directly.
- The RTS/CTS mechanism can also be disabled in the following situations :
  1. If the bandwidth demand id low;
  2. If all the stations are concentrated in an area such that all of them able to hear the transmissions of every other stations;
  3. If the contention level for the channel is low.
- The default value for this threshold is 128 and, by definition, an AP is heard by all stations in its BSS and will never have a hidden node.

7.13.2 The Retry Counters :

- Every MAC frame is associated with two retry counters namely a short retry counter and a long retry counter.
- The short retry counter is associated with short frames (i.e., the frames with size less than threshold).
- Whereas the long retry counter is for controlling the long frames.
- Every transmitted MAC frame is associated with a lifetime timer in addition to the counters.
- This information helps the MAC to determine whether or not to cancel the transmission of a frame and, hence discard it or not.
- If the transmission is unsuccessful, the corresponding counters are incremented according to the frame size.
- As soon as the counters reach the threshold values defined in the MIB the frame is discarded.

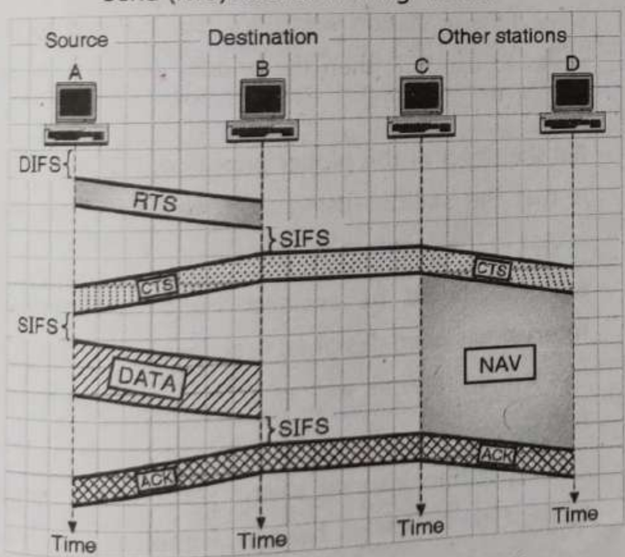
7.13.3 Distributed Co-ordination Function (DCF) :

- IEEE has defined two protocols at the MAC sublayer. One of these two protocols is called as the distributed co-ordination function (DCF).
- 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. 7.13.3. 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 Inter frame Space (DIFS). After this waiting time the station A sends a control frame called as Request to Send (RTS) as shown in Fig. 7.13.3.



(G-2100) **Fig. 7.13.3 : CSMA/CA and NAV**

2. After receiving the RTS, the destination station B waits for a specific amount of time called the Short Inter frame 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.

Network Allocation Vector (NAV) :

- The question here is how do other stations restrain from sending their data when one channel is already transmitting ?
- In other words how is the collision avoidance is practically accomplished ?
- The answer to both these questions is a special feature called as NAV.
- The concept of NAV i.e. Network Allocation vector is as follows :
- When station A sends an RTS frame (see Fig. 7.13.3), which consists of the time duration for which A needs to use the channel, the stations which are affected by this transmission create a timer called as NAV.
- The NAV will indicate the amount of time that must pass before these stations can check again, whether the cannel has again become idle.
- This happens every time when a station sends its RTS frame, the other stations will initiate their NAV.
- During the NAV interval no other station will initiate its transmission.
- In this way the collision avoidance aspect of the CSMA / CA protocol is accomplished.
- The other stations check the channel for idleness only after the expiry of their NAV.

Collision During Handshaking :

- If the collision takes place when the RTS and CTS frames are in transition, then it is called as collision during handshaking.
- In such a situation, two or more stations try to send the RTS frame at the same time, which may collide with each other.
- But in CSMA/CA there is no mechanism to detect such collisions. So the collision of RTS frames also will go undetected.
- Then how will the sources know that a collision has taken place ?
- Well, a source will assume that the collision has taken place if it does not receive the **CTS** frame from the receiver in response to RTS.
- In such events, the sender applies the **back-off** strategy and tries after sometime.
- This is how the collision during handshaking is handled by CSMA/CA in the wireless environment.

7.13.4 Hidden Station Problem :

GTU : S-12, S-20, W-20

University Questions

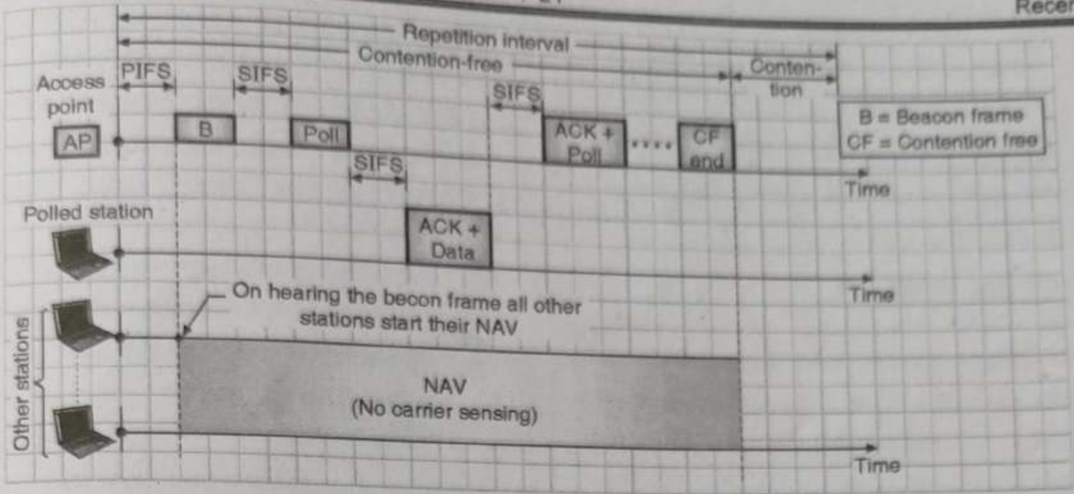
Q. 1 Explain the terms :
1. Hidden- terminal
2. Exposed –terminal **(S-12, 4 Marks)**

Q. 2 Explain the hidden-node problem and exposed-node problem in context of mobile ad-hoc networks. **(S-20, W-20, 7 Marks)**

- Let us see now, how CSMA/CA avoids the hidden station problem.
- Refer Fig. 7.13.3. Actually the RTS and CTS frames (handshake frames) are used to solve the hidden station problem.
- As shown in Fig. 7.13.3, the RTS message from A can reach B but not C (because C is out of range of A).
- In response to this, station B sends the CTS frame. Since both A and C are in the range of B, the CTS frame will reach stations A as well as C.
- Due to this CTS frame station C will understand that some hidden station (A in this case) is already using the channel.
- Therefore C will refrain from transmitting. This will avoid the possible collision.

7.14 Point Co-ordinate Function (PDF) :

- 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 inter frame space called PIFS has been defined to give priority to PCF over DCF. This inter frame 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. 7.14.1.
- The repetition frame is repeated continuously.
- As shown in Fig. 7.14.1, 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. 7.14.1.



(G-2101) **Fig. 7.14.1 : 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.

7.14.1 Fragmentation :

- In the wireless communication, the frames often get corrupted because the wireless environment is extremely noisy. The source has to retransmit the corrupt frame.
- Therefore the fragmentation process which is the process of dividing a large frame into small ones is recommended by the protocol.
- This is because in the event of corruption and retransmission, it is always better to resend a small frame than a big one.

7.14.2 Exposed Station Problem :

GTU : S-12, S-20, W-20

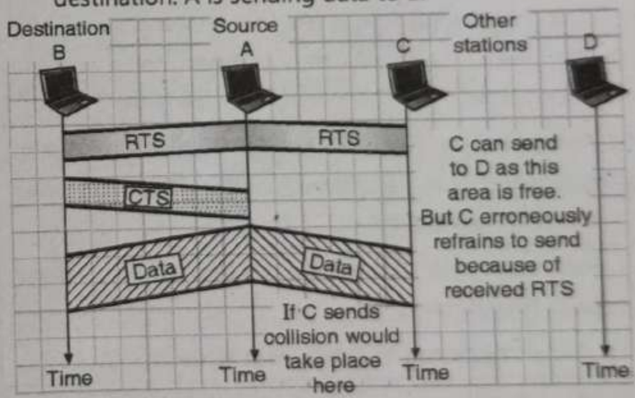
University Questions

Q. 1 Explain the terms :

1. Hidden- terminal
2. Exposed –terminal **(S-12, 4 Marks)**

Q. 2 Explain the hidden-node problem and exposed-node problem in context of mobile ad-hoc networks. **(S-20, W-20, 7 Marks)**

- Earlier in this chapter the problem of hidden station and its remedy have been discussed.
- The **exposed station problem** is a similar problem.
- In this problem, a station refrains from using the common even when no other station is using it (i.e. the channel is actually free).
- In order to understand this concept clearly, refer Fig. 7.14.2 where A is the sending station and B is the destination. A is sending data to B.



(G-2155) **Fig. 7.14.2 : Exposed station problem**

- 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. 7.14.2, station C is in the range of station A. In other words C is exposed to A.
- So C listens to what A is transmitting and decides to refrain itself from sending its message to D.
- This causes wastage of channel capacity.
- The handshaking messages RTS and CTS are not helpful in solving the exposed station problem.

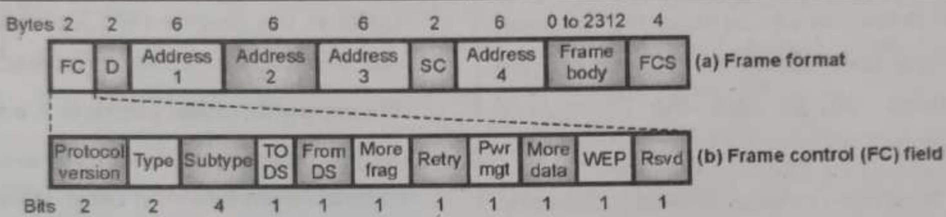
- In fact station C refrains itself when it hears the RTS message from station A.
- This happens because station C does not know that the communication between A and B does not affect the zone between C and D.

7.15 Framing in WLAN :

- The MAC layer accepts MAC Service Data Units (MSDUs) from higher layers and adds to it its headers and trailers to create MAC Protocol Data Units (MPDU).
- Optionally, the MAC may fragment MSDUs into many smaller frames, in order to increase the probability of successful delivery of each individual frame.
- A MAC frame contains the header followed by MSDU followed by the trailer contain the following information :
  1. Addressing information
  2. IEEE 802.11-specific protocol information
  3. Information for setting the NAV
  4. Frame check sequence.

General Frame Format :

- The general format of a MAC layer frame is as shown in Fig. 7.15.1. It consists of nine fields.



(G-2149) **Fig. 7.15.1 : Frame format**

- Various important fields in this frame are as follows :

1. **FC (Frame Control) :**

- This 2 byte long field is used for defining the type of the MAC frame. It also defines some control information.
- As shown in Fig. 7.15.1, the FC field has been subdivided into 11 subfields. Table 7.15.1 describes these subfields in short.
- Each frame type in this table has been discussed later on in this chapter.

Table 7.15.1 : Subfields in FC field

Field	Bits	Description
Version	2	Current version is 0.
Type	2	Type of information : Management (00) central (01) or data (10).
Subtype	4	Defines subtype of each type of frame (see Table 7.15.2).
To DS	1	Defined later.
From DS	1	Defined later.
More frag	1	If this is 1, it means more fragments.
Retry	1	If this is 1, it means retransmitted frame.
Pwr mgt	1	If it is 1, it means station is in power management mode.
More Data	1	If it is 1, it means station has more data to send.
WEP	1	Wired Equivalent Privacy (Encryption implemented).
Rsvd.	1	Reserved.

2. **Duration ID (D/ID) :**

- This is a 2-byte long field which is used to define the transmission which is used to set the value of NAV.
- In one control frame, it is also used to define the ID of the frame.

3. **Addresses Field :**

- As shown in Fig. 7.15.1, there are four address fields from address – 1 to address – 4 and each field is of 6 - byte length.
- As will be discussed later on the values of **To DS** and **From DS** sub fields will decide the meaning of each address field.

4. **SC (Sequence Control) :**

- The sequence control or SC field is 2 byte or 16 bit long.

- Out of these 16 bits, the first four bits are used for defining the fragment number.
- The sequence number which is same for all the fragments is defined by the remaining 12-bits in SC.
- The four bit long fragment number sub-field is assigned to each fragment of an MSDU.
- The field for the first fragment is set to zero while subsequent fragments are incremented sequentially.
- The 12 bit long sequence number sub-field has a constant number for each MSDU which is incremented for each following MSDUs.

5. **Frame body :**

- This is a field with variable length up to 2304 bytes and 2312 bytes when encrypted.
- The information contained in this field, is specific to the particular data or management frame.

6. **FCS :**

- The frame check sequence is a 4-byte long field and it carries the CRC-32 error detection sequence.

7.15.1 Advantages of WLANs : GTU : W-11

University Questions

Q. 1 Mention some of the advantages and disadvantages of WLANS ? Mention the design goals of WLANS ? **(W-11, 7 Marks)**

- Following are some of the major advantages of WLANs :
  1. WLAN is cheaper than wired LAN, because wires are not required.
  2. WLAN can be laid down where it is difficult to run cables e.g. Historical buildings.
  3. It is possible to form WLAN using laptops.
  4. Any standard Wi-Fi device can work anywhere in the world.
  5. WPA2 protocol used for Wi-Fi is secure protocol so WLANs are safe.
  6. Easy installation and you don't need extra cables for installation.
  7. WLAN are often useful in disasters situation e.g. earthquake and fire. Wireless network can connect people in any disaster.
  8. it is economical due to the tiny area access.

7.15.2 Disadvantages of WLAN : GTU : W-11

University Questions

Q. 1 Mention some of the advantages and disadvantages of WLANS ? Mention the design goals of WLANS ? **(W-11, 7 Marks)**

- Following are some of the major limitations of WLANs :
  1. Spectrum assignment and operational conditions are not same worldwide.
  2. Radiated power is limited to 100 mW. So the range will be limited.
  3. Wi-Fi networks have a limited range typically 35 m or 120 ft indoor and 100 m or 300 ft outdoor.
  4. There are data security risks. Wi-Fi networks are not protected thoroughly.
  5. Wi-Fi connections can be easily disrupted.
  6. With increase in the number of devices in a WLAN, its data transfer rate decreases.
  7. WLANs may interfere with other WLANs and wireless networks, which use the same frequency band.
  8. Low data transfer rate than wired connection.

7.15.3 Applications of Wireless LAN :

- Due to flexibility and possibility to configure in a variety of topologies, WLANs can be used in a number of varied applications. Some of them are as follows :
  1. For accessing the Internet, checking E-mails and receive/send instant messages when the user is moving.
  2. WLANs can set up networks in the locations affected by earthquakes or other disasters where no suitable infrastructure is available and wired networks have been destroyed.
  3. In places of historic importance, where wiring may not be permitted, the WLAN can be used easily and effectively.

Ex. 7.15.1 : A Wi-Fi system operates at 1 Mbps. Calculate the data transfer time required for a 20 KB file. **S-20, W-20, 3 Marks**

Soln.

Given : File size = 20 KB, data transfer rate = 1 Mbps

To find : Data transfer time

- Data transfer time is the time required for one file of 20 KB to be transferred.
- It is given by,

Data transfer time = file size/ data transfer rate

$= 20 \times 10^3 / 1 \times 10^6$

$= 20$ ms ...**Ans.**

Ex.7.15.2 : A Wi-Fi access point transmits + 20 dBm power. The receiver sensitivity of a wireless device in the network is specified as – 85 dBm. Determine the maximum allowable path loss, ignoring other power losses.

S-20, W-20, 3 Marks

Soln.

Given : Wi-Fi, Transmitted power = 20 dBm, Receiver sensitivity = – 85 dBm

To find : Maximum allowable path loss

- The receiver sensitivity is defined as the minimum input power required for it to decode the received signal without introducing any error.

Sensitivity = Transmitted power – maximum path loss

∴ Maximum path loss = Transmitted power – Sensitivity

∴ Maximum path loss = 20 + 85 = 105 dBm ...**Ans.**

7.16 Wireless MAN (WMAN) :

- The WMAN (Wireless MAN) is a Broadband Wireless Access (BWA) technology.
- It is used for the residential and commercial applications, because WMAN provides high capacity, high speed and high efficiency multimedia services.
- Wi-MAX is basically a Wireless MAN standard for broadband wireless communication.
- The IEEE developed the 802.16 standard known as Wi-MAX (Worldwide interoperability for microwave access (Access)).
- Wi-Max provides the **last mile** wireless broadband internet access, which is capable of carrying data-intensive applications.

7.16.1 Wi-MAX :

- Wi-MAX provides wireless (broadcast) connectivity all over the large metropolitan city.
- In June 2001, Wi-MAX forum defined Wi-MAX (802.16) as worldwide interoperability for microwave access.
- Wi-MAX is a standard technology, which allows the delivery of last-mile wireless broadband access.
- It is used as an alternative to using cables and DSL (digital subscriber line).
- Wi-Max operates over both licensed and non-licensed frequency bands using following two configuration.
- It extends its coverage area to town and cities wirelessly through the following configurations :

A. Non-line-of-sight (NLOS) :

- In this type of configuration, a small antenna on the mobile unit is attached to the Wi-MAX tower.
- Similar to Wi-Fi, Wi-MAX uses a lower frequency range of 2 - 11 GHz in NLOS configuration.

B. Line-of-sight (LOS) :

- In this type of configuration, a fixed dish antenna points in a straight line at the Wi-MAX tower from a rooftop or a pole.
- As the line-of-sight connection is more stable and stronger, it can send more data with less number of errors.
- Line-of-sight transmissions use higher frequencies with approximate frequency range of 66 GHz.
- The main purpose of Wi-MAX is to work as a wireless Internet service provider (WISP) or as a carrier network that covers the entire cities and regions with broadband Internet access.
- If we consider all the factors, the average cell range for most Wi-MAX networks will be of 4-5 miles in NLOS applications which is much less than that in the LOS communication.
- In LOS applications, Wi-MAX networks will have services range up to 16 km (10 miles).
- Service beyond the range of 10 miles is definitely possible.

- However for the heavily loaded networks providing service beyond 10 miles is not desirable due to scalability factor.

7.16.2 Wi-Bro (Wireless Broadband) :

- In South Korea, Wi-MAX is known as wireless broadband (Wi-Bro).
- Similar to mobile Wi-MAX, the Wi-Bro also is based on the IEEE 802.16e standard.
- But the design of Wi-Bro is more robust with respect to the speed of subscriber as compared to BS (base station).
- The maximum channel bandwidth used by Wi-Bro is 8.75 MHz and it uses only TDD(Time division duplex) for its operation.
- Wi-Bro uses the frequency band of 2.3 GHz which is used by the Wi-MAX devices as well.

7.16.3 Need of Wireless MAN (WMAN) :

- There are many restrictions on mobility and connection establishment in the two wireless networks: i.e. WLANs and WPANs.
- The first restriction is the range of WLAN and WPAN networks.
- It is only a few hundred meters from the source of the RF signal.
- WLAN and WPAN allow the users to be mobile only in this area.
- Another restriction on these users is that they should stay within line-of-sight of antennas.
- Wireless MAN is a group of technology that avoids all the problems occurring in WLAN and WPAN and provides wireless connectivity across a large metropolitan city.
- Wireless MANs are needed because :
  1. They can provide high speed connection.
  2. They provide wireless services to customers in the metropolitan area.
  3. Lower cost.
  4. They have high efficiency.

7.17 IEEE 802.16 (Wi-MAX) : GTU : W-17

University Questions

Q. 1 Explain in detail Wi-Max Technology. (W-17, 7 Marks)

- Wi-MAX is basically a Wireless MAN standard for broadband wireless communication.
- IEEE 802.16 standard offers a communication path between a core network such as PSTN or the Internet and a subscriber site.

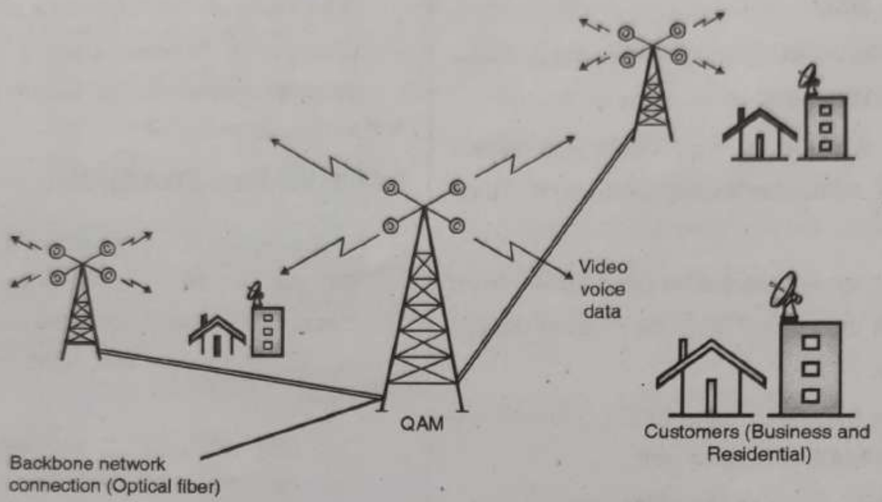
7.17.1 Wi-Max Standards :

- Following are the three working groups were formed for the air interface between a base transceiver station and a subscribers transceiver station because 802.16 standards are concerned with these air interface :
  1. IEEE 802.16.1 : Provides air interface for frequencies of 10-66 GHz.
  2. IEEE 802.16.2 : Coexistence of broadband wireless access system.
  3. IEEE 802.16.3 : Provides air interface for licensed frequencies between 2-11 GHz.
- The aim of IEEE 802.16 is to offer high-speed Internet access to residential and commercial subscribers without using cables.
- It can support services such as VoIP (voice over IP) and TCP/IP applications with different QoS requirements.

7.17.2 Structure of WMAN :

- Fig. 7.17.1 shows the structure of the wireless MAN.
- The IEEE developed the 802.16 standard as a replacement to the local network operators.
- The 802.16 WMAN provides a standard solution for a cable free telecommunication service market.
- The IEEE 802.16 standard was published in 2001. Before this time, there were two other wireless MAN solutions already existing.
- They were :
  1. Multichannel Multipoint Distribution System (MMDS).
  2. Local Multipoint Distribution System (LMDS).

- These two operated at different frequencies in the millimeter wavelength range.
- Both these WMAN solutions suffered due to lack of standardization.
- So their use remained restricted.
- The MMDS solution worked in 2.4 GHz or 5 GHz band and had a range up to 50 km.
- MMDS was designed originally for the wireless CATV solution, without a backward channel from the customer.



(L-430) **Fig. 7.17.1 : Broadband wireless MAN IEEE 802.16**

- However, in order to make as much revenue as possible the MMDS solutions are used for voice and internet services.
- The data rates for such applications are 128 kbps to 3 Mbps downstream i.e. from base station to subscriber and 128 kbps upstream from subscriber to the base station.
- The subscribers can access telephony and ISP (Internet Service Provider) through a modem.
- 802.16 MMDS and LMDS use the frequencies in the band 2 GHz to 60 GHz.
- The drawback of microwaves is that with increase in frequency these waves become more and more directional.
- They travel in a straight line and can be easily absorbed by water.
- Therefore rain, snow and even trees absorb these electromagnetic waves and introduce errors in the received signal.
- In order to overcome this problem, the signal produced by the base station and the customer stations are encoded using Hamming codes.

7.17.3 IEEE Project 802.16 (Wi-Max) :

- Wi-Max is the outcome of the IEEE 802.16 project.
- This project was taken up as an effort to standardize the broadband wireless systems in 2002.
- The other name for this standard is **wireless local loop (WLL).**
- We will first compare the 802.16 project with the 802.11 project that is the wireless LAN standard. 802.16 is a standard designed for wireless WAN or MAN.
- In IEEE 802.11, the base station and a host are separated by a short distance but in IEEE 802.16 this distance can be significantly increased (typically tens of kilometers).
- 802.11 projects define a connectionless service but 802.16 projects are designed for a connection-oriented service.

7.17.4 New Standards :

- IEEE 802.16 was later revised and the following two new standards were created.
- These standards do not alter the basic principle of original 802.16.

- Instead they concentrate on the nature of two services :
  1. IEEE 802.16 d - Concentrates on fixed Wi-Max.
  2. IEEE 802.16 e - Defines the mobile Wi-Max.

7.17.5 Spectrum Allocation :

- There is no uniform global licensed spectrum for Wi-Max.
- However the three licensed spectrum profiles published by the Wi-Max forum are : 2.3 GHz, 2.5 GHz and 3.5 GHz.

7.17.6 Specifications of IEEE 802.16 :

- Table 7.17.1 summarizes the IEEE 802.16a WiMAX specifications.

Table 7.17.1 : 802.16 WiMAX specifications

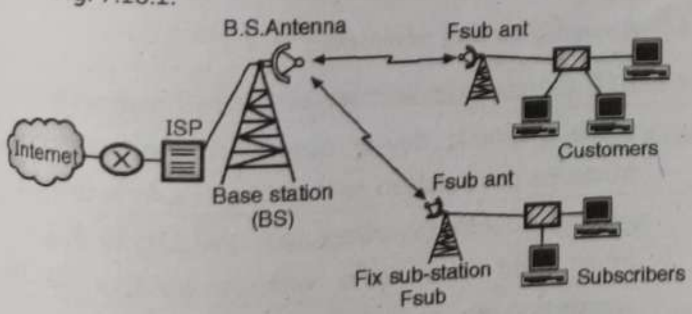
Sr. No.	Parameter	Value
1.	RF band	2-11 GHz
2.	Modulation	Single carrier, OFDM
3.	Data rate	Peak data rates to 70 Mbps
4.	Multiple access	OFDMA, TDMA
5.	Duplex technique	TDD, FDD
6.	Network topology	Point to multipoint, Mesh topology

7.18 Wi-Max Services :

- The following two types of services are provided by Wi-Max to its subscribers :
  1. Fixed Wi-Max services.
  2. Mobile Wi-Max services.
- Let us discuss them one by one.

7.18.1 Fixed Wi-Max Services :

- The principle behind fixed Wi-Max is as shown in Fig. 7.18.1.

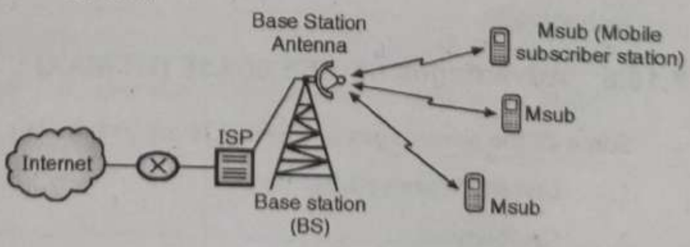


(G-2167)**Fig. 7.18.1 : Fixed Wi-Max**

- The fixed Wi-Max services can provide almost all the services provided by the wired telephone and network companies in a wireless manner.
- As shown in Fig. 7.18.1, a fixed Wi-Max consists of a base station **(BS)**, fixed substation **(FSub)**, antennas and wireless subscribers.
- The communication between the base station and substations is bidirectional in nature.
- The base station is connected to the wired Internet through an ISP (Internet service provider).
- The base station radiates (transmits) this information to the substations using its antenna. The same antenna can receive the data from the substations and convey it to the Internet.
- The substations have their own antennas, which can either receive or transmit the data.
- The data received from the base station is given to the devices connected to substations through connecting wires.
- In order to optimize the performance of the system, the base station can use different types of antennas, such as omni-directional, sector or panel antennas.
- A beam steering **adaptive antenna system (AAS)** or a simultaneously transmitting and receiving **MIMO** antenna is used by the Wi-Max system for improvement in its performance.
- The AAS antenna can focus its energy in the direction of subscriber while transmitting while it can focus in the direction of the transmitting subscriber station while receiving in order to maximize the received energy.

7.18.2 Mobile Wi-Max Services :

- The concept of mobile Wi-Max is illustrated in Fig. 7.18.2. You will notice its similarity with the fixed Wi-Max.



(G-2168) **Fig. 7.18.2 : Mobile Wi-Max**

- Thus principally the mobile Wi-Max is same as the fixed Wi-Max except one change.
- Here the subscribers are not fixed ones. Instead they are mobile stations which can move from one place to the other.
- This is very similar to the cellular telephone system. Hence some issues like roaming are present in mobile Wi-Max as well.

7.18.3 Internet Access :

- Wi-Max is capable of providing at home or mobile internet access to anyone across the whole city or even whole country.
- It is relatively cheap to use Wi-Max to provide Internet access to the remote locations.

Connecting :

- We can use a Wi-Max USB MODEM for mobile Internet Devices that can provide connectivity to a Wi-Max network. They are known as subscriber stations (SS).
- Portable units of Wi-Max are in the form of handsets similar to smart phones, PC USB dongles and embedded devices in laptops.

7.18.4 Mobile Phones based on Wi-Max :

- HTC launched the first Wi-Max enabled mobile phone called the Max 4G in 2008 only for Russia.
- Its next generation was made available in America in March 2010.
- This mobile is capable of carrying out data and mobile sessions simultaneously.

7.18.5 Spectral Efficiency :

- One of the biggest advantage of Wi-Max is its high spectral efficiency.
- This is due to the multiple reuse and smart antenna technologies.

7.18.6 Advantages of IEEE 802.16 (Wi-MAX) :

- Some of the advantages of IEEE802.16 are as follows :
  1. Last mile connectivity
  2. Flexibility
  3. Scalability
  4. Roaming among networks
  5. Other advantages

1. Last-mile connectivity :

- In many areas customer cannot get broadband access through cable connections or DSL due to some practical limitations of cables and DSLs.
- As DSL can reach only about 3 miles i.e 18,000 ft from central office switch it cannot serve many urban or suburban areas.
- These problems can be solved by using wireless broadband which are easy to scale, faster to install and flexible.
- In this way, 802.16 standards will help to solve the problems of last-mile.
- It helps to accelerate the operation of 802.11 hotspots and small office/home Wireless LANs.

2. Flexibility :

- IEEE 802.16 standards are flexible. It is beneficial to a business that frequently moves its operations e.g. a construction company having offices at different building sites.
- It is easy to set up wireless broadband access quickly at a new site as compared to setting up a DSL line.

3. Scalability :

- The 802.16 standard is scalable. It supports flexible channel bandwidths for cell planning in both licensed and license-exempt spectrum e.g. if an operator is assigned the spectrum of 16 MHz, then he can divide this spectrum into two sectors (each of 8 MHz) or four sectors (each of 4 MHz).
- The number of users can be increased by focusing power on increasingly narrow sectors by maintaining good range and throughput.

4. Roaming among networks :

- IEEE 802.16e standard allows handoff mechanism in which a mobile device can switch the connection from one base station to the other. i.e. from one 802 network to other network (e.g. 802.11b to 802.16), from wired network to wireless 802.11or 802.16 connection etc.

- With the use of 802.11, its network users can stay connected by moving around a building or a hotspot.
- They lose their connection if they travel out of the specified range.
- With the use of 802.16e, its users can stay best connected by 802.11 when they are within hotspot.
- When they leave the hotspot, they can be connected to 802.16 within WiMAX service area.
- 802.16 will allow the users to stay connected within a complete metropolitan area. e.g. when stationary a notebook can get connected through either Ethernet or 802.11 and will remain connected with 802.16 when roaming the city.

Other Advantages :

- Following are some other advantages of WiMAX :
  1. It supports very high-speed voice and data transfer over longer distances.
  2. A single WiMAX base station serves hundreds of users.
  3. It is considered to be a cheaper alternative to broadband-wired technologies such as ADSL, cable modem etc.
  4. Higher speeds can be achieved.
  5. It can provide connectivity to a larger area.

7.18.7 Disadvantages of Wi-MAX :

- Following are the disadvantages of Wi-MAX :
  1. LOS (Line of Sight) connection is required for the subscribers located at the far away from the Wi-MAX Base Station.
  2. Bad weather conditions such as rain will interrupt the Wi-MAX signal and often cause loss of connection.
  3. Wi-Max is power-consuming technology and requires significant electrical support.
  4. Installation cost is high.
  5. Multiple frequencies are used to deploy Wi-MAX.
  6. An inherent problem with Wi-Max is that it cannot operate at higher bit rates over long distances. We can get either higher bit rates or longer distances but not both at a time.
  7. The Wi-MAX network has lack of quality service because there are hundreds of people trying to get access at the same tower so due to heavy traffic it is difficult to maintain high quality.

7.18.8 Uses / Applications of Wi-Max :

- The Wi-Max can be used in the following applications :
  1. To provide portable mobile broadband connectivity.
  2. It can be used as an alternative to cable, Digital Subscriber Line (DSL) for providing a broadband access.
  3. To provide services such as Voice on IP (VoIP).
  4. For providing a source of Internet connectivity.
  5. Web browsing and instant messaging
  6. Wireless telephone services

7.18.9 Comparison of IEEE 802.11 and IEEE 802.16 : GTU.: W-12, S-15, S-16, S-18

University Questions

Q. 1 Compare Wi-Fi and WiMAX in brief. **(W-12, 4 Marks)**

Q. 2 Compare Wi-Fi and Wi-MAX system parameters . **(S-15, 7 Marks)**

Q. 3 Compare Wi Fi and Wi Max technologies. **(S-16, 7 Marks, S-18, 3 Marks)**

Sr. No.	Parameter / Characteristics	IEEE 802.11 (Wi-Fi)	IEEE 802.16 (WiMAX)
1.	Type of standard	This is designed for Wireless LANs.	Designed for wireless WAN, MAN.
2.	Distance between BS and subscriber	Very short	Very long (few tens of km).
3.	Type of service	Connection less	Connection oriented

Sr. No.	Parameter / Characteristics	IEEE 802.11 (WI-FI)	IEEE 802.16 (WIMAX)
4.	Number of users	Few	Large
5.	Bandwidth	Small (fixed 20 MHz)	Large (1.5 to 28 MHz)
6.	Frequency band	ISM band	Millimeter waveband and micro waveband
7.	QoS	Not guaranteed	All transmissions are QoS guaranteed
8.	Range	30-100 m	Up to 50 km
9.	Usage	Indoor	Outdoor
10.	Data rate	Upto 54 Mbps	Up to 134 Mbps
11.	Frequency band	License-free bands	License-free as well as licensed bands

7.19 Wireless PAN (WPAN) :

Definition :

- A **WPAN** is simply a short-distance network that allows many devices within a small area to connect to one another with wireless links.
- WPAN is a Wireless Personal Area Network. It is one-step down from WLANs.
- The WPANs cover smaller areas as compared to WLANs and need to use less power for transmission.
- WPANs are used for networking of portable and very small computers, cell phones, printers, speakers, microphones, etc.
- They are short-range to very short-range wireless networks.
- WPANs are used to exchange data between devices within the reach of an individual.

Examples of WPAN :

- The best example of WPAN is Bluetooth. Bluetooth can be found in many consumer electronics devices such as mobile phones, PDAs and wireless headsets etc.
- The IEEE 802 has established the IEEE 802.15 standard for WPANs.
- In wireless technologies, inter-working to generate heterogeneous wireless environment is an issue of WPANs.

7.19.1 Need of Wireless PAN :

- Wireless PANs are needed because of the following reasons :
  1. A WPAN allows the communication and data exchange between the devices that are in very close proximity.
  2. WPAN allows devices to generate or offer data and voice access points and personal ad hoc connectivity. It can be used as a replacement for connecting cables.
  3. The operating range for WPAN devices is within a personal operating space (POS) of up to 10 meters.
  4. The WPAN devices are expected to offer secure modes of operation.
  5. WPAN fixed devices do not affect the primary functions such as the form factor and power consumption of the devices.
  6. As WPANs use the license-free radio frequencies (e.g. ISM band), WPAN technology can coexist with other RF technologies.
  7. WPAN usually consumes less power, it is low cost and more secure as compared to other wireless technologies.

7.20 ZigBee (IEEE 802.15.4) :

GTU : S-16, S-18, W-19

University Questions

Q. 1 What is ZigBee ? Explain in details ZigBee networks. **(S-16, 7 Marks)**

> **Q. 2** What is Zigbee? Describe the different topologies used in zigbee network. **(S-18, 7 Marks)**
>
> **Q. 3** What is ZigBee ? Explain in details ZigBee networks. **(W-19, 7 Marks)**

- ZigBee is a low rate wireless PAN (LR-WPAN), that was developed by IEEE 802.15.4 task group.
- IEEE 802.15.4 task group focused on low data rate WPAN solutions with low complexity and very long battery life (few months to several years).
- Hence, ZigBee is a low power, low data rate, low bandwidth and close proximity wireless adhoc network.

Frequency bands :

- ZigBee is intended to operate in the unlicensed and international frequency bands.
- The three frequency bands allocated to this standard are 868 MHz, 915 MHz and 2.4 GHz bands.

Type of modulation :

- ZigBee transmits a spread spectrum modulated signal by using either binary PSK (BPSK) or minimal PSK (MPSK) modulation depending on the data rate.

Range :

- The range of ZigBee standard is between 10 and 75 meters line-of-sight (LOS) depending on power consumption.
- The ZigBee MAC layer supports different adhoc topologies and guaranteed packet delivery.

Security :

- ZigBee networks are secured by 128 bit symmetrical encryption keys. ZigBee is best suitable for intermittent data transmission.

7.20.1 Features of ZigBee : GTU : W-14

> **University Questions**
>
> **Q. 1** Explain the salient features of ZigBee networks. **(W-14, 7 Marks)**

- Some of the important features of this standard are as follows :
  1. Low battery consumption.
  2. Low cost.
  3. It is easy to implement.
  4. Low data rate (upto 250 kbps).
  5. Small range (10 to 75 m).
  6. Secured communication by 128 bit symmetrical encryption key.
  7. It uses low power digital radio links for connections.
  8. Frequency bands : 868 MHz, 915 MHz, 2.4 GHz.
  9. Uses spread spectrum communication.
  10. A ZigBee network can support up to 65000 nodes per network.
  11. ZigBee can automatically establish its network.
  12. It uses smaller packers as compared to Bluetooth or Wi-Fi.
  13. Type of modulation : BPSK, MPSK.

7.20.2 Radio Specifications :

Table 7.20.1 : Radio specifications of ZigBee

Sr. No.	Parameter	Specification
1.	Frequency bands	868 MHz, 915 MHz, 2.4 GHz.
2.	Spread spectrum	DSSS
3.	Modulation	BPSK, MPSK.
4.	Maximum range	75 m
5.	Maximum data rate	250 kbps
6.	IEEE standard	802.15.4
7.	Topologies	Star, mesh and cluster tree

7.21 ZigBee Topologies : GTU : S-18

> **University Questions**
>
> **Q. 1** What is Zigbee? Describe the different topologies used in zigbee network. **(S-18, 7 Marks)**

- The ZigBee specification supports the following three network topologies :
  1. Star topology.
  2. Mesh or peer to peer topology.
  3. Cluster tree topology.

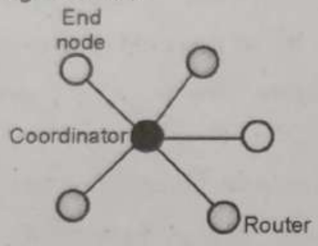
7.21.1 Star Topology : GTU : S-18

University Questions

Q. 1 What is Zigbee? Describe the different topologies used in zigbee network. **(S-18, 7 Marks)**

Schematic diagram :

- The star topology used for a ZigBee network is as shown in Fig. 7.21.1(a).



(G-2651) **Fig. 7.21.1(a) : Star topology**

- It has a single central controller node called coordinator which establishes the communication between the network devices.
- The coordinator node needs to be an FFD but the other devices can be either RFDs or FFDs.
- Once an FFD is activated for the first time, it can become a coordinator and establish its own network.
- A network identifier is chosen by each star network.
- This identifier is such that it is not being used by any other network within the communication range.
- Due to a unique identifier, each star network can operate independently.
- Every node in the network is synchronized with the PAN coordinator by using Beacons.

Applications :

- Following are the applications of star topology :
  1. Home automation
  2. Personal computer (PC) peripherals
  3. Games.

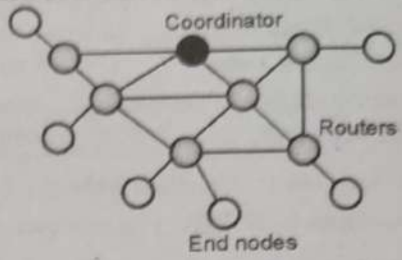
7.21.2 Mesh (Peer to Peer) Topology : GTU : S-18

University Questions

Q. 1 What is Zigbee? Describe the different topologies used in zigbee network. **(S-18, 7 Marks)**

Schematic diagram :

- Fig. 7.21.1(b) illustrates the mesh topology. It is also called as peer to peer topology.



(G-2652) **Fig. 7.21.1(b) : Mesh (Peer to peer) topology**

- As shown, there is only one coordinator. However unlike the star topology, here any device can communicate with any other device present in its range.
- This type of topology allows a multiple hop communication that increases the network reliability.
- This topology does not beacons. But not using beacons reduces the control and increases number of collisions as compared to beacon controlled networks.

Applications :

- Mesh topology is used in the following applications :
  1. Industrial monitoring and control.
  2. Wireless Sensor Network (WSN).
  3. Asset and inventory tracking.

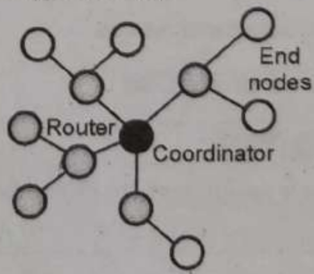
7.21.3 Cluster Tree Topology : GTU : S-18

University Questions

Q. 1 What is Zigbee? Describe the different topologies used in zigbee network. **(S-18, 7 Marks)**

Schematic diagram :

- A ZigBee network using the cluster tree topology is as shown in Fig. 7.21.1(c).



(G-2653) **Fig. 7.21.1(c) : Cluster tree topology**

- This toplogy is a special case of peer to peer topology.
- As shown in Fig. 7.21.1(c), most of the devices connected in cluster tree network are FFDs and an

RFD may be connected as a leaf node at the end of a branch.

- One FFD acts as the coordinator. Any FFD can operate as a router and provide synchronization services to other routers and end devices.
- The coordinator forms the first cluster of devices. It establishes itself as the cluster head and chooses an unused cluster identifier.
- Then the coordinator broadcasts beacon frames to all neighboring devices.
- On receiving a beacon frame a candidate device may request the coordinator a permission to join the network.
- If the permission is granted, the coordinator adds this new device as a child device in the neighbor's list.
- Then the coordinator starts transmitting beacons periodically so as to allow the other candidate devices to join the network.

Advantages :

1. The cluster tree topology is multicluster, hierarchical structure.
2. It has the advantage of increasing the coverage area.

Disadvantage :

- The disadvantage of this topology is increase in message latency (delay).

7.21.4 Applications of ZigBee :

- The application areas of ZigBee are :
  1. Automation of commercial buildings.
  2. Engineering applications.
  3. Industrial applications.
  4. Home / office automation.
  5. Telecommunications.
  6. RFID applications.
- Some of these applications are elaborated below.

1. Automation of commercial buildings :

- In a commercial building, ZigBee can be used to monitor the building maintenance.
- The ZigBee wireless network can be used to monitor the operation of the smoke-detectors and the positions of the fire-door.
- Such networks are particularly useful for large commercial buildings with a large number of floors.
- With a ZigBee network a central station can remotely monitors every smoke detector.
- Also we can use a ZigBee device to switch on and off a light without using any wire.

2. Home / office automation :

- We can also use Zigbee devices for the office and residential automation.
- They can be used for monitoring and controlling, heating, lighting, cooling and door-locking mechanisms.
- ZigBee home automation can be used for monitoring the home security systems and smoke detectors.

3. Telecommunications :

- A ZigBee mobile device is formed if a ZigBee device is embedding a into a mobile phone or PDA and it can easily communicate with the other ZigBee devices.
- The ZigBee mobile device can transmit and receive messages, share ring tones, images and contacts as well.
- A ZigBee mobile device can be used to communicate with another ZigBee device that can detect the critical condition of a patient.

7.21.5 Comparison of Bluetooth and ZigBee :

Table 7.21.1 : Comparison of BT and ZigBee

Sr. No.	Parameter of comparison	Bluetooth	ZigBee
1.	IEEE standard	802.15.1	802.15.4
2.	Type of network	WPAN	WPAN
3.	Frequency bands	2.4 GHz	2.4 GHz, 868 MHz, 915 MHz
4.	Data rate	1 Mbps	20 to 250 kbps
5.	Maximum range	10 m	75 m
6.	Topologies	Tree	Star, mesh and cluster tree
7.	Spread spectrum technique	FHSS	DSSS

Sr. No.	Parameter of comparison	Bluetooth	ZigBee
8.	Maximum nodes per network	7	65000
9.	Battery life (days)	Upto 7	Upto 7000
10.	Security	Secure communication	Secure communication
11.	Applications	Files, photos transfer	Monitoring and control
12.	Type of modulation	GFSK	BPSK, MPSK

7.22 Multi-antenna Technologies :

- Usually there is one input and one output providing connection between the network and mobile for a radio channel.
- In the mobile antenna systems, an additional antenna is added on the base station uplink for macro deployment.
- Macro deployment is obtained through a cross polarized antenna i.e. one antenna and two inputs/outputs.
- In order to obtain better resistance against fading on the uplink, the base station connects transmitter to one port and receiver to other port.
- The base station does the Micro-diversity processing to improve the quality of signal by using algorithms like maximal ratio combining.
- To maximize the throughput over the radio link,the signals are combined from scattering and multipath in 4G systems.
- Multi-antenna techniques are used to improve the capacity of mobile communication systems without increasing the spectrum.
- To achieve this, Multi-antenna system uses smart antenna systems and multiple input multiple output (MIMO) .

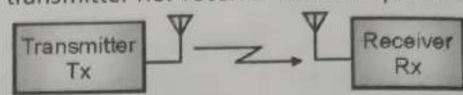
Multi-antenna Techniques :

- 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)

7.22.1 Single Input Single Output (SISO) :

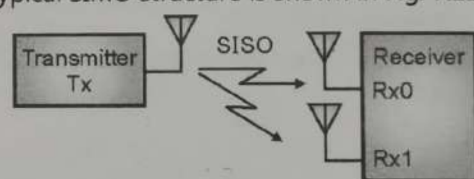
- SISO stands for Single Input and Single Output. As shown in Fig. 7.22.1, it consists of one antenna for transmission and one for reception.
- SISO is a conventional radio system where neither the transmitter nor receiver has multiple antenna.



(G-2720) **Fig. 7.22.1 : SISO (Single Input Single Output)**

7.22.2 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. 7.22.2.



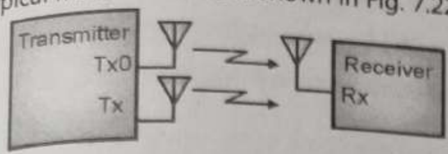
(G-2721) **Fig. 7.22.2 : SIMO (Single input multiple output)**

- 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.

7.22.3 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. 7.22.3.

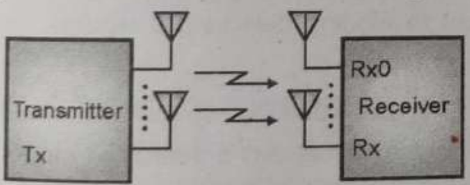


(G-2722) **Fig. 7.22.3 : MISO (Multiple input single output (MISO)**

- 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.

7.22.4 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. 7.22.4.



(G-2723) **Fig. 7.22.4 : MIMO(Multiple Input Multiple Output)**

7.23 MIMO Systems :

Principle :

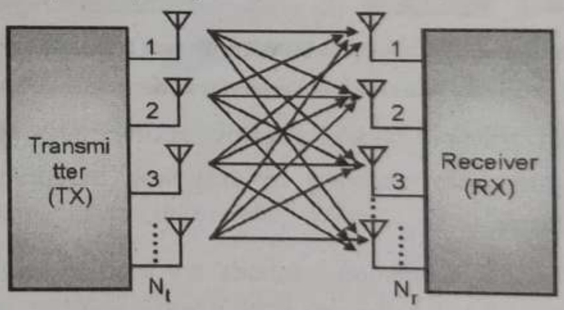
- The Multiple-Input Multiple-Output (MIMO) system uses multiple antennas on both the transmitter and receiver.
- They have dual capability of combining the SIMO and MISO technologies.
- They can also increase capacity by using Spatial Multiplexing (SM).
- The MIMO method has some clear advantages over 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.

7.23.1 Types of MIMO :

- The Multiple Input multiple Output (MIMO) method can be divided into various forms depending on uses.
- MIMO is basically the combination of all the multiple antenna techniques such as SISO, SIMO and MISO.
- It can use the beam forming or the spatial Multiplexing methods.
- MIMO can be categorized into the following two types :
  1. Multi-antenna types and
  2. Multi-user types.
- Multi-antenna types are as follows: SISO (Single-input Single-output), SIMO (Single-input Multiple-output) and MISO (Multiple-input Single-output).

Block diagram :

- Fig. 7.23.1 shows the block diagram of multiple-input multiple-output system.



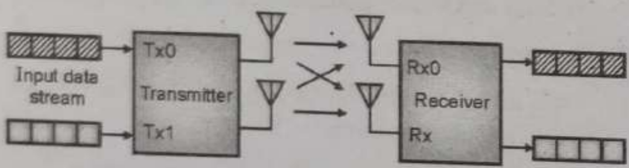
(G-2736) **Fig. 7.23.1 : Block diagram of a multiple-input multiple-output system.**

- 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.

7.23.2 A 2 x 2 MIMO :

- Refer Fig. 7.23.2. In a MIMO system, "Input" and "output" are the variables that describe the transmission medium or channel between the transmitter and the receiver.
- These two words are being used with respect to the transmission medium.
- That means, a base station with two transmitting antennas would give the channels MI (Multiple Input) and at the receiver with two antennas receives two outputs from the channel to constitute the MO (Multiple Output).
- The data streams transmitted and received here are assumed to mutually independent.
- The MIMO in Fig. 7.23.2 is known as a 2 x 2 MIMO as two transmitting and two receiving antennas are used.



(G-2737)**Fig. 7.23.2 : A 2 x 2 MIMO with two transmitters and two receivers with high speed independent data streams**

- The multiple parallel streams provided by a MIMO system are decoded by scattering produced by cluster.
- Channel estimation methods are used to separate the individual channels at the receiver end.
- Redundant data required for control or error control purpose is transmitted on the channels with diversity MIMO systems like **STBC** (Space Time Block Code) and **SFBC** (Space Frequency Block Code).
- With two antennas at all the antenna sites, the typical MIMO is a 2 x 2 MIMO which is suitable for 4G indoor system.
- The data speed can be doubled if the scattering is perfect with no correlation between the signal paths.
- However practically it is not possible to double the data speed because of interferences in buildings.

7.23.3 Advantages of MIMO :

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

7.23.4 Disadvantages of MIMO :

- Following are some of the advantages of MIMO :
  1. Each antenna requires individual RF units to process the radio signal.
  2. Device battery drains quickly as it has to process complex signal processing algorithms
  3. Higher hardware complexity

7.23.5 Applications of MIMO :

- 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.

7.24 Software Defined Radio (SDR) :

GTU : S-14, S-16, S-17, W-19

University Questions

Q. 1 What is software defined radio? List key features of software defined radio. Also, mention its applications. **(S-14, 7 Marks)**

Q. 2 Write a short note on software defined radio. **(S-16, S-17, W-19, 7 Marks)**

Definition :

- A software-defined radio (SDR) is a radio communication system where the major part of its functionality is implemented by means of software in a personal computer or embedded system.

Need of SDR :

- There has been an exponential growth in the need of people to communicate.
- The communication includes data communications, voice communications, video communications, broadcast messaging, command and control communications, emergency response communications, etc.
- Therefore it has become necessary to modify the radio devices easily and cost-effectively to suite this new business requirement.

Advantages :

- Software Defined Radio (SDR) technology has the following advantages:
  1. Higher flexibility,
  2. It is cost efficient and
  3. It has the power to drive communications forward,
  4. It provides with wide-reaching benefits to service providers and product developers through to end users.

Definition of Radio :

- A radio is defined any type of device that transmits or receives signals wirelessly, in the Radio Frequency (RF) spectrum to transfer information from one place to the other.
- The examples of a radio are cell phones, computers, car door openers, vehicles, and televisions.

Definition of SDR :

- The Software Defined Radio, is also known as Software Radio or SDR.
- The SDR Forum, working in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) established the following definition of SDR.
- It says that the Software Defined Radio is defined as the"Radio in which some or all of the physical layer functions are software defined" or the "radio that provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions (such as hopping), and waveform requirements of current and evolving standards over a broad frequency range."

Implementation of SDR :

- We can implement a SDR with the help of software modules running on a generic hardware platform of DSPs (Digital Signal Processors) and general purpose microprocessors to implement radio functions such as modulation/demodulation, signal generation, coding and link-layer protocols.
- This would help in building reconfigurable software radio systems in which the dynamic selection of parameters is possible.

7.24.1 Features/ Advantages of SDR :

GTU : S-14, S-16, S-17, W-19

University Questions

Q. 1 What is software defined radio? List key features of software defined radio. Also, mention its applications. **(S-14, 7 Marks)**

Q. 2 Write a short note on software defined radio. **(S-16, S-17, W-19, 7 Marks)**

- Regardless of the means by which the radio is reconfigured, a fully implemented SDR will have the ability to navigate a wide range of frequencies with programmable channel bandwidth and modulation characteristics.
- Some of the important features of SDR are as follows :
  1. Multiband operation
  2. Multicarrier operation
  3. Multimode operation
  4. Multirate operation
  5. It can have a variable bandwidth
  6. Ability to navigate a wide range of frequencies
  7. Programmable channel bandwidth
  8. Programmable modulation characteristics

1. **Multiband operation :**

- The traditional radio architectures can operate on a single band of frequencies.

- However many applications like cellular communications, need to work on wide range of frequencies.
- A SDR is a multiband radio that can operate on two or more bands either sequentially or simultaneously.

2. **Multicarrier operation :**

- A multicarrier also called multichannel radio can simultaneously operate on more than one frequency.
- This may be within the same band or in two different bands.
- This is generally seen in a base station that may be servicing many users at once or a user terminal that may be processing both voice and data on different carriers.

3. **Multimode operation :**

- A SDR is capable of working with many different standards and it can be reprogrammed whenever required.
- Multimode operation indicates the ability of SDR to process different kinds of standards such as AM, FM, GMSK, and CDMA and many more.

4. **Multirate operation :**

- SDR is a multirate radio because it can process different parts of the signal chain at different samples rates.
- It is also capable of working in different modes that require different data rates. For example a SDR can process GSM at 270.833 kSPS (kilo Symbols Per Second) or CDMA at 1.2288 MCPS (Mega Chips Per Second).

5. **Variable Bandwidth :**

- A traditional radio is designed to work in a fixed channel bandwidth with help of a analog filter.
- However an SDR uses digital filters which allow it to have a programmable bandwidth

6. **Seamless Connectivity :**

- If the SDR is not compatible with a particular network technology in a particular region, then it is possible to install an appropriate software module on it resulting in seamless network access across various geographies.

7. In addition to these a SDR has some other important feature/advatages such as programmable channel bandwidth and modulation characteristics.
8. The development costs can be reduced substantially because of the reusable software being used.
9. Over-the-air or other remote reprogramming is possible while a radio is in service. This allows to make "bug fixes" remotely which reduces the time and costs associated with operation and maintenance.
10. SDR reduces the costs involved in providing end-users with access to ubiquitous wireless communications which enables them to communicate with anyone, anywhere, anytime in whatever manner is appropriate.

7.24.2 Problems in SDR Communications :

GTU : S-14, S-16, S-17, W-19

University Questions

Q. 1 What is software defined radio? List key features of software defined radio. Also, mention its applications. **(S-14, 7 Marks)**

Q. 2 Write a short note on software defined radio. **(S-16, S-17, W-19, 7 Marks)**

- The problems in SDR communication are as follows:

1. **Low battery life :**

- SDRs have on-board processors alongwith the other necessary hardware.
- Hence it consumes a lot more energy compared to the conventional radio equipments.
- This increases the discharge rate of the battery used in the handheld SDR units which are battery operated.
- The battery needs frequent recharging which increases the energy costs and reduces the battery life.

2. **High setting up costs :**

- The costs for setting up an SDR system are very high because we need to use a processor and other additional hardware alongwith the necessary software to set up an SDR system.

3. **Needs longer development time :**

- The software part of an SDR needs to be developed as per the requirements of the application for which it is being designed.
- The development and testing of such software consumes a lot of time.

4. **Low software reliability :**

- Because of the limitations of the on-board hardware, the software reliability is affected.
- The software reliability is further reduced due to its high complexity.

5. **Possibility of intermodulation distortion :**

- There is always a possibility of intermodulation distortion because of the wide range of operating frequency and use of nonlinear high efficiency power amplifiers in the SDRs.

6. In order to cover a wide frequency range, a suitable hardware needs to developed which can adapt to the different frequency ranges.

7.24.3 Applications of SDR :

GTU : S-14, S-16, S-17, W-19

University Questions

Q. 1 What is software defined radio? List key features of software defined radio. Also, mention its applications. **(S-14, 7 Marks)**

Q. 2 Write a short note on software defined radio. **(S-16, S-17, W-19, 7 Marks)**

- Some of the major applications of SDR are as given below :
  1. Military applications
  2. Amateur and home use
  3. The high performance SDR
  4. Web SDR
  5. Wildlife tracking
  6. Radio astronomy and
  7. Medical imaging research

7.25 UWB Radio : GTU : W-14, S-17, S-18, W-19

University Questions

Q. 1 Explain in details about architecture of UWB radio and its applications. **(W-14, 7 Marks)**

Q. 2 Write a short note on UWB radio. **(S-17, 7 Marks, W-19, 4 Marks)**

Q. 3 Explain the working of UWB radio. Discuss the features, advantages anddisadvantages of UWB technology. **(S-18, 7 Marks)**

Definition :

- Ultra-wideband (UWB) was formerly known as pulse radio, but the FCC and the International Telecommunication Union Radio communication Sector (ITU-R) currently define UWB as an antenna transmission for which emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the arithmetic center frequency.
- **Ultra-wideband** (also known as **UWB**, **ultra-wide band** and **ultraband**) is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum.
- The **UWB (Ultra Wideband) technology** is a wireless broadband system that provides a communication connection that supports transfer of data at high rates, digital video and audio streams.
- It was launched to replace the connecting wires used in applications like high-fidelity home TV, DVD that require transmission rates above 1 Mbps and low power consumption.
- UWB technology is a short range technology (up to 10 meters) that can support very high speeds (up to 1 Gbps).

Principle :

- Unlike spread spectrum, UWB transmits in a manner that does not interfere with conventional narrowband and carrier wave transmission in the same frequency band.
- Ultra-wideband is a technology for transmitting information that is spread over a large bandwidth (>500 MHz); this should, in theory and under the right circumstances, be able to share spectrum with other users.
- In the UWB radios low-power, high-bandwidth, and very short duration pulses are emitted that can support data rates comparable to wired Ethernet (100 Mbps and above).

- Thus UWB has the advantages of high data rates and low power consumption, that makes it ideal for WBANs. UWB is still in its initial stages of commercial use.

Standards / frequency band :

- The UWB is defined in the IEEE 802.15.3 standard. The standard IEEE 802.15.3 is also known as WiMedia.
- The physical layer of IEEE 802.15.3 works in the unlicensed frequency band of 2.402 – 2.480 GHz.
- The aim of IEEE 802.15.3 is to reach the higher data rates between 11 and 55 Mbps, required for the applications such as high definition video and high-fidelity audio.
- For WPANs, the WiMedia Ultra Wideband (UWB) technology is suitable because it delivers high speed, low power multimedia abilities for the Personal Computer (PC), market sections of mobile and automobile.
- IEEE 802.15.3 is one step ahead with respect to spread spectrum used in WLANs because, with low power it sends digital data over a frequency band having a wide spectrum.
- Typically the spectrum occupied is wide i.e. at least 25% of center frequency.
- That means it will be 250 MHz for a system with 1-GHz center frequency.
- In the 2.4 GHz ISM band the 802.15.3 standard describes high rate WPAN specifications that supports data speeds of 11 Mbps, 22 Mbps, 33 Mbps, 44 Mbps and 55 Mbps.
- IEEE 802.15.3 supports for ad-hoc networks and peer-to-peer networks.

Channel plans :

- High rate WPANs piconets will support the neighbour and child piconets.
- Two different channel plans supported by 802.15.3 standard and limited to a bandwidth of 15 MHz are : high-density channel plan and coexistence channel plan.

No multipath fading :

- Another important feature of pulse-based UWB is that as the pulses are very short, most signal reflections do not overlap the original pulse, and there is no multipath fading.
- However, there is still multipath propagation and inter-pulse interference present in UWB systems which must be overcome by using some coding techniques.
- Each pulse in a pulse-based UWB system occupies the entire UWB bandwidth.
- This allows UWB to reap the benefits of relative immunity to multipath fading However, it is susceptible to inter symbol interference.

Error correction :

- For error correction and detection these two channels use TCM (Trellis Code Modulation) and FEC (Forward Error Correction) techniques respectively.
- UWB transmits short-range and low power signals. It transmits a very short and accurately timed digital pulse of duration less than 1 ns.
- In UWB the sender and receiver should be synchronized with a very high accuracy.
- Multi-path propagation will not be an issue here, if the sender knows the exact time of arrival of pulse.
- This is because within a very short time slot, only the strong signal will be detected.
- IEEE 802.15.3 can be used for wireless LANs that transmits data at very high rate over shortest distances.

7.25.1 UWB Radio Specifications :

GTU : W-14, S-17, S-18, W-19

University Questions

Q. 1 Explain in details about architecture of UWB radio and its applications. **(W-14, 7 Marks)**

Q. 2 Write a short note on UWB radio. **(S-17, 7 Marks)**

Q. 3 Explain the working of UWB radio. Discuss the features, advantages anddisadvantages of UWB technology. **(S-18, 7 Marks)**

Q. 4 Write a short note on UWB radio. **(W-19, 4 Marks)**

- Table 7.25.1 summarizes the radio specifications of UWB (IEEE 802.15.3).

Table 7.25.1 : Specifications of UWB radio

Sr. No.	Parameter	Value
1.	Data speed	Up to 1 Gbps
2.	RF band	2.402 – 2.480 GHz ISM band
3.	Modulation scheme	QPSK / QAM (Trellis coded or uncoded)
4.	Multiple access	OFDM
5.	Duplex method	TDD
6.	Channel access	CSMA/CA
7.	Power consumption	< 80 mA
8.	Coverage range	Up to 10 meters
9.	Data rate	11 Mbps – 55 Mbps
10.	Configuration	Peer-to-peer
11.	Number of channels	79
12.	Pulse width	Less than 1 ns

7.25.2 UWB Features :

GTU : S-18

University Questions

Q. 1 Explain the working of UWB radio. Discuss the features, advantages anddisadvantages of UWB technology. **(S-18, 7 Marks)**

- Following are some important features of UWB :
  1. High data transfer rates.
  2. Short range.
  3. Low power consumption.
  4. Immunity to external interference.
  5. Large bandwidth
  6. Uses unlicenced ISM frequency band of 2.4 GHz.
  7. Uses OFDM for multiple access.
  8. Uses OPSK/QAM for modulation.
  9. Standard: IEEE 802.15.3.
  10. No multipath fading.

7.25.3 Antenna Systems in UWB :

GTU : S-17, S-18, W-19

University Questions

Q. 1 Write a short note on UWB radio. **(S-17, W-19, 7 Marks)**

Q. 2 Explain the working of UWB radio. Discuss the features, advantages anddisadvantages of UWB technology. **(S-18, 7 Marks)**

- The UWB systems use the following antennas :

Distributed MIMO (Multiple Input Multiple Output) :

- So as to increase the transmission range, this system exploits distributed antennas among different nodes.

Multiple-antenna :

- Multiple-antenna systems (such as MIMO) are used to increase system throughput and reception reliability.
- Since UWB has almost impulse-like channel response, a combination of multiple antenna techniques is preferable as well.
- Due to MIMO spatial multiplexing and the high throughput of UWB system it is possible to form a short-range networks with multi-gigabit rates.

7.25.4 UWB Advantages :

GTU : S-17, S-18, W-19

University Questions

Q. 1 Write a short note on UWB radio. **(S-17, W-19, 7 Marks)**

Q. 2 Explain the working of UWB radio. Discuss the features, advantages anddisadvantages of UWB technology. **(S-18, 7 Marks)**

- Following are some of the important advantages of UWB :
  1. It has the ability of sharing the frequency spectrum.
  2. Large channel capacity
  3. Immunity to external interference.
  4. High data rates.
  5. Low power consumption.
  6. It provides a secure connection.
  7. Large bandwidth can support applications like real time H.D. video streaming.
  8. It has an ability to work with low SNR.
  9. No multipath fading.

7.25.5 UWB Disadvantages :

GTU : S-18

University Questions

Q. 1 Explain the working of UWB radio. Discuss the features, advantages and disadvantages of UWB technology. **(S-18, 7 Marks)**

- Following are some of the important disadvantages of UWB :
  1. Short range.
  2. UWB devices are power limited.
  3. UWB transmission is vulnerable to attacks.
  4. Susceptible to inter symbol interference.

7.25.6 UWB Applications :

GTU : W-14, S-17, W-19

University Questions

Q. 1 Explain in details about architecture of UWB radio and its applications. **(W-14, 7 Marks)**

Q. 2 Write a short note on UWB radio. **(S-17, W-19, 7 Marks)**

- Ultra-wideband characteristics are well-suited to short-distance applications, such as PC peripherals.
- Due to the low emission levels permitted, the UWB systems are preferred in short-range indoor applications.
- Due to the short duration of UWB pulses, it is easier to engineer high data rates.
- However data rate decreases with increase in the range.
- Conventional orthogonal frequency-division multiplexing (OFDM) technology may also be used, subject to minimum-bandwidth requirements.
- High-data-rate UWB can be used for the following applications :
  1. To enable wireless monitors.
  2. For efficient transfer of data from digital camcorders.
  3. For wireless printing of digital pictures from a camera without the need for a personal computer.
  4. File transfer between cell-phone handsets and handheld devices such as portable media players.
  5. UWB is well-suited for radio-frequency-sensitive environments, such as hospitals.
  6. Ultra-wideband is also used in "see-through-the-wall" precision radar-imaging technology.
  7. Ultra-wideband pulse Doppler radars have also been used to monitor vital signs of the human body, such as heart rate and respiration signals as well as human gait analysis and fall detection.

7.25.7 Comparison between WPAN Systems :

Table 7.25.2 : Comparison between various WPAN systems

Sr. No.	Parameter	802.15.1 (BT)	802.15.3 (UWB)	802.15.4 (Zigbee)
1.	Name of technology	Bluetooth	High rate WPAN (WiMedia)	Low rate WPAN (Zigbee)
2.	Operational spectrum	2.4 GHz ISM band	2.402 – 2.480 GHz ISM band	2.4 GHz, 868 MHz, 915 MHz
3.	Maximum Data rate	upto 1 Mbps	11 Mbps – 55 Mbps	250 Kbps at 2.4 GHz 20 Kbps at 868 MHz 40 Kbps at 915 MHz
4.	Coverage range	<10 m	<10 m	< 20 m
5.	Power consumption	1 mA – 60 mA	< 80 mA	20 – 50 μA (very low current drain)
6.	Channel access	TDD	CSMA/CA	CSMA/CA
7.	Physical layer details	FHSS (1600 hops/S)	QPSK, Trellis coded QPSK, 16/32/64 QAM	DSSS with BPSK or MSK
8.	Configuration	Piconet / Scatternet	Peer-to-peer	Star / peer-to-peer
9.	Interference	Present	Present	Present
10.	Price	Low	Medium	Very Low
11.	Security	Less	Very high	Security features in development

7.26 Wireless Ad hoc Network :

GTU : W-17, S-17, W-19

University Questions

Q. 1 Explain Adhoc Networks in brief. **(W-17, 3 Marks)**

Q. 2 With neat diagram explain wireless Ad-Hoc network. **(S-17, 7 Marks)**

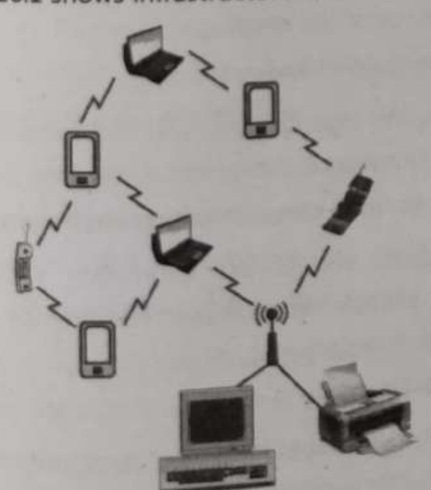
Q. 3 Explain wireless Ad-Hoc network. **(W-19, 4 Marks)**

Definition :

- A Wireless ad hoc network is a group of independent terminals or nodes which communicate with each other by forming a multihop radio network.
- It maintains a connectivity in decentralized manner.
- As the communication between the nodes takes place over the wireless (Radio) links, they have to contend with some effects of radio communication such as interference, noise and fading etc.
- As compared to a wired network, the links in wireless adhoc network have less bandwidth.
- In wireless adhoc networks or simply an adhoc network, each node functions as a router and a host and the network control is distributed among the nodes.

Examples :

- Examples of wireless ad hoc network are Wireless Sensor Networks (WSN), Mobile Adhoc Networks (MANETs), Wireless Mesh Networks (WMN) and Vehicular Ad hoc Networks (VANETs).
- Fig. 7.26.1 shows infrastructure-less network.



(G-1881) Fig. 7.26.1 : Wireless Ad hoc network

7.26.1 Need of adhoc Wireless Networks :

GTU : W-13

University Questions

Q. 1 Discuss the need and features of Ad hoc wireless network. **(W-13, 5 Marks)**

- Ad-hoc wireless networks are needed because it has the following characteristics :

1. **Wireless:**
   - Nodes communicate wirelessly and share the same media(radio, infrared).
2. **Ad-hoc base:**
   - A mobile ad-hoc network is a temporary network formed dynamically in an arbitary manner by collection of nodes as need arise.
3. **Autonomous and infrastructureless:**
   - Ad-hoc network do not depend on any established infrastructure or centralized administration.
   - Each node acts as an independent router and generates independent data.
4. **Multi-hop routing:**
   - No dedicated routers are necessary, every node acts as router and forwards each other's packet to enable information sharing between mobile hosts.
5. **Mobility:**
   - Each node is free to move about while communicating with other nodes.

7.26.2 Features of Wireless Ad hoc Network :

GTU : W-13

University Questions

Q. 1 Discuss the need and features of Ad hoc wireless network. **(W-13, 5 Marks)**

- In order to determine the efficiency and effectiveness of wireless Ad hoc network, certain critical features are classified into two types :

  1. Quantitative features. 2. Qualitative features.

7.26.3 Quantitative Features :

GTU : W-13

University Questions

Q. 1 Discuss the need and features of Ad hoc wireless network. **(W-13, 5 Marks)**

- The quantitative features of wireless Ad hoc networks includes :
  1. Network settling time
  2. Network join time
  3. Network depart time
  4. Network recovery time
  5. Frequency of updates (Overhead)
  6. Storage requirement
  7. Scalability.

Network settling time :

- Network settling time is the time required for a collection of mobile nodes for their automatic organization and reliable transmission of the first task.
- Network settling time is very important if a network has not been in operation for a while and should start up and promptly send messages.

Network join time :

- Network join time is the time needed for an entering group of node or a node into the ad hoc wireless network.

Network depart time :

- Network depart time is the time required for the ad hoc wireless network to know the loss of one or more nodes.
- Ad hoc wireless network rearrange itself to route around the departed nodes.

Network recovery time :

- Network recovery time is the time required for the wireless network to recover after a condition of reorganization of the network for :
  1. Collapsed part of the network because of failure of nodes or traffic overload. It becomes functional again if the nodes becomes operational or the traffic load is reduced.
  2. The reorganization of network due to node mobility and resume reliable communication.

Frequency of updates (Overhead) :

- In a given time, a number of control packets are required to maintain the proper wireless network operation.

Storage requirement :

- Wireless ad hoc networks requires the storage space in bytes containing routing tables and other management tables.

Scalability :

- Network scalability is the number of nodes that ad hoc network can scale to and preserves communication reliably. The wireless network must able to scale thousands of nodes.

7.26.4 Qualitative Features : GTU : W-13

University Questions

Q. 1 Discuss the need and features of Ad hoc wireless network. (W-13, 5 Marks)

- The qualitative features of wireless Ad hoc networks includes :
  1. Knowledge of nodal locations.
  2. Effect to topology changes.
  3. Adaptation to radio communication environment.
  4. Power consciousness.
  5. Single or multichannel.
  6. Unidirectional or bidirectional links.
  7. Preservation of network security.
  8. Quality of service and handling of priority messages.
  9. Real time voice services.
  10. Real time video services.

Knowledge of nodal locations :

- The routing algorithm should require local or global knowledge of the network.

Effect to topology changes :

- The routing algorithm should have complete updates of restructuring or incremental updates.

Adaptation to radio communication environment :

- The nodes should use estimation knowledge of fading, shadowing, multiuser interference on links in their routing decisions.

Power consciousness :

- The network should be power consciousness and use routing mechanisms which consider the remaining battery life of a node.

Single or multichannel :

- The routing algorithm should use a separate control channel.
- Multichannel execution is used in some applications which makes the network vulnerable.

Unidirectional or bidirectional links :

- The routing algorithms should perform efficiently on unidirectional or bidirectional links.

Preservation of network security :

- The routing algorithm should support the fidelity of the network.

Quality of service and handling of priority messages :

- The routing algorithm should provide quality of service.
- It should support messaging and reduction of latency for delay sensitive real time traffic.

Real time voice services :

- The network supports simultaneous real time multicast voice services.

Real time video services :

- The network supports real time multicast video services.

7.26.5 Advantages of Wireless Ad hoc Network :

- Following are the advantages of wireless Ad hoc network :
  1. Wireless Ad hoc network can be set up rapidly.
  2. The wireless network functions eventhough individual node fails. That means wireless Ad hoc networks are flexible.
  3. As compared to cellular networks, they are spectrally more efficient. Nodes can make better use of the channel as each node can communicate with any other node.
  4. The multiple simultaneous communication can be possible in ad hoc networks.
  5. The deployment cost is low because there is no requirement of base station and backbone infrastructure.

7.26.6 Applications of Wireless Ad hoc Network :

- As the nature of wireless ad hoc network is dynamic and self-organizing, they can be useful in the situations where rapid network deployments are required or there is an issue in less cost to deploy and manage network infrastructure.
- Following are the application areas of wireless Ad hoc network :
  1. In military communications wireless ad hoc network is used for search and rescue operations where the robustness and deployment speed is critical.
  2. It is used in the sensor networks for sensing forest fires, studying wildlife, monitoring buildings etc.
  3. It is used in historical buildings where wires cannot be placed.
  4. It is used in MANET of satellites which are designed for emergency applications like rescue operation, disaster management etc.
  5. Wireless ad hoc network is used wireless local area networks where placing wires is not possible.
  6. It is used in vehicular communication where node is the vehicle equipped with a communication device for applications like road sign alarm, collision warning, traffic information etc.
  7. To obtain the information of monuments, wireless ad hoc networks are used in museums.
  8. It is used in e-commerce to purchase or sell goods in shopping malls.
  9. It is used in college campus to share educational information between the students and staff.

7.26.7 Difference between Ad-hoc and Cellular Networks : GTU : S-14

University Questions

Q. 1 Differentiate ad-hoc wireless networks from cellular networks. **(S-14, 7 Marks)**

Sr. No	Parameters	Cellular network	Ad Hoc network
1.	Type of routing	Centralized, all the traffic goes through the Base Station	Distributed, No centralized system such as Base station needed
2.	Type of Switching	Circuit Switching	Packet Switching
3.	Number of Hops	single hop type	Multiple hops
4.	Topology	Star	Mesh
5.	Application	For voice traffic	For best effort data traffic
6.	Cost and time for installation	Higher cost and takes more time for installation	Lower cost and does not take more time for installation
7.	Call drops	Low call drops during mobility due to seamless connectivity across region	Higher breaks in the path during mobility
8.	Network maintenance	requires periodic maintenance and hence it is costly.	nodes are self organising and hence it is less costly
9.	Frequency re-use	Static frequency re-use.	Dynamic frequency re-use
10.	Bandwidth (BW) mechanism	The allocation of BW is guaranteed and easy.	The allocation of BW is based on shared channel using complex MAC algorithms.
11.	Technologies	IS-95, IS-136, GSM, Mobile WiMAX, CDMA, LTE	WLAN 802.11e

7.27 5-G and Above Wireless Networks :

- The 4G technology has now been deployed and the research for the next generation named as 5G has already begun.
- It is considered to be the next major phase of mobile telecommunication standard after 4G.
- The 5G standard will be made commercially available by 2020. This standard is way beyond just the faster data speeds or faster mobile devices.
- 5G will provide an access to high and low speed data services. It will involve combination of existing and evolving systems.

7.27.1 Why 5-G?

- Fifth generation technology is useful because of the following reasons :
  1. It provides very High speed, high capacity, and low cost per bit.
  2. It supports interactive multimedia, voice, video, Internet, and other broadband services, more effectively.
  3. 5G technology offers Global access and service portability.
  4. It can provide the high quality services due to high error tolerance.
  5. 5G technology uses remote management so that user can get better and fast solution.
  6. With the use of 5G technology the uploading and downloading speed will be very high.

7.27.2 Features of 5-G :

- Following are the most important features of 5G :
  1. Ubiquitous connectivity
  2. It provides Speed up to 10 Gbit/s.
  3. The 5G technology supports virtual private network.

4. The uploading and downloading speed of 5G technology is high.
5. 5G network is very fast and reliable.
6. Larger data volume per unit area (i.e. high system spectral efficiency).
7. High capacity to allow more devices connectivity concurrently and instantaneously.
8. Lower battery consumption.
9. It provides better connectivity irrespective of the geographic region.
10. Larger number of supporting devices.

7.27.3 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

7.27.4 Expectations in 5-G Network :

- In future, 5G will be necessary worldwide because of the increasing traffic rates of data, voice, and video streaming.
- 5G technology will have the capability to share the data everywhere, every time, by everyone.
- The 5G technology is expected to cater the following requirements :
  1. 10-100 times higher data rate.
  2. 10 times longer battery life for low power devices.
  3. 10-100 times higher number of connected devices.
  4. 5-times reduced end to end latency.
  5. 1000 times higher mobile data volume per area.

7.27.5 Technologies of 5G :

- Major technologies included in 5G are :
  1. MIMO (Multiple Input Multiple Output)
  2. Ultra radio access design (RAN)
  3. Flexible duplexing

7.27.6 Advantages of 5-G Technology :

- 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.

7.27.7 Applications of 5-G :

- 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

7.27.8 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.
  7. 5G network should support many devices from cars to wearable devices to household appliances and many more.
  8. 5G network must provide the data rate of multiple gigabits per second.
  9. 5G technology should provide dynamic, universal, user-centric, and data-rich wireless services to fulfil the high expectation of people.
  10. 5G will have to define the uncertainties related to security threats including trust, privacy, cyber security, which are growing across the world.
  11. Building the smart cities is the main goals of the 5G network. Smart cities can provide the required 5G infrastructure. These smart cities can provide mobile industrial automation, vehicular connectivity, and other IoT applications by providing a connection with low latency and high reliability.
  12. 5G technology is expected to improve in order to meet all the requirements in terms of data rate, latency, switching time between different radio access technologies, and energy consumption.
  13. The designed 5G networks should have very high reliability.

7.28 Security Issues in Wireless Networks : GTU : W-13

University Questions

Q. 1 List the security issues of wireless networks. **(W-13, 3 Marks)**

- In today's world, the information has become an asset.
- Therefore we need to safeguard it from different types of attacks.
- The three aspects of information security are confidentiality, integrity and availability.
- In the recent years, the information is being distributed over long distances over the computer networks.
- Therefore even though the three basic aspects of security have remained unchanged, their scope has widened to a great extent.

Need For Security :

- One important drawback of wireless LANS is it is not secure and the data transmitted through them can easily be broken and modified.
- In wireless networks the security is much more serious and compulsory than the wired networks.
- In all the wireless systems, a definite and specific level of security is compulsory.
- If the sensitive data in the field of financial institutions, banks, military networks or data concerning to terrorists etc. is sent over the wireless system then extra security is needed for the privacy and confidentiality.

7.28.1 Security Issues of Wireless Networks :

GTU : W-13, S-20, W-20

University Questions

Q. 1 List the security issues of wireless networks. **(W-13, 3 Marks)**

Q. 2 Briefly discuss security threats in wireless network and suggest possible ways of protection. **(S-20, W-20, 7 Marks)**

- The three network security goals/issues are :
  1. Confidentiality.
  2. Integrity.
  3. Availability.

1. **Confidentiality :**

- Confidentiality of information refers to hiding it from the unauthorized access.
- The information needs to be kept confidential while storing, as well as while transmitting it from one user to the other.

2. **Integrity :**

- The security of integrity of information refers to avoiding any unauthorized change in the information.
- Any changes in the information must be allowed only to authorized persons through an authorized mechanism only.

3. **Availability :**

- The information should not be available to any unauthorized person but it should be always available to an authorized entity.

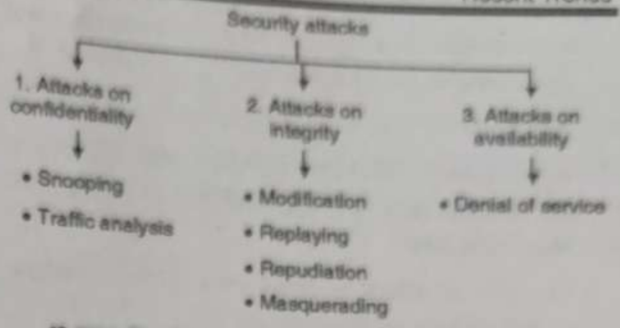
7.28.2 Attacks :

GTU : S-20, W-20

University Questions

Q. 1 Briefly discuss security threats in wireless network and suggest possible ways of protection. **(S-20, W-20, 7 Marks)**

- The three goals of information security can get threatened by the **security attacks.** Fig. 7.28.1 shows classification of attacks.



(G-2338) **Fig. 7.28.1 : Classification of security attacks**

7.28.3 Attacks on Confidentiality :

GTU : S-20, W-20

University Questions

Q. 1 Briefly discuss security threats in wireless network and suggest possible ways of protection. **(S-20, W-20, 7 Marks)**

1. **Snooping :**

- Snooping is defined as an unauthorized access to the information or as an unauthorized interception of the information.
- Snooping can be prevented by making the information non intelligible to the unauthorized entity.

2. **Traffic analysis :**

- Even after making the data non intelligible, an attacker can collect some other information such as email addresses of the sender or receiver by monitoring the online traffic.

7.28.4 Attacks on Integrity :

GTU : S-20, W-20

University Questions

Q. 1 Briefly discuss security threats in wireless network and suggest possible ways of protection. **(S-20, W-20, 7 Marks)**

- The four types of attacks on integrity are modification, masquerading, replaying and repudiation.

1. **Modification :**

- In this type of attack, the attacker modifies the intercepted data to make it beneficial to himself.

2. **Masquerading :**

- Masquerading is also called as spoofing. In this type of attack, the attacker impersonates somebody else.

- For example, stealing the PIN of a credit card and pretending to be the customer.

3. **Replaying :**

- In this type of attack, the attacker obtains a copy of the message sent by a user and tries to replay it for his own benefit.
- This type of attack is often seen in the messages related to the bank transactions.

4. **Repudiation :**

- In this type of attack either the authorized sender or the authorized receiver is involved.
- The sender of a message may later on deny that he has sent that message or the receiver after actually receiving the message, may deny that he has received the message.

7.28.5 Attacks on Availability :

GTU : S-20, W-20

University Questions

Q. 1 Briefly discuss security threats in wireless network and suggest possible ways of protection. **(S-20, W-20, 7 Marks)**

- The only one type of attack on the availability is the denial of service.

Denial of Services (DoS) :

- In this type of attack, a system may be slowed down or totally interrupted by the attackers.
- This could be done by using various strategies such as :
  1. By flooding the server with bogus requests.
  2. By intercepting and deleting the server's response to client.
  3. By intercepting and deleting the client's request to the server.

7.29 Security Issues in 5G and Above Technologies :

- In 5G and above technologies, security will play a very important role because in addition to supporting the basic packet traffic it also accommodates wide variety of applications.
- Some of the major security issues in 5G and above technologies are as follows :
  1. Network architecture and infrastructure
  2. Rigid authentication
  3. Privacy protection
  4. Evolved threat landscape
  5. Energy efficiency
  6. Mobility and
  7. Heterogeneous access

1. **Network Architecture and Infrastructure :**

- Network architecture and infrastructure is a very important part of security implementation.
- 5G needs a robust network architecture with enhanced security features to support a wide range of applications with high end security requirements.
- Therefore advanced technologies, like Network Functions Virtualization (NFV) / Software Defined Network (SDN) and virtualization are being considered for 5G networks.
- In traditional networks, security of network elements (NEs) depends on how well their physical units could be isolated from one another.
- However, in 5G, the isolation will work in a very different way as virtual NEs are on cloud-based infrastructure.

2. **Rigid authentication:**

- The security requirements for different applications could differ considerably among services.
- The Internet of Things (IoT) devices, require highly capable security method.
- The network based default of usual hop-by-hop security method might not be effective enough.
- Instead an enhanced and rigid authentication method is a necessity for IoT devices.
- For example, biometric based identification could be a very suitable authentication method for smart phones .

3. **Privacy Protection :**

- In 5G networks, it is necessary to offer differentiated QoS (Quality of service) due to wide range of applications.

- For this, there should be some method within the networks which can sense the type of service being used by the user, to offer better privacy.
- However, adding enhanced privacy methods makes implementation of 5G a greater challenge.

4. **Evolved Threat Landscape :**

- The 5G networks will work as a central infrastructure for communication and number of other applications.
- However this central architecture approach creates a major concern for the users.
- If the central architecture is down due to some reason, it will effect a wide range of communication and daily life of users and corporate.
- To avoid this, 5G needs well defined protocols which should be resilient against different kind of attacks and disasters .

5. **Energy efficiency aspects of 5G systems :**

- Latest technology that claims to be able to fulfill the needs of 5G is Massive MIMO.
- The overall efficiency of Massive MIMO technology is achieved by using more antennas than devices.
- This means some of the devices will act as a network access point.
- To support larger bandwidth (30 to 300 GHz) with 1 to 10 mm wavelength, it uses small cells to enhance area spectral efficacy.
- Massive MIMO can use very simple multiplexing and encoding methods, so that these methods can be implemented using very simple hardware.
- However it may result in low resources utilization, especially in terms of power.

6. **Mobility :**

- Mobility is a challenge in short range cellular networks.
- Mobility have additional issues to handle in millimeter wave MIMO system as there is no surety for locked precise beam forming on targets that are mobile.

7. **Heterogeneous Access :**

- Due to the increased demand for data and the number of online devices the need for heterogeneous access becomes an integral part for 5G network.
- Heterogeneous environment provides simultaneous access to diverse access technologies. However different access technologies must build an architecture by considering 5G network security requirements.
- However the challenges associated with heterogeneous network have not yet been successfully solved.

Review Questions

Q. 1 Define the term WiFi.

Q. 2 Explain the basic configuration of wireless LAN.

Q. 3 Define BSS and ESS.

Q. 4 Explain different types of stations in ESS.

Q. 5 Write a short note on physical layer specifications of IEEE 802.11.

Q. 6 Explain 'Hidden Node' and 'exposed node' problem in wireless LANs.

Q. 7 Define and explain DCF and PCF.

Q. 8 Explain the architecture of wireless LAN 802.11 with suitable diagram.

Q. 9 Explain the term Ad hoc networking.

Q. 10 State and explain the wireless LAN requirements / properties.

Q. 11 State applications of Wi-Fi.

Q. 12 What are the issues related to medium access control protocol ?

Q. 13 Explain in detail Ad-hoc networking.

Q. 14 Explain in detail MAC sublayer of WLAN.

Q. 15 Write a short note on point co-ordinate function (PDF).

Q. 16 Write a short note on wireless PAN.

Q. 17 What are the needs of WPAN ?

Q. 18 What is the concept of software defined radio ? Elaborate in detail.

Q. 19 Write note on : Software defined radio.

Q. 20 What is software Defined Radio ?

Q. 21 Describe the concept of software defined radio, Explain it in detail.

Q. 22 Explain the advantages of Software Defined Radio Communication Systems.

Q. 23 List out advantages of SDR in communication.

Q. 24 Write short note on : Problems in SDR communications.

Q. 25 Define UWB.

Q. 26 State the principle of UWB.

Q. 27 Why there is no multipath fading in UWB ?

Q. 28 State the radio specifications of UWB.

Q. 29 State important features of UWB.

Q. 30 Explain various applications of UWB.

Q. 31 Define : Wireless ad-hoc network.

Q. 32 Write a note on wireless ad-hoc network.

Q. 33 What are the features of wireless ad-hoc network ?

Q. 34 Explain the advantages of wireless ad-hoc network.

Q. 35 Discuss the applications of wireless ad-hoc network.

Q. 36 What are the challenges and issues which affect the performance of an ad hoc wireless system ?

Q. 37 Explain the following : ZigBee technology

Q. 38 What is ZigBee ? State the following for it.

(a) Frequency bands

(b) Type of modulation

(c) Range

Q. 39 State the features of Zigbee.

Q. 40 State the radio specifications of Zigbee.

Q. 41 Explain the ZigBee technology ? Discuss different types of network topology that are supported in ZigBee.

Q. 42 Explain the ZigBee technology. Discuss different network topologies that are supported in ZigBee.

Q. 43 Write short note on : ZigBee.

Q. 44 Explain the ZigBee technology. Discuss different types of network topology that are supported in ZigBee.

Q. 45 State and explain the applications of Zigbee .

Q. 46 Compare Bluetooth and Zigbee .

Q. 47 What is the need of wireless MAN ?

Q. 48 Define Wi-Max and state its types.

Q. 49 State the two types of Wi-Max services and explain any one of them.

Q. 50 Compare IEEE 802.11 with IEEE 802.16.

Q. 51 What are the advantages of IEEE 802.16 ?

Q. 52 Write a short note on 802.16 architecture.

Q. 53 List the various features of WiMAX.

Q. 54 Discuss the requirements of 5G.

Q. 55 List out various challenges in 5G service.

Q. 56 Explain the advantages and disadvantages of 5-G.

Q. 57 State the applications of 5-G.

Q. 58 Write short notes on : security challenges in 5G.

7.30 University Questions and Answers :

Q. 1 Answer following questions with respect to Wi-MAX technology :

1. What is its full-form?
2. Which multiple access method does it use?
3. What is its approximate coverage range in km?
4. What is the upper limit on data rate ?
5. What is the range of radio channel bandwidth?
6. Write two applications. **(S-12, 6 Marks)**

Ans.:

1. Full Form :

– Worldwide interoperability for microwave access (Access)

2. Multiple access method :

– Orthogonal frequency division multiple access (OFDM)

3. Approximate coverage range : Upto 50 km

4. Upper limit on data rate : Upto 134 Mbps

5. Range of radio channel bandwidth : 1.5 to 28 MHz

6. Applications :

– To provide services such as Voice on IP (VoIP) and Wireless telephone services.