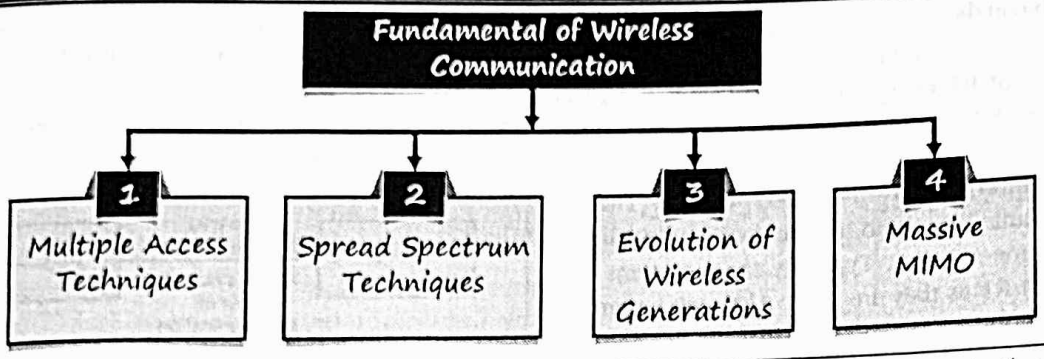


1.1 TYPES OF WIRELESS COMMUNICATION SYSTEM

Introduction

Wireless communication involves transmission over longer distances without wires. In this air is used as transmission medium.

Examples of Wireless Communication Systems are : Mobile Phones, GPS Receivers, Remote Controls, Bluetooth, WiMax, Wi-Fi etc.

What is Wireless Communication ?

- Wireless communication does not require any physical medium for transmission of data. It uses air or space as transmission medium. Since, space only allows for signal transmission without any guidance, the medium used in Wireless Communication is called Unguided Medium.
- For transmission and reception purposes antennas are used. Antenna radiates in the form of electromagnetic waves. Hence in wireless communication system both transmitter and receiver have antenna within it.

1.1.1 Advantages of Wireless Communication

1. Cost	2. Mobility
3. Easy installation	4. Reliability
5. Flexibility	

1. **Cost :** Wireless communication carries signal through space. Hence it does not require any wire. The cost of cables is reduced as compared to wired communication.
2. **Mobility :** Wireless communication provides portable devices in use. Hence it provides mobility to the user.
3. **Ease of Installation :** The set up and installation of the wireless network is really very easy as compared to wired communication as no cables are involved.
4. **Reliability :** Reliable communication is achieved by wireless communication. As the cables are not involved, there are no chances of system failure due to cable damage.
5. **Flexibility :** Wireless communication enables people to communicate regardless of their location.

1.1.2 Disadvantages of Wireless Communications

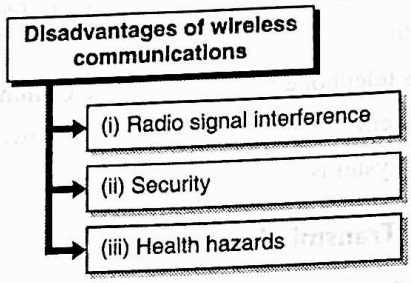


Fig. 1.1.1 : Disadvantages of wireless communications

(i) Radio signal interference

Signals from other wireless devices can disrupt its radio transmission or a wireless device can itself be a source of interference for other wireless devices. e.g. Commonly used wireless devices like cordless phones, elevator motors, microwave ovens etc. transmit radio signals that can interface with wireless LAN operation. They can cause errors. Also Bluetooth and WLAN devices both operate in the same radio frequency, potentially resulting interference between these devices.

(ii) Security

A wireless communication device transmits radio signals over a wide open area, Hence, security is a major concern. It is possible for an intruder with a notebook computer and wireless N/C to intercept the signals from a nearby wireless network. Because of more of business, network traffic can contain sensitive information, it becomes a serious issue for many users. Some wireless technologies can provide added levels of security with authorization features earlier to gaining access to the network. Network administrators can limit access for approved wireless devices only.

(iii) Health hazards

Biological damage can be produced as a result of High power levels of RF energy. However, we do not know as to how much levels of RF energy can lead to adverse health effects. The continuous radiations at lower levels can be harmful to sensitive body organs. The RF energy is emitted by radio transmitters in the wireless communication systems. Typically these systems emit low levels of RF as they are used. Although research is carried to solve these problems there is no clear information about the biological effects of this type of radiations.

1.1.2(A) Applications of Wireless Communication

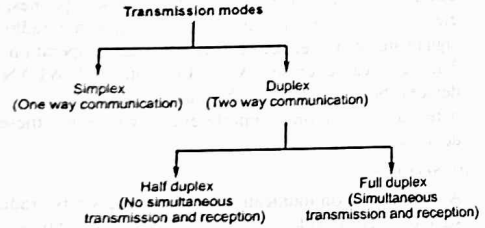
1. IR wireless communication.
2. Satellite communication
3. Broadcast radio
4. Microwave radio
5. Bluetooth
6. Zigbee
7. Cordless telephone
8. Mobile Communication
9. DTH system
10. Wireless power transfer
11. Security systems

1.1.3 Transmission Modes

Definition : Transmission mode defines the direction of flow of signal between two connected devices.

There are three modes of transmission, namely :

(i) Simplex
(ii) Half duplex and
(iii) Full duplex

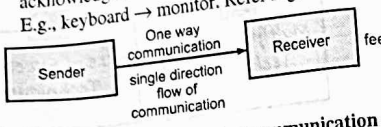


(1A3)**Fig. 1.1.2 : Types of transmission modes**

(i) Simplex Mode

GQ. Define Simplex systems regarding wireless communication.

- It is one way communication. In this mode, transmission is in only one direction, e.g., TV/Radio broadcasting, etc.
- In this, sending device does not require acknowledgement response from receiving device. E.g., keyboard → monitor. Refer Fig. 1.1.3.



(1A4)**Fig. 1.1.3 : Simplex communication**

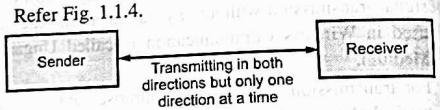
- Analogically, simplex mode is like one way road where vehicles travel only in one direction, and no vehicle is allowed from opposite direction.

(ii) Half duplex mode

GQ. Define duplex mode of electronic communication.
GQ. Define half duplex type of communication.

- This is two-way communication, but one at a time. In this mode, sender and receiver, both can send and receive but one at a time. Analogically, it is still a one-way road where vehicles from opposite side has to wait till the road gets empty. e.g. Walkie-talkie.

Refer Fig. 1.1.4.



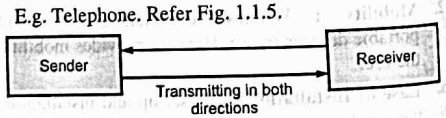
(1A5)**Fig. 1.1.4 : Half duplex communication**

- It saves bandwidth as only one frequency is used for transmission and reception.

(iii) Full duplex mode

GQ. Define Full duplex channel regarding wireless communication.
GQ. Define duplex mode of electronic communication.

- It is also called as double-duplex.
- In this mode, two-way communication happens, simultaneously. Analogically, it is two-way road where traffic can flow in both directions at the same time. E.g. Telephone. Refer Fig. 1.1.5.



(1A6)**Fig. 1.1.5 : Full duplex communication**

Module 1

1.1.4 Comparison of Simplex, Half Duplex and Full Duplex Communication

GQ. Differentiate between simplex and duplex mode of communication.

Table 1.1.1 : Comparison of Simplex, Half Duplex and Full Duplex Communication

Sr. No.	Parameter	Simplex	Half duplex	Full duplex
1.	Direction of communication	Unidirectional	Two directions as one at a time.	Two-directional simultaneously
2.	Send / receive	Sender can only send data	Sender can send and receive data, but one at a time.	Sender can send and receive data, simultaneously.
3.	Performance	Least performing mode of transmission.	Better than simplex.	The most performing mode of transmission.
4.	Example	TV and radio broadcasting, keyboard and monitor communication	Walkie- talkie	Telephone
5.	Sketch	Refer Fig. 1.1.3	Refer Fig. 1.1.4	Refer Fig. 1.1.5

1.1.5 Cordless Telephone System

GQ. Illustrate operation of cordless telephone system with the help of neat sketch.

- Cordless telephones are a full duplex telephone system designed for in home use.
- It is invented in 1980s. Earlier cordless phones were actually the extensions of the standard telephones.

(A) Block diagram (B) Working Principle
(C) Operation (D) Features

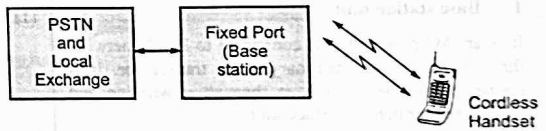


Fig. 1.1.6: Concept of cordless telephone system

(A) Block diagram

(1) Refer Fig. 1.1.7. It shows block diagram of cordless telephone system.

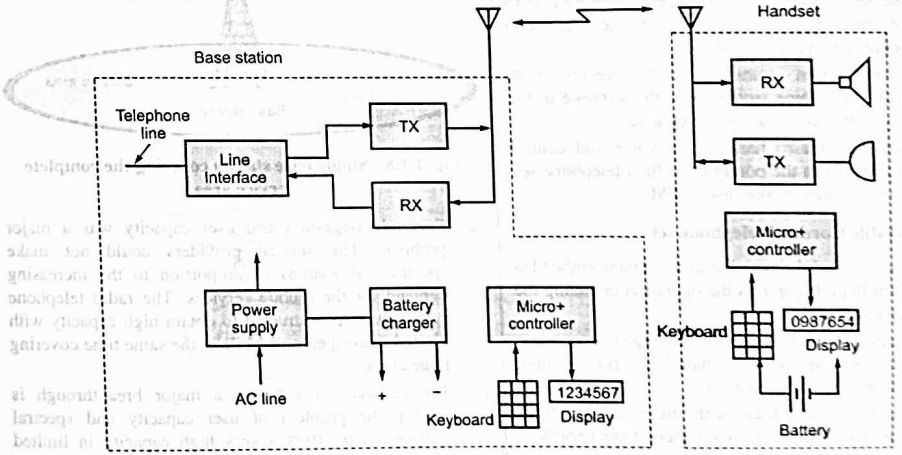


Fig. 1.1.7 : Detail block diagram of cordless telephone system

(2) Cordless telephone works on the principle of wireless radio communication between base station and the Cordless handset. They don't have cords attached to the handset.

(B) Working Principle

- Cordless telephones operates on the **principle of full duplex radio communication**. It makes use of radio communication to connect a portable handset to dedicated base station. The base station has the wireline connection from the PSTN telephone exchange.
- **Operating frequency** – 46 MHz to 49 MHz or 902 MHz to 928 MHz It uses narrowband FM for radio communication. The channel bandwidth used is 30 kHz to 100 kHz depending upon the modulation and frequency band used. Nowadays few countries have allocated 2 – 4 GHz band to cordless telephone communication.

(C) Operation

Refer Fig. 1.1.7. It consists of two parts.

1. Base station unit
2. Portable cordless telephone set

1. Base station unit

(i) It is an AC powered unit connected to PSTN network through jack. It is stationary radio transceiver. It is connected to the local loop through a wireline and telephone company interface unit.

(ii) The interface unit functions same as that of a standard telephone set. The main function performed by it is to interface the cordless telephone with the local loop while being transparent to the user.

(iii) The base station transmits and receives both supervisory and voice signals over the wireline in the same way as that of a standard telephone.

(iv) The base station also handles the voice and control signals to and from the portable cordless telephone set. This communication makes use of FM.

2. Portable Cordless telephone set

(i) Both base unit and the portable unit contains embedded microcontrollers. It controls the operation including the keyboard and display.

(ii) It is battery powered. It can be rechargeable in some cases. It is capable of handling full duplex communication with the base unit.

(iii) It is able to communicate with the base unit from certain specified distance of few meters. Latest cordless telephones may work for larger distances.

(D) Features

There are three classes of cordless telephones :

1. **Class 1 :** Analog phones : FM radio carrier : 43 to 50 MHz range, transmitter output power : 500 mW, transmission range : 1000 ft.
2. **Class 2 :** Digital phones : 900 MHz, use Gaussian FSK.
3. **Class 3:** Spread spectrum phone : 900 MHz carrier, use direct sequence spread spectrum, transmission power up to 1 W, transmission range is up to 5000 to 7000 ft.

Advantages

1. Cordless telephones provides portability.
2. Simple design.

Disadvantages

1. It provides very limited range to the user.
2. It is not possible to maintain the call if the user travels outside the range of the base station.
3. Signal strength is weak many a times. Therefore there are chances of calls getting disconnected.

1.1.6 Cellular Telephone System

(1) In earlier days, a single high powered transmitter with an antenna mounted on a tall tower was used to cover a large service area as shown in Fig. 1.1.8.

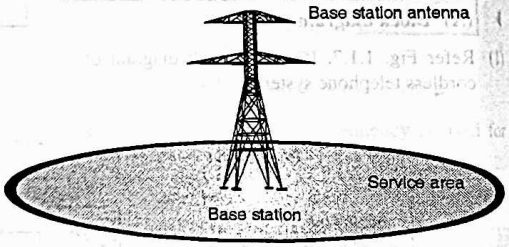


Fig. 1.1.8 : Single base station covering the complete service area

(2) Spectral congestion and user capacity was a major problem. The service providers could not make spectrum allocations in proportion to the increasing demand for the mobile services. The radio telephone system was reconstructed to obtain high capacity with limited radio spectrum while at the same time covering large areas.

(3) The cellular concept was a major breakthrough is solving the problem of user capacity and spectral congestion. It offers a very high capacity in limited spectrum.

(4) In the cellular concept, the single high power transmitter is replaced with many low power transmitters each providing coverage to only a small part of service area as shown in Fig. 1.1.9.

(5) Each base station is allocated a portion of the total number of channels and nearby base stations are assigned different group of channels.

(6) The neighbouring base stations are assigned different groups of channels so that the interference between the base stations is minimized.

(7) If these base stations and their channel groups are systematically placed throughout a market then the available channels are distributed throughout the service area. They can be reused as many time as possible or as many times as essential.

(8) The co-channel interference is kept below the acceptance level. As the demand for the service increase, the number of base stations can be increased to supply an additional radio capacity with no additional increase in the radio spectrum. This is the principle of all modem wireless communication systems as it allows a fixed number of channels to service a large number of subscribers by reusing the channels throughout the service area.

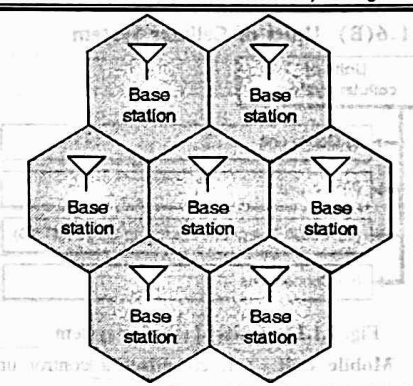


Fig. 1.1.9 : Cellular concept

(9) The cellular concept allows each cellphone to be manufactured with the same set of channels, so that any mobile can be used anywhere in the service region.

1.1.6(A) Basic Cellular System

A basic cellular system comprises of three units : a mobile unit, a cell site and a Mobile Telephone Switching Office (MTSO) as shown in Fig. 1.1.10.

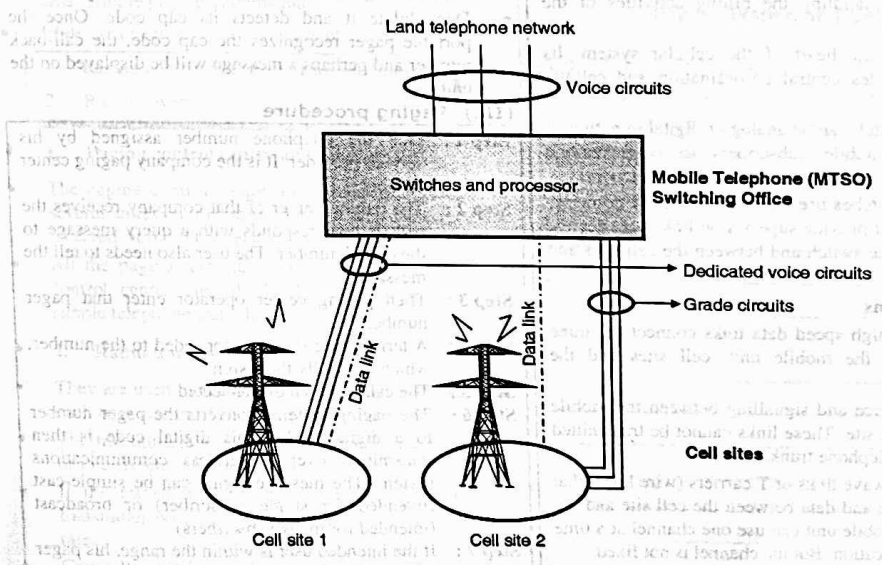


Fig. 1.1.10 : A cellular system

1.1.6(B) Units of Cellular System

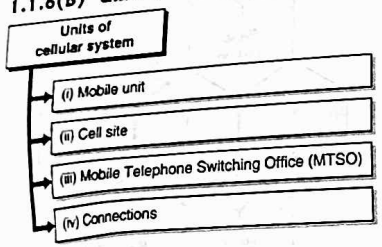


Fig. 1.1.11 : Units of cellular system

- *(i) Mobile unit* : It comprises a control unit, a *transceiver and* an antenna system.
- *(ii)* Cell site : Its function is to provide interface between the mobile units and MTSO. It comprises of a control unit, radio cabinets, antennas, a power plant and data terminals.
- (iii) Mobile Telephone Switching Office (MTSO)
  - It is the central co-ordinating unit for all cell sites. It comprises of the cellular processor and the cellular switch.
  - It interfaces the telephone company zone offices. The MTSO is responsible for controlling the call processing operations and handling the billing activities of the subscriber.
  - The MTSO is the heart of the cellular system. Its processor provides central co-ordination and cellular administration.
  - The cellular switch can be analog or digital in nature. It connects the mobile subscribers to other mobile subscribers and to the nationwide telephone network.
  - The cellular switches use voice trunks. They comprise of data links that provide supervision links between the processor and the switch and between the cell sites and the processor.
- (iv) Connections
  - The radio and high speed data links connect the three subsystems i.e. the mobile unit, cell sites and the MTSO.
  - It carries the voice and signalling between the mobile unit and the cell site. These links cannot be transmitted over standard telephone trunks.
  - They use microwave links or T carriers (wire lines) that carry both voice and data between the cell site and the MTSO. Each mobile unit can use one channel at a time for its communication. But the channel is not fixed.
  - It can be any channel in that service area. Each cell site has multichannel capabilities that can connect to different mobile units simultaneously.

1.1.7 Paging System

- Paging systems are **simplex wireless communications** systems. They are used to send brief messages to a subscriber.
- The type of the message can be numeric message, alphanumeric message or a voice message.
- Paging systems are used to notify the subscriber about something through message. It can also be used to send news headlines, stock quotations and faxes etc.

(I) Features of Paging System

(1) Early paging systems used FM. Nowadays paging systems use FSK or PSK.
(2) Data rate : 200 bps to 6400 bps.
(3) The carrier frequency bands used are - 138 MHz to 175 MHz, 267 MHz to 284 MHz, 310 MHz to 330 MHz, 420 MHz to 470 MHz and several frequency slots within the 900-MHz band.
(4) Alphanumeric messages length is 26 and 40 characters.

(II) What is cap code used in pagers?

- A pager is assigned a special code called cap code.
- The cap code includes a sequence of digital bits or a combination of digits and letters.
- The cap code is broadcast along with the paging party's telephone number.
- If the portable paging unit is within range of the broadcasting transmitter, it will receive the signal.
- Demodulate it and detects its cap code. Once the portable pager recognizes the cap code, the call-back number and perhaps a message will be displayed on the unit.

(III) Paging procedure

Step 1 : Dial the telephone number assigned by his service provider. It is the company paging center number.
Step 2 : The paging center of that company receives the call. It then responds with a query message to the dialed number. The user also needs to tell the message.
Step 3 : Then paging center operator enter that pager number.
Step 4 : A terminating signal is appended to the number, which is usually the # sign.
Step 5 : The caller is then disconnected.
Step 6 : The paging systems converts the pager number to a digital code. This digital code is then transmitted over a wireless communications system. The message signal can be simple-cast (intended for single subscriber) or broadcast (intended for many subscribers).
Step 7 : If the intended user is within the range, his pager will receive the page message. New pagers are capable of displaying messages, telephone number of the paging party.

(IV) Block diagram

GQ. With block diagram write operation of paging system.

Refer Fig. 1.1.12. It shows wide area paging system.

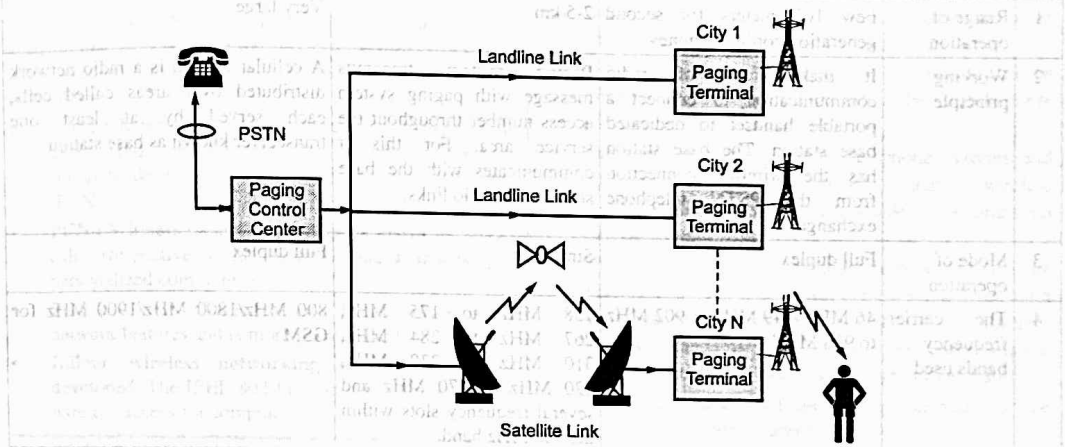


Fig. 1.1.12 : A wide area paging system

- The paging systems vary in complexity and coverage area. Simple paging systems may cover 2 to 5 km.
- Wide area paging system consists of :
  1. Paging control centre and landline links
  2. Radio towers

1. Paging control centre and landline links

- The paging control centre transmits page messages to several cities at the same time. These messages are received from PSTN network.
- All the paging terminals are connected to the paging control centre through the landline links. They are simple telephone trunk lines.

2. Radio towers

- They are used to simultaneously broadcast a page from each base station. This process is known as simulcast.
- The transmitters may be located within the same area or in different cities or countries.
- If the transmitters are located far away, then large transmitter power is required. This also lowers the data rate.
- Generally, satellite links are used for communicating with far away paging terminals.

1.1.8 Comparison of Cordless Phones, Paging System and Cellular Phones

GQ. How paging system differs from cellular phone system? Compare w.r.t. capacity, operation, applications and system requirement.

GQ. Differentiate between paging system and cordless telephone system. (any four points)

Note

Table 1.1.2 : Comparison of cordless phones, paging system and cellular phones

Sr. No.	Parameter	Cordless telephones	Paging systems	Cellular phone
1	Range of operation	Few 100 meters for second generation cordless phones	2-5 km	Very large
2	Working principle	It makes use of radio communication to connect a portable handset to dedicated base station. The base station has the wireline connection from the PSTN telephone exchange.	Paging system transmits message with paging system access number throughout the service area. For this it communicates with the base stations via radio links.	A cellular system is a radio network distributed over areas called cells, each served by at least one transceiver known as base station.
3	Mode of operation	Full duplex	Simplex	Full duplex
4	The carrier frequency bands used	46 MHz – 49 MHz or 902 MHz to 928 MHZ	138 MHz to 175 MHz, 267 MHz to 284 MHz, 310 MHz to 330 MHz, 420 MHz to 470 MHz and several frequency slots within the 900 MHz band.	800 MHz/1800 MHz/1900 MHz for GSM
5	Standards used	CT2, DECT, PACS, GSM	POCSAG. FLEX, GSC	AMPS, NAMPS, USDC, IS-95
6	Advantages	Portability, full duplex communication	Alphanumeric messages, news etc can be sent, global connectivity is provided via satellite linking.	Mobility, full duplex communication, wireless communication etc.
7	Limitation	Range of communication is less	No voice communication	Issues like signal fading etc.

1.1.9 Comparison of Wireless System

Table 1.1.3 : Comparison of mobile communication system : Mobile station

Service	Coverage Range	Required Infra-structure	Complexity	Hardware cost	Carrier Frequency	Functionality
TV Remote Control	Low	Low	Low	Low	Infrared	Transmitter
Garage Door Opener	Low	Low	Low	Low	< 100 MHz	Transmitter
Paging system	High	High	Low	Low	< 1 GHz	Receiver
Cordless phone	Low	Low	Moderate	Low	< 1 GHz	Transceiver
Cellular phone	High	High	High	Moderate	< 2 GHz	Transceiver

Table 1.1.4 : Comparison of mobile communication system : Base station

Service	Coverage Range	Required Infra-structure	Complexity	Hardware cost	Carrier Frequency	Functionality
TV Remote Control	Low	Low	Low	Low	Infrared	Receiver
Garage Door Opener	Low	Low	Low	Low	< 100 MHz	Receiver
Paging system	High	High	High	High	< 1 GHz	Transmitter
Cordless phone	Low	Low	Low	Moderate	< 1 GHz	Transceiver
Cellular phone	High	High	High	High	< 2 GHz	Transceiver

1.2 TREND IN CELLULAR RADIO AND PERSONAL COMMUNICATION

A lot of research and activities carried out throughout the world since 1989 for development of the wireless systems that combine the network intelligence of PSTN's with modern digital signal processing and the RF technology.

- In the UK three companies were allocated spectrum in 1800 MHz for Personal Communication Services (PCS) to develop Personal Communication Networks (PCN).
- **PCN :** Wireless system where user can make or receive calls irrespective of the location using a light weight personalized communicator.
- **PCS :** A new wireless system that comprises more network features and is more personalized.
- **Indoor wireless networking systems** are being developed. The IEEE 802.11 is standard developed for wireless access for computers inside buildings.

1.3 WIRELESS NETWORK GENERATIONS/ EVOLUTION OF WIRELESS STANDARDS

(1) In 1958, the Bell system proposed a 75 MHz system at 800 MHz. In US by 1934, 194 municipal police radio systems and 58 state police stations had adopted Amplitude Modulation (AM) mobile communication systems for public safety. Around 5000 radios were installed in the mobiles. However, vehicle ignition noise was a major problem for these mobile users.

(2) In 1935, Armstrong invented and demonstrated the Frequency Modulation (FM) mobile communication system for the first time. Frequency Modulation is the primary modulation method used for mobile communication systems throughout the world.

(3) Many mobile users in 1960's was not connected to the Public Switched Telephone Network (PSTN). Hence, they were not able to directly dial telephone numbers from their vehicles.

(4) With the boom in Citizens Band (CB) radio and cordless appliances the number of mobile users and portable radio in 1995 was about 100 millions (37%) of the US-population. Then the subscription-based wireless has been experiencing the customer growth rates in excess of 50% per year.

(5) The creation, revolution and evolution of the mobile wireless systems started in early 70's. But it gained huge popularity in 90's decade. Mobile cellular subscribers are increasing 40% per year, and by the end of 2010 there will be 4 times more mobile cellular subscription than fixed telephone lines.

(6) During past 20 years, the mobile industry has seen improvements in digital and RF circuit fabrication, new very large-scale circuit integrations and miniaturization thereby. These technologies make the mobile more portable, cheaper and reliable.

(7) The rapid growth in cellular telephone systems and infrastructures has proved that wireless communications are a robust, viable voice and data transport mechanism.

(8) This success in the cellular system led to the advancement of the newer mobile systems with improved features and facilities. Based on different wireless standards and technologies used, mobile communication is categorized in different generations.

(9) There are generations from 0 G to 5 G based on the technology changes. Refer Fig. 1.3.1.

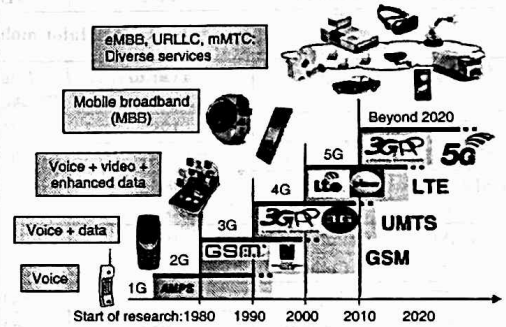


Fig. 1.3.1 : Evolution of mobile generations

1.3.1 Mobile Radio Systems Around the World

- Many mobile radio standards have been developed for wireless systems throughout the world.
- Table 1.3.1 lists the major mobile radio standards in North America.
- Table 1.3.2 lists the major mobile radio standards in Europe and Table 1.3.3 lists the major mobile radio standards in Japan.

Table 1.3.1 : Major mobile radio standards in North America

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	π/4 DQPSK	30 kHz
CDPD	Cellular	1993	FH/packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	185-1.99 GHz	GMSK	200 kHz
PACS	Cordless/PCS	1994	TDMA/FDMA	185-1.99 GHz	π/4 DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
IDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

Table 1.3.2 : Major mobile standards in Europe

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
ETACS	Cellular	1985	FDMA	900 MHz	FM	25 kHz
NMT-450	Cellular	1981	FDMA	450-470 MHz	FM	25 kHz
USDCNMT-900	Cellular	1986	FDMA	890-960 MHz	FM	12.5 kHz
GSM	Cellular/PCS	1990	TDMA	890-960 MHz	GMSK	200 kHz
C-450	Cellular	1985	FDMA	450-465 MHz	FM	20 kHz/10 kHz
ERMES	Paging	1993	FDMA	Several	4-FSK	25 kHz
CT2	Cordless	1989	FDMA	864-868 MHz	GFSK	100 kHz
DECT	Cordless	1993	TDMA	1880-1900 MHz	GFSK	1.728 MHz
DCS-1800	Cordless/PCS	1993	TDMA	1710-1880 GHz	GMSK	200 kHz

Table 1.3.3 : Major mobile radio standards in Japan

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
JTACS	Cellular	1988	FDMA	860-925 MHz	FM	25 kHz
PDC	Cellular	1993	TDMA	810-1501 MHz	π/4-DQPSK	25 kHz
NTT	Cellular	1979	FDMA	400/800 MHz	FM	25 kHz
NTACS	Cellular	1993	FDMA	843-925 MHz	FM	12.5 kHz
NTT	Paging	1979	FDMA	280 MHz	FSK	12.5 kHz
NEC	Paging	1979	FDMA	Several	FSK	10 kHz
PHS	Cordless	1993	TDMA	1895-1907 MHz	π/4-DQPSK	300 kHz

Syllabus Topic : Evolution of wireless generations – 1G to 5G (Based on technological differences and advancements)

1.4 MOBILE RADIO STANDARDS

1.4.1 0G : Zero Generation (1970's)

- The first public mobile service was made available after world war II in 1946 in 25 major American cities only.
- It was not based on the cellular approach and hence was not able to support handover mechanism. They are usually referred as radio telephones. The systems included in 0G are as shown in Table 1.4.1.

Table 1.4.1 : Systems included in 0G

Sr. No.	Name of the technology	Implementation year	Features	Disadvantages
1.	PTT (Push To Talk)	1946	1. FM is used 2. RF bandwidth = 120kHz 3. Half duplex mode.	Large RF bandwidth was used.
2.	MTS (Mobile Telephone Service)	1950	1. Number of channels were doubled keeping the same spectrum by FCC as compared to PTT. 2. Bandwidth was reduced to almost 30kHz for voice transmissions.	Spectrum efficiency was an issue.
3.	IMTS (Improved Mobile Telephone Service)	Mid 1960's	1. Automatic channel trunking. 2. Full duplex system. 3. Auto dial facility.	Spectrally inefficient.

1.4.2 1G : First Generation (1980 to 1990)

GQ. Give full forms of the following acronyms: AMPS.

(1) First generation mobiles can be thought of as the basis of today's mobile systems as cellular approach was first developed in this era during 1950's and 1960's. The cellular approach increased the spectrum usage effectively as compared to 0G.

(2) The basic idea of cellular radiotelephony was based on frequency reuse scheme used in television stations or radio stations by telecommunication's committees. First generation phones were analog cell phones and were able to give the speed upto 2.4 kbps.

(3) **There are many 1 G standards available but the important and majorly used are :**

(i) AMPS (advanced mobile phone system)

(ii) NAMPS (narrowband advanced mobile phone system)

Table 1.4.2 which shows various first generation technologies.

Table 1.4.2 : 1G standards

Sr. No.	Name of the technology	Implementation year	Features	Disadvantages
1.	NTT (Nippon Telephone and Telegraph), Japan developed first cell phone	1979	1. Frequency band of operation – 800 MHz 2. 600 FM duplex channels were used. 3. 25 kHz was channel spacing used in each direction (i.e. forward and backward) 4. Handover mechanism implemented	Interoperation between countries was not possible.
2.	NMT450 (Nordic Mobile Telephone System) in Europe	1981	1. Frequency of operation – 450 MHz 2 Channel spacing used is 25 kHz 3 Modulation used - FM 4. Multiple access scheme used - FDMA	
3.	AMPS (Advanced Mobile Phone Service) in USA	1983	1. Frequency of operation - 800 MHz 2. FDMA was used. 3. Channel spacing – 30 kHz 4. Modulation used - FM 5. Bandwidth allocated by FCC - 40 MHz	
4.	NAMPS (narrowband advanced mobile phone service)	1992	1. Frequency band : 824 - 894 MHz 2. Multiple access scheme used : FDMA 3. Modulation : FM 4. Channel bandwidth : 10 kHz	
5.	ETACS (European Total Access Cellular System) in Europe	1985	1. Frequency band - 900 MHz 2. Multiple access scheme used - FDMA 3. Modulation used - FM 4. Channel bandwidth – 25 kHz	Smaller bandwidth channels were used so degradation in SNR and coverage range was observed.

- There are few more examples of first generation mobile systems like RTMI in Italy, YACS in UK, Radiocom 2000 in France, C-450 in Germany etc.

1.4.2(A) Advantage & Disadvantages of 1G : First Generation

Advantages

1. Channel bandwidth - 30kHz
2. Modulation used - FM
3. Multiple access scheme used - FDMA

Disadvantages

1. It has low capacity unreliable handoff.
2. Poor voice quality.
3. No security as the voice calls were played back in radio towers so they were more susceptible to noise.
4. No encryption.
5. Limited capacity.

1.4.3 2G : Second Generation (1990's)

GQ. Give comparisons between GSM, IS-136 and IS-95.
GQ. Illustrating the upgrade paths briefly describe 2G cellular network.
GQ. With diagram explain various 2.5 G and 3Gs upgrade paths for the major 2G technologies.

- Second generation standards use digital modulation techniques and TDMA or CDMA is employed. Based on multiple access technology used second generation standards are categorized. Refer Fig. 1.4.1, it shows tree structure of second-generation standards.

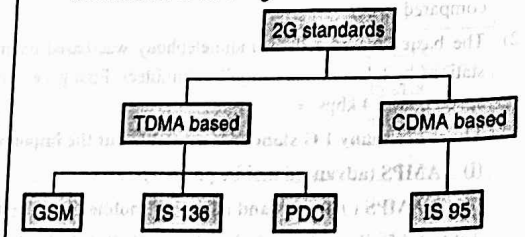


Fig. 1.4.1 : Tree structure of 2G standards

- Second generation standards are first of their kind in application of digital modulation and digital signal processing in mobile handset and Base station.
- Major advantage of this generation is efficient frequency spectrum utilization. It offers at least three times increase in the spectrum efficiency as compared to first generation technologies.

TDMA based standards

1. GSM (Global System for Mobile)
2. IS136 (Interim Standard- 136)
3. PDC (Pacific Digital Cellular)

CDMA based standard

IS 95 (Interim Standard -95)

Table 1.4.3 : 2G standards

Sr. No.	Name of the technology	Implementation year	Features	Disadvantages
1.	GSM	First launched in Finland in 1991 but received popularity worldwide in late 1990's in many countries	1. TDMA/FDD based standard. 2. 8 voice channels per carrier with 200 kHz carrier separation. 3. Frequency band – 800 MHz (Europe), 1900 MHz (US PCS) 4. Modulation scheme - 0.3GMSK 5. Data rate : 14.4 kbps 6. SMS facility provided. 7. Circuit switched data.	It faces bandwidth constraints.
2.	IS-136 (Also known as NADC - North American Digital Cellular or USDC - US Digital Cellular)	1990's	1. Frequency band – 800 MHz and 1500 MHz (Japan) and 1800 MHz (US PCS) 2. TDMA/FDD based standard 3. Modulation - $\pi/4$ DQPSK 4. Carrier separation - 30 kHz 5. Data rate - about 48.6 kbps 6. 3 voice channels per carrier.	Power inefficiency results in frequent battery recharges
3.	PDC (Pacific Digital Cellular) (Japan)	1990's	1. Frequency band - 800MHz and 1500MHz (Japan) and 1800MHz (US PCS) 2. TDMA/FDD based standard 3. Modulation - $\pi/4$ DQPSK 4. Carrier separation - 25 kHz 5. Data rate - about 42 kbps 6. 3 voice channels per carrier.	
4.	IS-95	1990's	1. Frequency band – 800 MHz (US cellular) 1800 MHz (US PCS) 2. CDMA/FDD based standard. 3. Modulation - BPSK with quadrature spreading. 4. Carrier separation : 1.25 MHz 5. Data rate - about 1.2288Mchips/sec 6. 64 voice channels per carrier.	Requirement of large bandwidth.

Apart from this there are few other standards like iDEN standard by Nextel was also present.

1.4.3(A) Advantage and Disadvantages of 2G : Second Generation

Advantages

1. 2G offers better security than 1G.
2. Digital technology static and background noise was not a problem.
3. Better voice quality and SMS facility.
4. Reliable handover mechanism.
5. Encryption is supported so better security in the system.
6. Digital signals consume less battery power.

Disadvantages

1. Powerful digital signals are required to make the mobile work i.e. if weak digital signal is present then it will not be sufficient to reach the cell-site, so limited network coverage.
2. Video data etc. is not supported.
3. As it makes use of circuit switching techniques are employed, there is limited internet browsing.

1.4.4 2.5G : 2.5 Generation

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

- As there were few disadvantages in the second generation mobile standards like limited support for internet browsing, new data centric approach was developed which was based on the advancements of the existing 2G networks. Few modifications in 2G infrastructure and software upgrades made high data rate internet browsing possible.
- 2.5G supports WAP (Wireless Access Protocol) which allows standard web pages to be viewed in a compressed format on mobile.
- The main requirement of 2.5G standard was to support backward compatibility for 2G standards since it would otherwise become very expensive system.
- There are 3 evolutions present for GSM and one for CDMA.

2.5G standards for GSM

- HSCSD (High Speed Circuit Switched Data)
- GPRS (General Packet Radio Service)
- EDGE (Enhanced Data Rate for GSM Evolution)

2.5G standards for CDMA

Refer Table 1.4.4.

Table 1.4.4 : 2.5G standards

Sr. No.	Name of the technology	Features	Disadvantages
1.	HSCSD for GSM	1. Individual user data is allowed on consecutive time slots so higher speed is obtained. 2. Circuit switched technology is used. 3. Data rate - up to 57.6 kbps 4 Channel bandwidth – 200 kHz 5. Software upgrade is required at BS. 6. New spectrum is not required.	Requires new handset.
2.	GPRS for GSM	1. Packet based standard supporting high data rate. 2. Supports more number of users than HSCSD. 3. Always on access to the network. 4. Bandwidth – 200 kHz 5. Requires routers and gateways as it is packet switched technology. 6. Data rate - up to 171.2 kbps	Requires new handset.
3.	EDGE for GSM	1. Supports 8-PSK and GMSK modulation schemes. 2. Channel bandwidth – 200 kHz 3. Data rate - upto 384 kbps	Requires addition of new hardware and software. Also requires new handset.
4.	IS-95B for CDMA	1. Supports 64 different user channels. 2 Data rate - up to 115.2 kbps (64kbps for single user) 3. Supports hard handoff. 4. Channel bandwidth - 1.25 MHz. 5. Requires new software in BSC. 6. New spectrum is not required.	New handset is required.

1.4.4(A) Advantage and Disadvantages of 2.5 G

Advantages

1. High data speed.
2. Supports packet data network communication.
3. Based on existing 2G network so reduces cost of replacement of entire infrastructure. Only few modifications are needed.
4. New spectrum is not needed.
5. Better frequency spectrum utilization.
6. Security of data is better.
7. Complex data like video are also supported. MMS is supported.

Disadvantages

1. New handset is required.
2. Limited web browsing as compared to 3G.
3. Does not support video conferencing.

1.4.5 3G : Third Generation (2000's)

GQ. Write a short note on 3G W-CDMA (UMTS).

GQ. Illustrating the upgrade paths briefly describe 3G cellular network.

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

- It allows the use of global frequency band of 2000 MHz range that will support a single globally accepted wireless communication standard.
- The gradual evolution of GSM, IS-136 and PDC together is WCDMA (Wideband CDMA). It is also called as UMTS (Universal Mobile Telephone System).
- Refer Table 1.4.5.

Table 1.4.5 : 3G standards

Sr. No.	Name of the technology	Features	Disadvantages
1.	WCDMA, UTRA (UMTS terrestrial radio access), CDMA II	1. Works with both TDD and FDD 2. Backward compatibility with GSM/DCS1900 3. Data rate - up to 2.048 kbps 4. Minimum Forward channel bandwidth – 5 MHz 5. Network structure and bit level packaging remains same as that of GSM. 6. Always on packet based wireless network. 7. Maximum 350 voice calls are supported simultaneously. 8. Better spectrum efficiency.	Complete change at the Base station equipment is required as there is a change in the spectrum. Also requires triband handsets.
2.	Cdma2000	1. Backward compatibility with IS 95A and IS 95B. 2. Cdma2000 1X supports data rate up to 307 kbps for user in packet mode. 3. Rapid adaptation in baseband signalling rates and chipping rates for each user. 4. Only software changes are needed for up gradation of 2G to cdma2000. 5. Duplexing method - TDD and FDD. 6. Uplink is implemented by simultaneous combination of multi carrier or direct spreading techniques whereas downlink is implemented using either multi carrier or direct spreading. 7. Carries both voice and data services on the same carrier.	Lack of international roaming capabilities.

Sr. No.	Name of the technology	Features	Disadvantages
3	Cdma2000 1xEV	1. Developed by Qualcomm inc. 2. High data rate packet standard. 3. Overlaid on existing cdma2000 or IS-95 or IS-95B networks. 4. It is also compatible with WCDMA. 5. Recognized as a part of IMT 2000. 6. Provides CDMA carriers with the option of installing radio channels with data only (cdma2000 1xEV-DO) or with data and voice (cdma2000 1xEV-DV)	
4.	UWC	1. TDMA is used. 2. FDD for outdoor and TDD for indoor usage. 3. Backward compatibility with GSM, IS-136. 4. Data rate - up to 722.2 kbps (outdoor) and 5.2Mbps (indoor).	
5.	TD-SCDMA	1. Overlaid on existing GSM infrastructure. 2. Uses TDMA/TDD technique. 3. Data rate : 384 kbps 4. Channel bandwidth 1.6 MHz 5. 5msec frame is divided into seven time slots allotted to single or multiple users. 6. Use of smart antenna technology.	

1.4.5(A) Advantages and Disadvantages of 3G

Advantages

1. Higher data rate as compared second generation and 2.5G mobile networks.
2. Bandwidth, security and reliability is more.
3. Supports interoperability among service providers.
4. Supports video conferencing services.
5. Provides backward compatibility to GSM and CDMA networks.
6. Overcrowding of channels is reduced by change in the radio spectrum.

Disadvantages

1. Cost of upgrading infrastructure is quite high which makes the system expensive.
2. New handsets are needed.
3. Power consumption is high so large power rating batteries are needed.

1.4.6 Comparison

GQ. Describe evolution of 1G, 2G and 3G mobile phone systems.
GQ. Explain the 1G, 2G, 2.5G and 3G Mobile Communications.

Table 1.4.6 : Comparison between all mobile radio standards

Sr. No.	Parameter	1G	2G	2.5G	3G	4G	5G
1.	Implementation year	1984	1991	1999	2002	2010	2015
2.	Standards	NMT, AMPS, NTT, ETACS	GSM, PDC, IS 136, IS 95	HSCSD, GPRS, EDGE	WCDMA, cdma2000, IMT2000, TD-SCDMA	Single unified standard	Single unified standard
3.	Technology	Analog cellular	Digital cellular	Digital cellular	Wideband CDMA, IP	LTE, Wimax	5G-LTE
4.	Multiple access technique used	FDMA	TDMA and CDMA	TDMA and CDMA	Wideband CDMA	CDMA	CDMA
5.	Data rates	2.4 kbps	14.4 kbps	171 kbps	3.1 Mbps	100 Mbps	Higher than 1Gbps
6.	Switching method used	circuit switching	circuit switching	circuit switching for voice and packet switching for data	packet switching	packet switching	packet switching
7.	Operating spectrum	800MHz	GSM:900MHz, 1800MHz, CDMA: 800 MHz	GSM : 900MHz, 1800MHz, CDMA : 800 MHz	2100 MHz	850 MHz, 1800 MHz	850 MHz, 1800 MHz
8.	Services	Voice	Voice and SMS	Voice and data	Integrated high quality of voice and data	Dynamic information access, wearable devices	Dynamic information access, wearable devices with AI (artificial intelligence) capabilities.
9.	Carrier frequency / Channel bandwidth	30kHz	200kHz	200kHz	5MHz	15MHz	28GHz
10	Whether analog or digital	Analog	Digital	Digital	Digital	Digital	Digital

Syllabus Topic : 5G – Key requirements and drivers of 5G systems

1.5 OPPORTUNITIES AND REQUIREMENTS IN 5G

- 5G is essential in near future as there is ever increasing demand of data rates for voice, video and data streaming by the entire world. The current 3G and 4G technologies will not be able to handle the increasing future internet data traffic.
- To tackle this increasing demand of traffic data rates 5G is proposed and is expected to support voice and video streaming by 2020.
- 5G include radical network design for installing Machine Type Communication (MTC). Also it is expected that 5G will support applications with varying parameters providing flexibility in the network.
- For this future 5G is not just the new sets of technologies but also it will require the huge upgradations in the equipment and devices In the network.
- To cater the high data rates combination of core and cloud technologies will be used in 5G.
- Overall 5G is expected to cover
  1. 10-100 times higher typical user data rate.
  2. 10 times longer battery life for low power devices.
  3. 10-100 times more connected devices.
  4. 5 times reduced end to end latency.
  5. 1000 times higher mobile data volume per area.

  Major technologies included in 5G are :
  1. MIMO (Multiple Input Multiple Output)
  2. Ultra radio access design (RAN)
  3. Flexible duplexing.

1.5.1 Key Requirements and Drivers of 5G

GQ. Discuss the requirements of 5G.

- 5G will use variety of different technologies operating at different spectrums to allow ubiquitous connectivity between humans and equipment. For this following are the requirements.

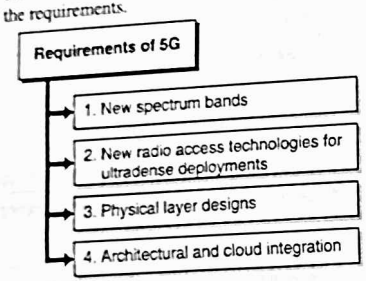


Fig. 1.5.1 : Requirements of 5G

1. New spectrum bands

- The current technologies and wireless standards are already very crowded and are not able to accommodate more system changes.
- They have already exhausted their licensed resources. This demands new spectrum for 5G mainly in the unlicensed band (5MHz).
- There are more spectrums available in 6-100 GHz range. This is required to meet the demands of high capacity and high data rates. This change in the spectrum should be such that it should also provide backward compatibility for previous generation technologies.

2. New radio access technologies for ultra-dense deployments.

- The huge developments in massive MIMO and beamforming technologies allow access of millimetre wave spectrum to support ultra-dense high-capacity scenarios.
- This requires new radio interfaces which will communicate with multiple MIMO units to obtain suitable sharp pensile beam. The advantage of this new radio access technology is that it provides continuous carrier bandwidth of 1-2 GHz.

3. Physical layer designs

- There is a need to optimize the bandwidth and power consumption in current technologies. Hence to achieve this in 5G, new technologies are combined with industry automations, transport systems, healthcare systems, education, gaming etc. all these applications require minimum latency may be below 1ms.
- To obtain low latency very small subframe length is required hence for this future 5G will employ flexible duplexing where frame length can be adjusted according to required service.
- This will require many changes at physical layer of 4G LTE.

4. Architectural and cloud integration

- In all accommodation of thousands of applications will be the key in 5G development.
- The parameters which are to be considered during development are :
  1. Data security
  2. Latency
  3. Smart communication
  4. Traffic capacity
  5. Data throughput
  6. Power consumption
  7. Technology convergence
- 5G implementation include pico cell structure for effective communication between the different nodes in and out of the network.
- The 5G network is expected to be capable of
  1. Load balancing
  2. Minimizing the interference
  3. Power adaptation etc.
- Refer Fig. 1.5.2, it summarizes all the basic requirements of 5G networks.

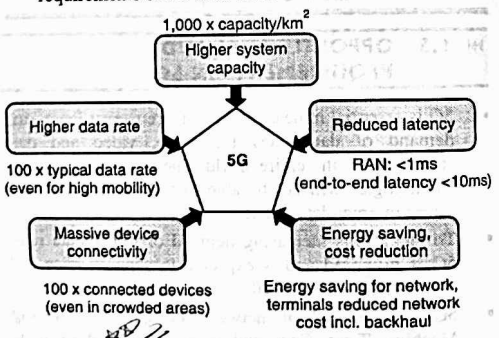


Fig. 1.5.2 : 5G requirements

1.6 OPEN WIRELESS ARCHITECTURE OF 5G NETWORK

GQ. Explain open wireless 5G architecture.

GQ. Compare 5G architectural layers with standard OSI model with neat sketch.

- Refer Fig. 1.6.1, it shows comparison between OSI layers and 5G layers. Fig. 1.6.2 shows it equivalent functional model for 5G architecture.

Application layer	Application (services)
Presentation layer	
Session layer	Open Transport protocol (OTP)
Transport layer	
Network layer	Upper network layer
	Lower network layer
Data link layer (MAC)	Open wireless architecture (OWA)
Physical layer	

Fig. 1.6.1 : Comparison between OSI layers and 5G layers

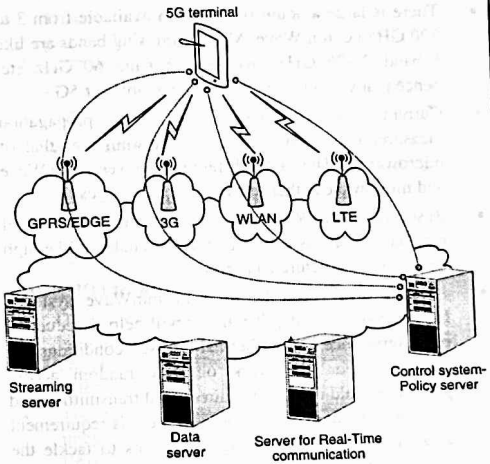


Fig. 1.6.2 : Functional architecture of 5G

Physical layer

- It corresponds to the physical layer and data link layer or Medium Access layer (MAC) of the OSI model.

  Physical layer + data link layer = OWA (Open Wireless Architecture)

Network layer

- Layer 2 of 5G is divided into upper and lower layers as shown in Fig. 1.6.1.
- The network layer of 5 G is based on IP. All 5G mobiles will use mobile IP standard. Each mobile will be Foreign Agent (FA), maintaining Care of Address (CoA). Mobile can be attached to several other mobiles at a time.

Open transport protocol

- It is the third layer of 5G which compares to transport and session layer of the OSI model.
- For all 5G devices it is assumed that transport layer can be downloaded and installed. Such mobiles will have the ability to download the desired version specifying wireless technology installed at the BS. This is known as open transport protocol.

Application

- It is the uppermost layer of 5G. This provides support for intelligent QoS management over wide variety of networks. 5G mobile phones are expected to test the service quality and store the measurement information in the database at the mobile terminal. This information may contain the parameters like delay, jitter, losses, bandwidth, reliability etc.
- Based on the information databases quality of the wireless service can be improved.

1.7 KEY TECHNOLOGIES FOR 5G

GQ. Write short notes on Disruptive technologies for 5G.

- Following are the advancement technologies which will direct the architectural and component based design changes in 5G network.

1. Device centric architecture
2. Millimetre wave (mmWave)
3. Massive MIMO
4. Smarter devices
5. Essential support for machine-to-machine communication (M2M)

1. Device centric architecture

There will be changes in BS centric approach of cellular systems in 5G. There may be changes in channel structures and the information routing based on priorities. The disruption in the cell centric approach is indicated in various different trends as explained below.

(i) Changes in base station designs

Due to rise of heterogeneous networks, there is a rapid growth in the number of base stations. Though the heterogeneous networks are standardized in 4G but, the LTE architecture was not designed accordingly. Hence few changes are required in 5G. The base stations in 5G should be able to handle different transmit powers, coverage areas etc.

(ii) Requirement of new spectrum

The requirement of new spectrum allows the coexistence of frequency bands with different propagation characteristics. This can be done by distinguishing information and control plane using phantom cell concept. In this high power nodes will handle control information using microwave frequencies and low power nodes will handle payload data using mm-Wave frequencies.

(iii) Incorporated baseband concept

It is developed in context with cloud based wireless access systems. It allows decoupling between the virtual node and the actual equipment assigned to that node can rest in different physical location of the network. All the equipment are kept in pool and dynamically assigned to different nodes depending on the measurement characteristics by the network operator.

(iv) Emerging service classes

It will require complete changeover in the architecture. It may be expected that architectural designs may change from centralized or partial centralized approach to the distributed approach.

(v) The use of smart devices

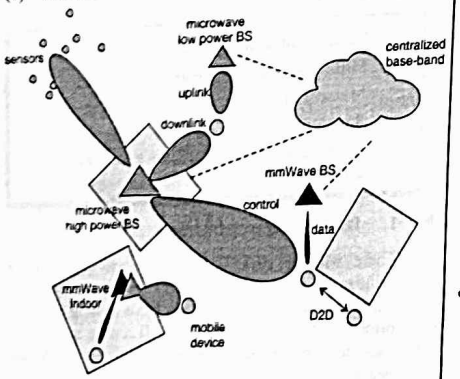


Fig. 1.7.1 : Device centric architecture

- It can affect the wireless system. It requires complete changeover in the architecture. In this the focus of the network is moved from network core to the peripheral devices.
- Based on these trends, it is expected that cell centric approach should be moved to device centric approach. A given device should be able to communicate by exchanging multiple information flows through several possible nodes present in the network.

2. Millimeter wave (mmWave)

There are two ways to access more microwave spectrum.

(i) Repurposing the spectrum

Though globally terrestrial TV spectrum is used for rural broadband access by repurposing it, still it has not made much of the spectrum available.

(ii) Sharing of spectrum

- It is suggested to double the current channel bandwidth. This will be the best case scenario for microwave frequencies.
- There is large amount of spectrum available from 3 to 300 GHz i.e. mmWave. Many promising bands are like E-band 71-76 GHz, license free band 60 GHz etc. hence many bands may become available for 5G.
- Current research has shown that propagation measurements of mmWave are bit similar as that of microwaves. The only difference between mmWave and microwave is that sensitivity to blockages.
- Research on mmWave will need more complex channel models in analysis and also study of enablers like high density infrastructure and relays.
- Antenna arrays can be used in mmWave systems. Large arrays and adaptive arrays will help in reduction of interference and thermal noise conditions in mmWave. For this work on new random access protocol should be done for directional transmitting and receiving antennas. In this process there is requirement of adaptive array processing algorithms to tackle the situation of blockage of beam by people etc. directional beam forming may help in this.
- One more major issue with mmWave is high power consumption of ADC and DAC. Hence conventional microwave hardware architecture needs to be replaced. Moreover hybrid architecture is needed.

Syllabus Topic : Massive MIMO

3. Massive MIMO

- It is large scale antenna system and it is multiuser antenna system. In this generally number of antennas at the base station are larger than the number of devices per signalling source.
- It reduces the frequency dependence in the channels and thus better spectral efficiency is achieved.
- It has a disruptive potential for 5G as

(i) It is scalable technology as in we can have flexible number of antennas involved at the node point. Hence there is no restriction on number of antennas at the base station provided TDD is used to enable the channel estimation through uplink pilot channel. This is not the case with current 4G system, where non-scalable MIMO system is used.

(ii) It supports new deployments and architectures. If the microcell BS are replaced by low gain resonant antennas then other deployments like arrays of antennas on the water tanks in rural areas is also possible. The massive MIMO which supports collocated arrays of antennas also supports the distributed deployment of antennas.

- Though this technology appears to be promising still practically it faces challenges like critical channel estimation, pilot contamination, coherent interference etc. many of these issues grow with increasing number of antennas. The entire system is still very costly.

4. Smart devices

There are three different technologies which can be incorporated in smart devices in 5G.

(i) D2D (ii) Local caching

(iii) Advanced interference rejection

(i) D2D (device to device)

- D2D is expected to handle data with low latency and high data rate. It is already studied in 3GPP as 4G add on. Now in 5G study will mainly focus on proximity detection for public safety.
- The main challenges while designing these devices are integration of D2D mode with duplexing techniques, flexible physical and MAC layer design of D2D in respect of hardware and software (protocol design) aspect etc.

(ii) Local caching

Local caching is better alternative to both at the radio access network edge (e.g., at small cells) and at the mobile devices. It is more suitable to audio/video kind of data. It will require huge amount of memory.

(iii) Advanced interference rejection

- Future mobile devices may have varying form factors. There may a situation in which the devices might incorporate multiple antennas with active interference rejection along with beamforming and spatial multiplexing.
- For advanced interference rejection, a joint design of transmitter and receiver processing, and proper control and pilot signals are the challenges

5. Essential support for machine to machine communication (M2M)

5G system is expected to support different classes of low data rate services like

(i) Large number of connected devices,

(ii) Very high link reliability,

(iii) Low latency and real time operation.

(i) Large number of connected devices : M2M services may require support for 10^4 number of interconnected devices like sensors, metering, other enablers etc.

(ii) Very high link reliability : It is expected that wireless links should also provide reliability same as that of wireline links.

(iii) Low latency and real time operation : Data needs to transferred within given time interval reliably is the major requirement in 5G.

1.8 ADVANTAGES AND DISADVANTAGES OF 5G

Advantages

1. 5G will bring all the other technological networks on one platform.
2. More effective and spectrum efficient as compared to previous mobile generations.
3. Technology to facilitate subscriber supervision tools for the quick action.
4. Higher transmission speed in Gbps and better channel bandwidth.
5. Supports backward compatibility.
6. Support heterogeneous services including private network.

Disadvantages

1. Practical implementation of the technology is still awaited.
2. Transmission speed claimed by technology is quite difficult to obtain in many parts of the world.
3. It will require huge infrastructural changes including mobile handset changes so seems to be costly system.
4. Security and privacy issues are still under research.

Syllabus Topic : Use Cases

1.9 USE CASES FOR 5G TECHNOLOGY

5G wireless standard can be used in variety of different areas. Some of the application areas are as shown below in Fig. 1.9.1.

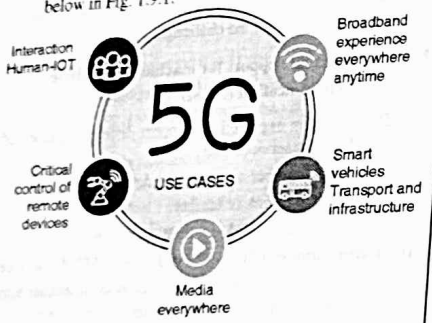


Fig. 1.9.1: 5G use cases

- **Mobile broadband access**: They are the key use cases and driving requirements of 5G technology. It covers the coverage, consistent user experience and service availability for new services such as streaming 3D videos, audio, interactive videos, mobile internet connectivity, cloud services etc.
- **The future of automotive**: There is vast scope in automotive for mobile communication in vehicles. Use cases include passenger entertainment, mobile access, car safety, driver assistance etc. These use cases needs high reliability and low latency.
- **Internet of things (IoT)**: This domain is upcoming in industrial automation. Nowadays almost each domain is covered in IoT. And it really helps in human machine interface.
- **Health**: With emerging 5G technology, health related applications are likely to grow. Lifeline fitness and smart healthcare products are likely to emerge. It needs ultra reliable, prioritized, real time and reserved capacity system. Also privacy is the main constraint in healthcare.
- **Smart society** : It deals with use cases in smart cities, smart homes, smart offices etc. It requires high bandwidth and fast completion of complex applications. This also needs high speed processing of large amount of data.

1.10 INTRODUCTION TO MULTIPLE ACCESS TECHNIQUE

- Multiple access technologies are used to support multiple users to share same radio spectrum.
- Sharing of the radio spectrum can be done in three ways, i.e. by sharing frequency, by sharing time or by allocating different codes to the users. Accordingly, three different basic types of multiple access techniques are categorised.
- They are FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access), and CDMA (Code Division Multiple Access).
- The main requirement of the this sharing techniques is that it should not affect the quality of the signal.
- With the use of multiple access techniques efficient utilization of spectrum is possible, also capacity of the system is increased.
- These techniques are grouped into narrowband and wideband systems depending on the bandwidth allocation to users.

1.11 DUPLEXING

❑ **Definition :** Sending and receiving data to and from Base station is done using two separate channels. One for uplinking and one for down-linking data from BS. This process is known as **duplexing**.

Two types of duplexing :

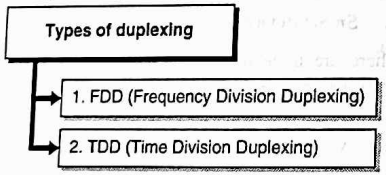


Fig. 1.11.1 : Types of duplexing

1.11.1 FDD (Frequency Division Duplexing)

- Refer Fig. 1.11.2 of FDD scheme.
- Each user is allocated two different frequency carriers. One for forward (downlink : from BS to MS) and one for reverse (uplink : from MS to BS) communication links.
- Each duplex pair consists of two simplex channels.
- Duplexer is needed in MS and BS.
- Spacing between the uplink and downlink frequencies is kept constant throughout the system.

Module 1

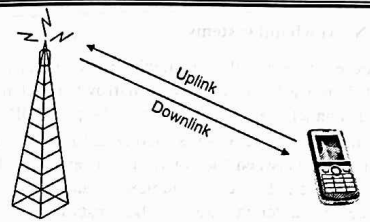


Fig. 1.11.2 : Frequency Division Duplexing

1.11.2 TDD (Time Division Duplexing)

Refer Fig. 1.11.3 of TDD scheme.

- Time is used instead of frequency for uplink and downlink of the data to and from BS and MS.
- Multiple users can share the same frequency channel by using different time slots.

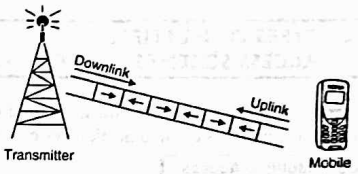
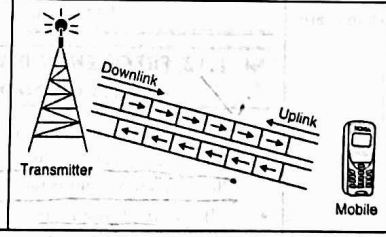
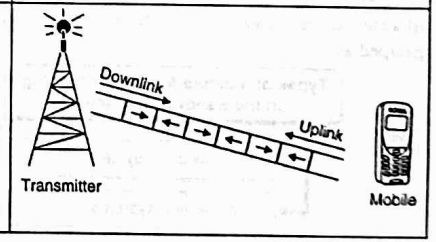


Fig. 1.11.3 : Time Division Duplexing

- Each duplex channel is provided with different time slot for uplink and downlink.
- Duplexer is not necessary but precise synchronisation is important in this scheme.
- Time latency is major issue hence it is more suitable for fixed wireless access systems when all the users are stationary as there is no change in the propagation delays among the users.

1.11.3 Comparison of FDD and TDD

Table 1.11.1 : Comparison of FDD and TDD

Sr. No.	Parameter	FDD	TDD
1	Working principle	Duplexing by allocation of two separate simplex channels for uplink and downlink between BS and MS.	Duplexing by sharing the frequency carrier and allocation of time slots for uplink and downlink between BS and MS.
2	Implementation	Easy	Complex
3	Need of duplexer in BS and MS	Required.	Not required.
4	Guard space between carriers	Required.	Not required as single carrier is shared.
5	Advantages	Easy to implement. Time latency is less. Simultaneous transmission and reception by transceivers. Synchronisation is not needed.	Efficient utilization of spectrum as single carrier is required. Duplexers are not needed.
6	Disadvantages	Wastage of bandwidth Use of duplexer makes the hardware complex.	Time latency is more. Synchronisation is needed. Simultaneous uplink and downlink is not possible.
7	Applications	Radio communication.	Cordless phones, short range portable access devices.
8	Diagram		

1.12 TYPES OF MULTIPLE ACCESS SCHEMES

The three main multiple access methods used to share the bandwidth in a wireless communication system are :

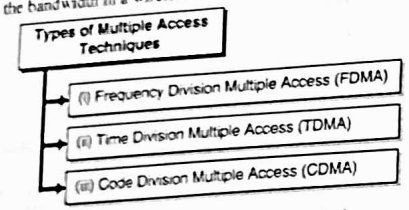


Fig. 1.12.1 : Types of multiple access techniques

(i) Frequency Division Multiple Access (FDMA)

In **Frequency Division Multiple Access (FDMA)**, individual channels are assigned to individual users and each user is allocated a unique frequency band or channel.

(ii) Time Division Multiple Access (TDMA)

The **Time Division Multiple Access (TDMA)** systems divide the radio spectrum into time slots and in one slot only one user is allowed to transmit or receive.

(iii) Code Division Multiple Access (CDMA)

In **Code Division Multiple Access (CDMA)** systems, the narrowband message signal is multiplied by a large bandwidth called spreading signal. This spreading signal is actually a pseudo noise code sequence and it has a higher chip rate than the data rate of the message signal.

1.12.1 Types of Multiple Access Depending on the Bandwidth Available

Depending on the bandwidth that is available to allocate to the users, the multiple access systems are grouped as:

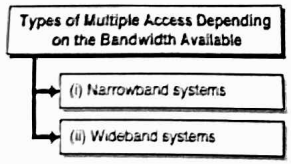


Fig. 1.12.2 : Types of Multiple Access Depending on the Bandwidth Available

(i) Narrowband systems

- In these systems, the available radio spectrum is divided into a large number of narrowband channels. These channels are working with the help of FDD.
- The frequency separation is increased to minimize the interference between the forward and reverse links on each channel. However, duplexers and a common transceiver antenna are to be installed in each subscriber unit.
- In **narrowband FDMA** a user is allocated a specific channel that is not shared by other users in observation. If FDD is used then the system is called as FDMA/FDD.
- In **narrowband TDMA**, a user shares the same radio channel but allocates a unique time slot to each user on the channel.
- A small number of users are separated in time on a single channel.
- The radio channels can be allocated using TDD or FDD while each channel is shared using TDMA. Such systems are called TDMA/FDD or TDMA/TDD access systems.

(ii) Wideband systems

- In these systems, the transmission bandwidth of a single channel is larger than the coherence bandwidth of the channel. So, multipath fading will not vary the received signal power. The frequency selective fades occur in a small part of the signal bandwidth at any instant of time.
- In these systems there are a large number of transmitters that transmit on the same channel.
- If TDMA is used then only one transmitter can access the channel at any instant of time. They can use FDD or TDD.
- If CDMA is used it allows all the transmitters to access the channel simultaneously. The systems can use FDD or TDD multiplexing techniques.

Syllabus Topic : Multiple Access Techniques - FDMA

1.13 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

- In wireless communication systems, the individual users are allocated individual channels. The channels or the frequency band is unique for each subscriber.
- The entire allowed radio spectrum is divided into many slices of the frequency bands and each band or channel is allocated to user. The channel allocation can be done on a demand basis to the users to request service.

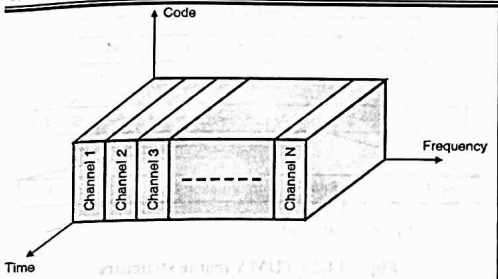


Fig. 1.13.1 : FDMA where different channels are assigned different frequency bands

- When a call is processed, no other user can share the same channel.
- In FDMA/FDD systems the users are assigned a pair of frequencies, one for the forward channel and other for the reverse channel.
- Fig. 1.13.1 shows the principle of FDMA scheme where different channels are assigned different frequency bands.

1.13.1 Features of FDMA

The features of FDMA are :

i) If a FDMA channel is not in use, it will be idle and not used by any other user. Hence, there is a chance of resource wastage.

ii) The FDMA channel uses one phone circuit at any instant of time.

iii) If voice channel is assigned in FDMA, then the mobile unit and the base station start transmitting simultaneously.

iv) FDMA needs tight RF filtering to minimize the adjacent channel interference.

v) The FDMA mobile unit uses duplexers as both the transmitter and receiver operate simultaneously. It results an increase in the cost of subscriber units and base stations.

vi) The complexity of FDMA systems is less.

vii) The FDMA systems have narrow bandwidth as each channel supports only one circuit per carrier.

viii) The symbol time is large in comparison to the delay spread. This indicates that the inter symbol interference is low and no equalization is required in FDMA narrowband systems.

ix) The cost of cell site is higher in comparison to the TDMA systems.

x) FDMA is a continuous transmission method. So few bits are required for overhead purposes (like synchronization and framing bits).

1.13.2 Nonlinear Effects in FDMA

- In this multiplexing method, the same antenna at the base station is shared by several radio channels.
- The power amplifiers are operated near saturation region for getting maximum possible power efficiency and it is **non-linear**.
- These non-linearities cause the spreading of signals over the entire frequency domain and result in Inter Modulation (IM) frequencies. IM is undesired RF radiation. It can interface with the other channels in the FDMA system. Adjacent channel interference can produce as a result of the spectrum spreading.
- Inter-modulation generates harmonics that cause interferences in the actual signal and inter-modulation must be minimized.

1.13.3 Number of Channels in a FDMA System

- In an FDMA/FDD system a single user occupies a single channel while call is in progress. The single channel is two simplex channels that are frequency duplexed with a separation.
- When a hand-off occurs or a call is completed, the channel is cleared so that another mobile subscriber can use it. The voice channels are sent on the forward channel from the base station to the mobile unit and on the reverse channel from the mobile unit to the base station.
- The **number of channels (N)** that can be simultaneously supported in a FDMA system is given by,

$$N = \frac{B_t - 2B_{guard}}{B_c}$$

Where, B_t : Total spectrum allocation

B_{guard} : Guard band allocated at edge of allocated spectrum

B_c : Channel bandwidth

1.13.4 Types of FDMA

There are two types of FDMA. They are :

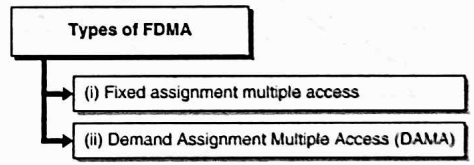


Fig. 1.13.2 : Types of FDMA

(i) Fixed Assignment Multiple Access (FDMA)

It is denoted as "FAMA". In this method the channels are assigned in a predetermined manner and distributed so that random changes in the capacity are not allowed.

(ii) Demand Assignment Multiple Access (DAMA)

If there are multiple stations there is a change of capacity. Then channel can be allocated according to the demand.

1.13.5 Merits of FDMA

(i) All stations can operate continuously all 24 hours without having to wait for their turn to come.

(ii) No synchronization is necessary.

(iii) The complexity of systems is low.

1.13.6 Demerits of FDMA

(i) Inter-modulation frequencies can cause adjacent channel interference.

(ii) As a result of non-linearities, inter-modulation products are generated.

(iii) It carries only one phone circuit at a time.

(iv) The cell site cost of FDMA system is high.

(v) The bandwidth of FDMA channels is narrow.

Syllabus Topic : Multiple Access Techniques - TDMA

1.14 TIME DIVISION MULTIPLE ACCESS

- It uses time instead of frequency. Different users share the same time slots of the complete time available.
- Each user to allocated a time slot in which the user can access the channel. In each slot only one user is allowed to transmit or receive.
- As shown in Fig. 1.14.1 each user is assigned a time slot so that channel may be thought as a time slot that reoccurs every frame where N slots comprise a frame.

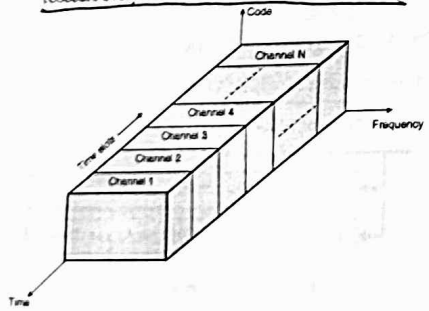


Fig. 1.14.1 : TDMA

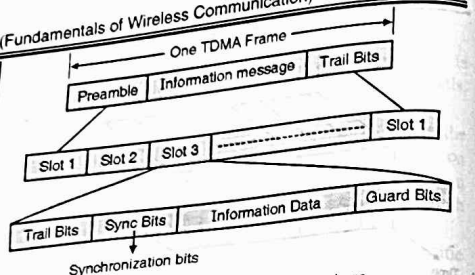


Fig. 1.14.2 : TDMA frame structure

- The TDMA systems transmit data in burst and buffer method. The transmission from different users is interfaced into a repeating frame structure as shown in Fig. 1.14.2.
- 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.

1.14.1 TDMA Features

(i) TDMA uses different time slots for transmission and reception. Hence, duplexers are not required. If FDD is used then a switch is used to switch between transmitter and receiver.

(ii) As the transmission rates are high adaptive equalization is necessary.

(iii) TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots. The number of time slots depend on parameters like bandwidth, modulation method etc.

(iv) Using TDMA we can allocate different number of time slots per frame to different users. Thus, bandwidth can be supplied on demand to different users by reassigning time slots depending on the priority.

(v) Data transmission is done in bursts. It results in low battery consumption as the transmitter of the subscriber can be turned off when it is not in use.

(vi) Guard time needs to be minimized. If the signal is transmitted at the edges of the time slot, it is suppressed to reduce the guard time. The transmitted spectrum will expand resulting in adjacent channel interference.

(vii) In TDMA, the handoff process is simple. An enhanced link control like that provided by Mobile Assisted Hand Off (MAHO) can be carried by the subscriber by listening on an idle slot in the TDMA frame.

(viii) Because of burst transmissions high synchronization overhead is needed in TDMA systems.

1.14.2 Number of Channels in TDMA System

The **number of channel slots** that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by number of channels available.

$$N = \frac{m\,(B_t - 2\,B_{guard})}{B_c}$$

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

1.14.3 Efficiency of TDMA System

- 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 : Number of equivalent bits in each guard time interval

The total number of bits per frame b_T is, $b_T = T_f\,R$

where, T_f : Frame duration

R : Channel bit rate

Thus, the frame efficiency is,

$$\eta_f = \left(\frac{1 - b_{overhead}}{b_T}\right) \times 100\,\%$$

Syllabus Topic : Multiple Access Techniques - CDMA

1.15 CODE DIVISION MULTIPLE ACCESS

- In this multiple access scheme, many users share the same carrier frequency (f_c). The narrowband message signal is also multiplexed with a spreading signal of larger bandwidth. This spreading signal is a pseudo noise code sequence, and it has higher chip rate than the data rate of the message signal.
- 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.
- The main advantage of CDMA when compared to other multiple access methods is reduced level of interference. As each user is allocated an individual pseudo random codeword that is orthogonal to the code words of the other users at the receiver end the receiver tunes to receive the intended signal of the user.
- To minimize the near-far problem power control is essential in CDMA systems. Power control is implemented at the base station by sampling the radio signal strength indicator (RSSI) levels of each mobile and then a power change command over the forward radio link.

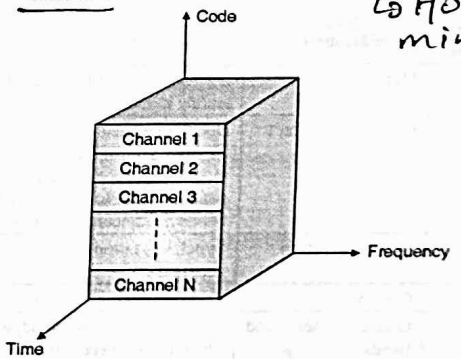


Fig. 1.15.1 : CDMA scheme

1.15.1 Features of CDMA

(i) In CDMA the channel data rates are very high. Hence, the symbol duration is short and less than the channel delay spread. As PN sequences have low auto correlation, multipath that is delayed by more than a chip will appear as noise. A Rake receiver can be used to improve the reception by collecting time delayed versions of the required signal.

(ii) If an undesired user has a high power compared to other user then near far problem arises at the CDMA receiver end.

(iii) CDMA uses cochannel cells. Spatial diversity can be used to provide soft handoff. Soft handoff is done by the MSC that can monitor a specific user from two or more base stations. Without switching the frequencies, MSC can decide the best version.

(iv) The CDMA system users share the same frequency. TDD or FDD can be used.

(v) CDMA has a soft capacity limit. If the number of users increases, the noise increases and system performance decreases.

(vi) Multipath fading can be reduced as the signal is spread over a large spectrum. If the spread spectrum bandwidth is greater than the coherence bandwidth of the channel, the frequency diversity will mitigate the effects of small-scale fading.

(vii) In CDMA systems self jamming is a problem. The spreading sequences of different users are not exactly orthogonal. This leads to self jamming.

Ex. 1.15.1 : In an omni-directional CDMA cellular system E_b/N_o required is 20 dB. If 100 users, each with a baseband data rate of 13 kbps are to be accommodated, determine the minimum channel bit rate of spread spectrum chip sequence assuming voice activity factor of 0.4.

Soln. :

Given : $\frac{E_b}{N_o} = 20$ dB, N = 100 users,

R = 13 kbps, $\alpha = 0.4$

To find : W = ?

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1)\alpha} = 10 \log \left(\frac{E_b}{N_o}\right)$$

$$20 = 10 \log \left(\frac{E_b}{N_o}\right)$$

$$\frac{E_b}{N_o} = \text{antilog } 2 = 100$$

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1)\alpha}$$

$$100 = \frac{W}{\frac{13 \times 10^3}{(100-1) \times 0.4}}$$

$$W = 100 \times (100-1) \times 0.4 \times 13 \times 10^3$$

$$W = 51.48 \text{ Mchips / sec} \quad \text{...Ans.}$$

1.15.2 Comparison of FDMA, TDMA and CDMA

Table 1.15.1 : Comparison of FDMA, TDMA and CDMA

Sr. No.	Parameter	FDMA	TDMA	CDMA
1.	Method	Overall bandwidth is shared among many stations.	Time sharing of satellite transponder takes place.	Sharing of bandwidth and time both takes place.
2.	Interference effect	Due to nonlinearity of transponder amplifiers, inter modulation products are generated due to interference between adjacent channels.	Due to incorrect synchronization, there can be interference between the adjacent time slots.	Both types of interferences will be present.
3.	Synchronization	Synchronization is not necessary.	Synchronization is essential.	Synchronization is not necessary.
4.	Code word	Code word is not required.	Code word is not required.	Code words are 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.
6.	Hand-over	Hard handover	Soft handover	Soft handover
7.	Allocated bandwidth	12.5 MHz	12.5 MHz	12.5 MHz

Sr. No.	Parameter	FDMA	TDMA	CDMA
8.	Frequency reuse	7	7	1
9.	Required channel bandwidth	0.03 MHz	0.03 MHz	1.25 MHz
10.	Number of RF channels	$\frac{12.5}{0.03} = 416$	$\frac{12.5}{0.03} = 416$	$\frac{12.5}{1.25} = 10$
11.	Control channels / cell	2	2	2
12.	Usable channels / cell	57	57	8
13.	Voice channels / cell	$57 \times 1 = 57$	$57 \times 4 = 228$	$8 \times 4 = 320$
14.	Sectors per cell	3	3	3
15.	Voice calls/sector	$\frac{57}{3} = 19$	$\frac{228}{3} = 76$	$\frac{320}{3} = 106$
16.	Key resources	FDMA assigns individual channels to individual users.	TDMA systems divide the radio spectrum into time slots.	CDMA systems use the same carrier frequency and can simultaneously transmit.
17.	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.
18.	System complexity	Lower	Higher	Higher
19.	System flexibility	Simple and Robust, inflexible	Flexible	Flexible

Syllabus Topic : Multiple Access Techniques - OFDMA

1.16 OFDMA (ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS)

1.16.1 Concept of OFDM

- OFDM is a technique in which bandwidth is divided into several orthogonal frequency subcarriers. There is no guard band in between adjacent subcarrier still the interference is avoided as there are orthogonal to each other.
- **Orthogonality :** Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different subcarriers.
- 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. Refer Fig. 1.16.1.

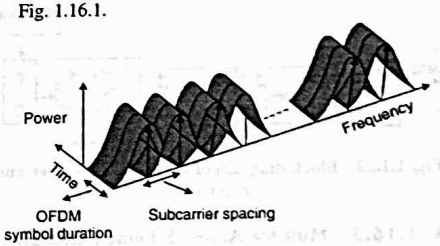


Fig. 1.16.1 : OFDM signal representation in time frequency domain

1.16.2 OFDM Transmitter and Receiver

Refer Fig. 1.16.2.

- **Serial To Parallel Conversion :** The input data is made compatible for transmission by converting it into suitable word size and then transmitting it parallelly using one carrier for each data word.

- **Modulator :** Each carrier which is to be used is allotted with the data whose amplitude and phase are chosen according to the modulation scheme being used (typically BPSK, QPSK, or QAM). It is used because of its simplicity and to reduce problems of fading due to amplitude variations.
- **IFFT :** IFFT on transmitter and FFT on receiver's side are used to reduce the use of I/Q modulators and demodulators. It is used to modulate and demodulate respectively. The data constellations on the subcarriers.
- **Cyclic prefix :** For OFDM the system bandwidth is broken up into N subcarriers, resulting in a symbol rate that is N times lower than the single carrier transmission. This low symbol rate makes OFDM naturally resistant to effects of Inter-Symbol Interference (ISI) caused by multipath propagation. Hence cyclic prefix is added. Due to this the transmitted signal becomes periodic and the effect of time dispersive multipath channel becomes equivalent to cyclic convolution, and it also discards the guard interval at the receiver. Due to these subcarriers remain orthogonal. Its length should not exceed the maximum excess delay of the multipath propagation channel.
- **Receiver :** The receiver basically does the reverse operation to the transmitter to retrieve the information transmitted.

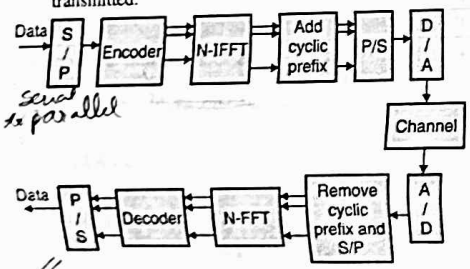


Fig. 1.16.2 : Block diagram of OFDM transmitter and receiver

1.16.3 Multiple Access Scheme based on OFDM : OFDMA

- *It is the extension of OFDM concept in multiuser environment.*
- *In this technique multiple user signals are separated in both time and frequency domains using OFDM symbols and subcarriers respectively.*
- *It uses multiple closely spaced subcarriers. These subcarriers are then divided further into group of subcarriers called as subchannels. These subcarriers in subchannels need not to be adjacent to each other.*
- Fig. 1.16.3 shows subcarriers of same colour represent subchannel group.

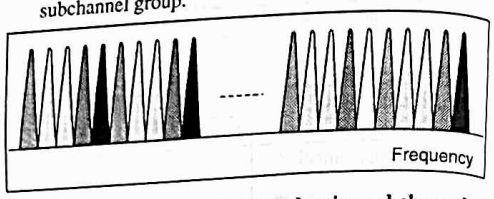


Fig. 1.16.3 : OFDMA spectrum showing subchannels

- Multiplexing is done by allocation of different subchannels or different OFDM symbols to different users to send and receive signals. The burst in OFDMA consists of several OFDM symbols.
- OFDMA can be well explained by the given example. Please refer Fig. 1.16.4.

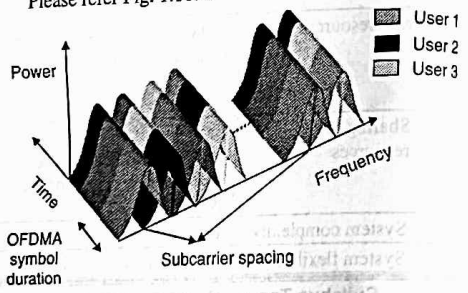


Fig. 1.16.4 : Example - Allocation of channels to the users in OFDMA

Subcarrier Allocation

- *The working principle of OFDMA is based on allocation of subchannels based on subcarrier allocation strategies.*
- *There are three types : Refer Fig. 1.16.5*
  - *SCAS (Sub Band Carrier Allocation Scheme)*
  - *ICAS (Interleaved CAS)*
  - *Generalized CAS*

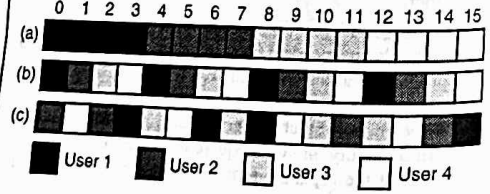


Fig. 1.16.5 : Subcarrier allocation schemes in OFDMA - (a) SCAS (b) Interleaved CAS (c) Generalised CAS

1. **SCAS (Sub Band Carrier Allocation Scheme) :** In this all the subcarriers of each user are grouped together. Hence it is easy to separate them using simple filter banks. However in this efficient use of frequency diversity is not done and it is affected by fading in the subcarriers of given users.
2. **ICAS (Interleaved CAS) :** The problems associated with SCAS are solved in this scheme. In this allocation of subcarriers is done with uniform spacing between them. Still it faces problem of restriction on resource allocation.
3. **Generalized CAS :** It is the most flexible and desirable method of subcarrier allocation. It gives choice to the users to select the best available subcarrier to transmit their information. Hence it provides complete use of channel frequency diversity. Also it provides flexibility in resource allocation.

OFDMA transmitter and receiver

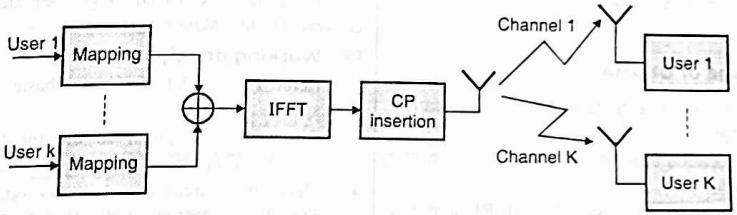


Fig. 1.16.6(a) : Block diagram of OFDMA transmitter for downlink path

Refer Fig. 1.16.6(a). It shows block diagram of OFDMA transmitter.

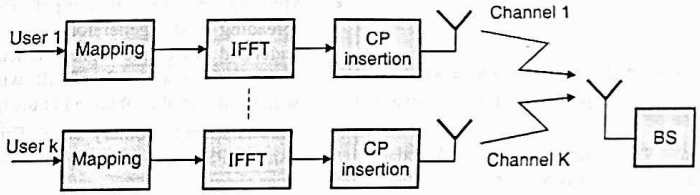


Fig. 1.16.6(b) : Block diagram of OFDMA transmitter for uplink path

- In the transmitter generally N subcarriers are allocated to K number of users using one of the above explained CAS scheme. Let M be length of the block of the data obtained by dividing the user data.
- Obviously, these M data symbols makes use of their respective subcarriers for modulation.
- On a downlink path, other subcarriers of length N block of data are modulated with data from other users and the modulated output is sent using conventional OFDM modulator.
- Cyclic prefix is then added the before OFDM symbol and then it is transmitted over k channels to k different users.
- On the uplink path the uplink transmitter leaves the other subcarrier empty and resulting N block with M empty subcarriers are then sent to IFFT. After that different CP is added to different symbols and then they are sent on different channels to the base station.
- At the receiver first CP is removed and then N point samples are passed through N point FFT.

Why synchronization of uplink is a difficult problem in OFDMA?

- OFDMA converts frequency selective channel into flat fading channel very efficiently.
- Hence for channel equalization one tap multipliers are used for each subcarrier. This output of equalizer is then used for detection.
- On downlink path each user picks up only M data symbols transmitted over its allocated subcarriers for channel equalization and detection purposes.
- But on uplink, the received signal is comprised of signals from all active users and hence it has different frequency offsets and different propagation delays.
- Hence offset correction needs to be applied in order to detect these signals.

- And all these parameters need to be dealt with jointly and hence synchronization is a difficult issue in OFDMA on uplink path.

☞ Advantages of OFDMA

1. Scalability
2. Intrinsic protection against Multi Access Interference (MAI)
3. Flexibility in resource management
4. Robustness to multipath channels
5. Simple equalization

☞ Disadvantage of OFDMA

1. It is extremely sensitive to timing errors and carrier frequency offsets.
2. Subcarrier allocation algorithms used at transmitter introduces complexity.
3. When the OFDMA signal passes through RF amplifier with non-linearities BER increases.
4. Cochannel interference is bit complex compared to CDMA.

☞ Applications

1. IEEE 802.20 (Mobile broadband wireless access)
2. WiMAX (Worldwide interoperability for microwave access)
3. ETSI (European Telecommunication's Standard Institute) broadband radio access network
4. Multiuser satellite communication
5. 4G LTE (Long Term Evolution) network

⏭ 1.17 SPREAD SPECTRUM

GQ. Write short note on : Spread Spectrum techniques.

☑ **Ans. :**

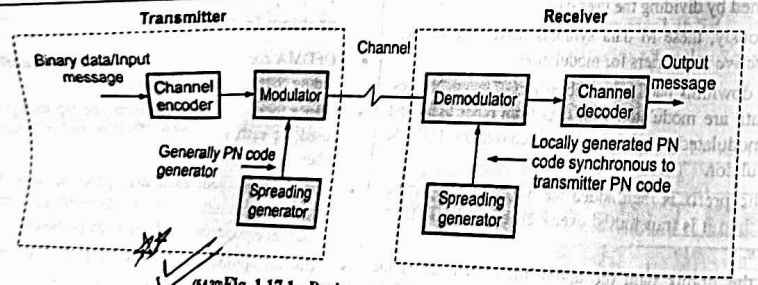
❑ **Definition :** The process in which narrowband signal is converted to wideband signal is called as spreading of spectrum.

☞ Concept of spread spectrum

If the signal is in KHz range, then after spreading it is converted to few MHz range.

☞ Working principle

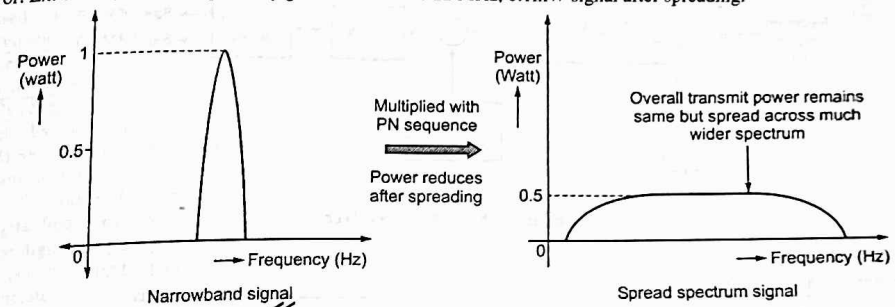
- Refer Fig. 1.17.1. It shows basic spread spectrum system.
- Binary data is given as the input to the channel encoder. This binary data is narrowband signal.
- Generally channel encoder adds redundant bits to the input binary data bits and provides it to the modulator.
- The modulator block actually comprises of multiplier and digital CW modulators.
- Multiplier has the other input from PN sequence or spreading code generator. This spreading code is wideband noise like signal. When the binary data is multiplied (modulo 2 added) with the PN code, a wideband signal is obtained at the output.
- This is spreaded binary code. This is then modulated using MPSK or MFSK modulators and then transmitted over channel.
- At the receiver, the signal is first demodulated by coherent or noncoherent detection methods.
- Once the spreading code is detected back, it is again multiplied with the locally generated PN code.
- Then the original binary data is recovered back.



(5A30) **Fig. 1.17.1 : Basic spread spectrum system**

- *The power of the narrowband signal is reduced to almost half or even less than that after spreading the signal. This is shown in Fig. 1.17.2.*
- *But the overall transmit power remains same even after spreading the signal. This power gets distributed over wider spectrum.*

- In earlier digital communication entire power was concentrated in tight bandwidth. This is not done in spread signal. For. Ex. 6MHz, 0.3 mW signal may get converted into 22 MHz, 0.1mW signal after spreading.

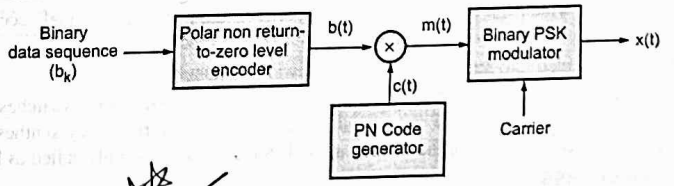


(5A31) **Fig. 1.17.2 : Concept of spread spectrum**

Syllabus Topic : Spread Spectrum Techniques – DSSS

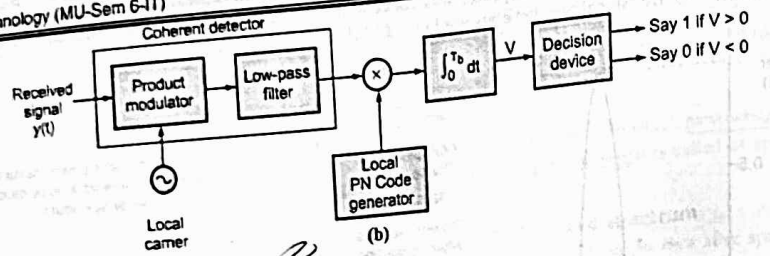
⏭ 1.18 DIRECT SEQUENCE SPREAD SPECTRUM (DSSS)

- Refer Fig. 1.18.1 (a).
- In DSSS, signal undergoes two stages of modulation.
- Initially binary data input b_k is converted into bipolar NRZ format. This NRZ signal is then given to the mixer. As this is the input data sequence, it is narrowband signal.
- The other input to the mixer is the wideband PN code c(t). Modulo 2 addition (EX-ORing operation) is carried out and output is provided to the next stage which is PSK modulator. This output of the multiplier is known as spreading code. It is now the wideband signal whose bandwidth is almost equal to the PN code signal.
- Therefore the transmitted signal is DS/BPSK signal. In BPSK, two phases 0 and π are present depending on the polarity of the data sequence. The waveforms are as shown in Fig. 1.18.2.
- Refer Fig. 1.18.1(b). At the receiver, the received signal is first given to the product modulator and low pass filter combination. The cut-off frequency of the low pass filter is equal to the original message signal. Coherent detection is carried out for detection of the spreading code from the BPSK output. The output of the coherent detector is the spreading code.
- This spreading code and locally generated PN code are then multiplied. Digitally modulo 2 addition or EX-OR operation is carried out. The condition of this PN code generation is that, it has to be same as that of the PN code used at the transmitter. This process is called as de-spreading.
- After the dispreading of the signal, it is given to the integrator. Integration is carried out for one bit duration.
- Integrator's output is provided to the decision device. The threshold is set for logic 1 and logic 0. If the incoming bit is above the threshold, it is declared as logic 1 otherwise logic 0. If the bit is exactly equal to the threshold then the decision device takes the decision randomly.
- Refer Fig. 1.18.2. It shows detail waveforms of DS/BPSK.

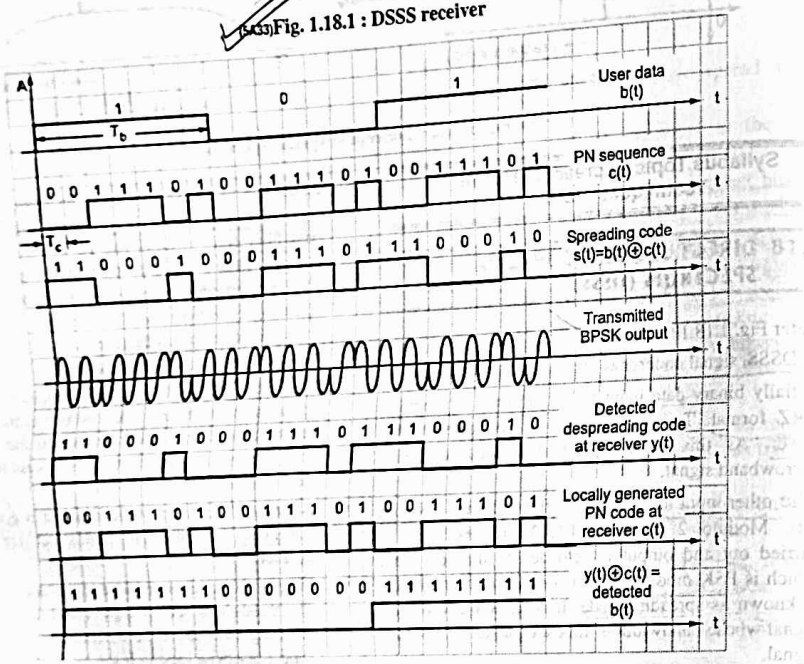


(a)

(5A32) **Fig. 1.18.1 : DSSS transmitter**



(5A33)Fig. 1.18.1 : DSSS receiver



(5A34)Fig. 1.18.2 : DS/BPSK waveforms

Syllabus Topic : Spread Spectrum Techniques - FHSS

1.19 FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)

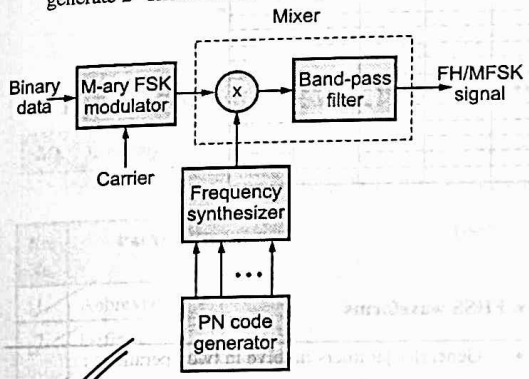
- The transmission method in which the carrier hops rapidly between the available channels according to the hopping pattern generated by PN sequence is called as frequency hopped spread spectrum.
- The allocated spectrum is divided into number of narrow bandwidth channels.
- Generally the modulation format used is M-ary FSK (MFSK). The MFSK signal switches between the carriers frequencies available pseudo randomly. These carriers are generated using the frequency synthesizer using the hopping sequence provided to it. The combination of the MFSK and FHSS techniques is simply called as FH/MFSK.

Working principle of FHSS

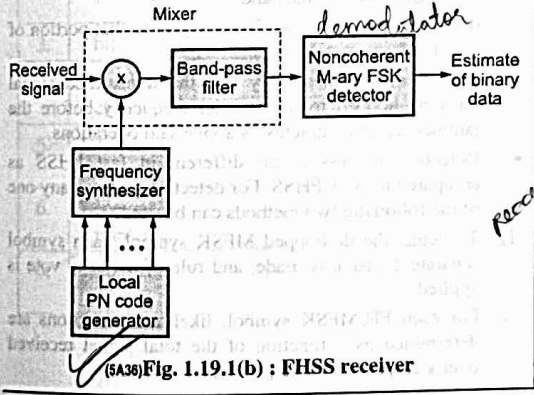
- Refer Fig. 1.19.1(a) and (b)
- This system is actually two step modulation process. Data modulation and frequency hopping modulation is carried out in it.

Module 1

- For data modulation purpose the MFSK transmitter is used, and frequency hopping is carried out by the frequency synthesizer controlled by PN code. In this the data symbol modulates the carrier whose frequency is determined by the hopping sequence generated by PN code.
- Initially the binary user data is given as input to the MFSK transmitter. The modulated output of the MFSK transmitter then applied to the mixer.
- To the mixer the other input is provided from the digital frequency synthesizer.
- The digital frequency synthesizer generates the carriers as per the hopping pattern generated by the PN code generator.
- The output of the mixer is then passed to the bandpass filter.
- The filter is so designed that it selects the sum frequency components resulting from the multiplication process.
- The successive k bits of PN code drives the frequency synthesizer. Hence frequency synthesizer is able to generate 2^k different carrier frequencies.



(5A35)Fig. 1.19.1(a) : FHSS transmitter



(5A36)Fig. 1.19.1(b) : FHSS receiver

- As large bandwidth of few GHz range is required for FHSS technique, therefore coherent detection is possible only within each hop.
- This is because the frequency synthesizer is not able to maintain phase coherence over successive hops. Hence non coherent detection is used in this technology.
- At the receiver, the signal is first mixed with the output of the frequency synthesizer.
- The output of the frequency synthesizer is controlled by the PN code generator. The PN code used at transmitter and receiver has to be same. Hence with the same key PN code is generally locally generated at the receiver. Mixer removes the frequency hopping in the received signal.
- The output of the mixer is given to the bandpass filter and then sent for the non coherent detection.
- The single tone carrier frequency is called as chip in context with FHSS. Hence the chip rate is given by,

$$R_c = \max(R_h, R_s)$$

Where R_c = chip rate ;

R_h = hopping rate

R_s = symbol rate

- At each hop the MFSK carrier tone frequencies are separated in frequency by an integral multiple of the chip rate R_c, this indicates that the transmitted symbol will not produce an adjacent channel interference (from one filter output to adjacent one) or spill over or crosstalk in other M-1 noncoherent matched filters in the MFSK receiver.

Advantages of FHSS

1. It needs shorter acquisition time
2. Robust technology

Disadvantages of FHSS

1. It requires frequency synthesizers which increases complexity of the system.
2. Sharp cut off filtering is needed at the receivers.

Applications of FHSS

1. WLAN (wireless LAN) standards
2. WPAN (wireless PAN) standards like Bluetooth etc.

1.19.1 Types of FHSS Technique

GQ. Describe different types of FHSS.

- Depending on the hopping rate there are two types of FHSS.

1. Slow FHSS	2. Fast FHSS

1. Slow FHSS (SFH)

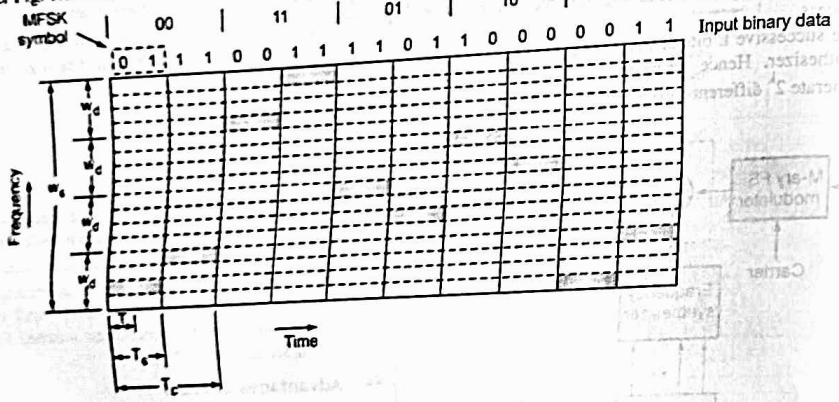
- Several modulation symbols are carried by single hop in slow FHSS. It means that it has N (number of bits) symbols per hop.
- Hence each symbol in slow FHSS is known as a chip.

In slow FHSS, $R_c = R_s = \frac{R_b}{K} \geq R_c$

Where, $k = \log_2 M$

- At each hop, the MFSK tone frequencies are separated by integer multiple of chip rate or symbol rate when $R_c = R_s$. This separation is necessary to provide desired degree of orthogonality between the frequencies and it also allows reliable noncoherent detection.
- Therefore, minimum bandwidth of an MFSK signal should be about MR_s.
- In this technique, the shortest uninterrupted waveform is nothing but the data symbol.

Refer Fig. 1.19.2(a).



(5A37)**Fig. 1.19.2 (a) : Slow FHSS waveforms**

- **Dwell time :** The time for which the receiver stays on the same frequency.
- Slow FHSS system has longer Dwell time. In the Fig. 1.19.2(a) one symbol of 2 bits are transmitted using single carrier frequency. After every symbol duration, the receiver hops to another carrier to send next MFSK symbol.

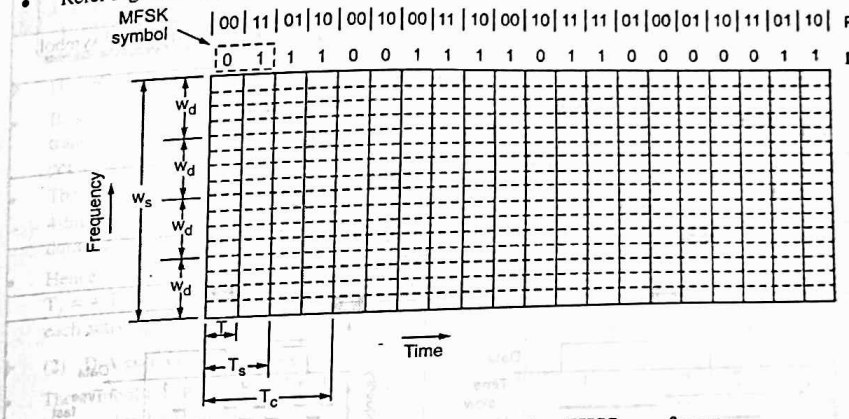
2. Fast FHSS (FFH)

- Several frequency hops are there to carry single symbol. It means that it has N hops per symbol.
- The shortest uninterrupted wave is that of a hop.
- Here each hop is a chip.
- In fast FHSS system MFSK is used in which $N = \log_2 M$ bits are used to determine which one of M frequencies should be used. [N = number of bits per symbol, M = number of different frequency tones used in MFSK]
- Generally jammers involve in two operations :
  (a) measurement of the spectral components of the transmitted signals and
  (b) retuning of the interfering signal to that portion of the frequency band.
- Therefore, it is necessary that the transmitted signal must be hopped to new carrier frequency before the jammer signal completes its above said operations.
- Detection process is bit different in fast FHSS as compared to slow FHSS. For detection purpose any one of the following two methods can be used.

(i) To detect the de-hopped MFSK symbol, each symbol separate decision is made, and rule of majority vote is applied.

(ii) For each FH/MFSK symbol, likelihood functions are determined as a function of the total signal received over k chips, and the largest one is selected.

- The detection method using the likelihood functions is more optimum as it reduces the probability of symbol error (E_b/N_0).
- In Fig 1.19.2(b), two carriers are used for transmission for one MFSK symbol. hence the hopping rate is more, and the dwell time is less.
- Refer Fig. 1.19.2(b).



(5A38)**Fig. 1.19.2(b) : Fast FHSS waveforms**

1.19.2 Comparison between DSSS and FHSS

GQ. Compare DSSS and FHSS.

Table 1.19.1 : Comparison between DSSS and FHSS

Sr. No.	Parameter	DSSS	FHSS
1.	Abbreviation	Direct sequence spread spectrum.	Frequency hopping spread spectrum.
2.	Definition	Wideband PN sequence is directly multiplied with the narrowband data sequence and wideband spreading code is obtained.	Wideband PN code is used to generate hopping pattern. Data bits are transmitted by changing carrier according to hopping pattern.
3.	Chip rate	$R_c = 1/T_c$	$R_c = \max(R_b, R_s)$
4.	Modulation technique used	BPSK	MFSK
5.	Interference immunity	Low	High
6.	Receiver complexity	More complex	Less complex
7.	Application	CDMA	Bluetooth technology makes use of fast FHSS