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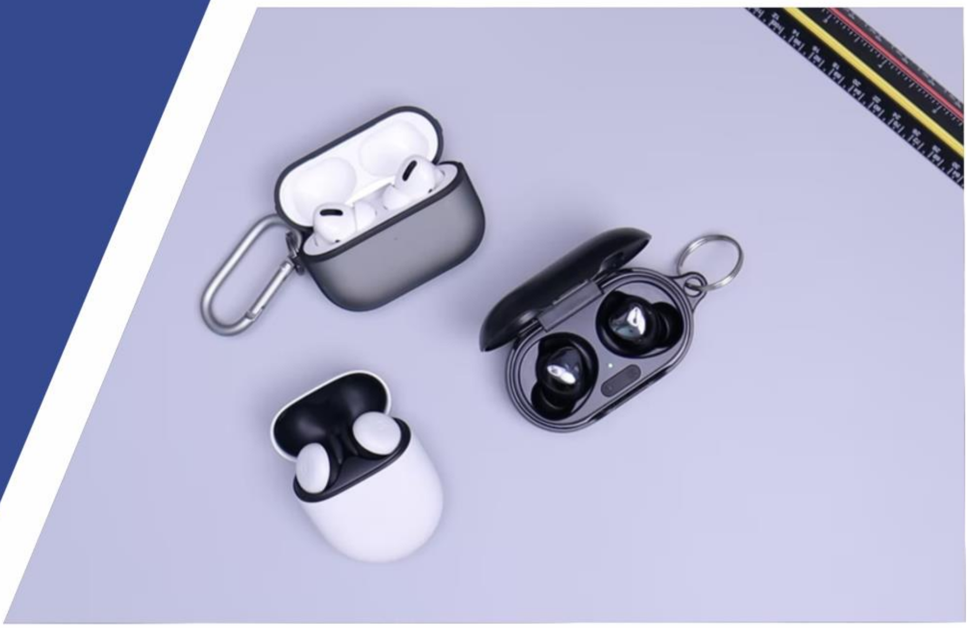

Wireless Communication I

Module 1

CIT 855 Wireless Communications I Module 1

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Unit 1 Introduction to Wireless Communication

1.0 Introduction

Wireless communication is experiencing its fastest growth period in history. This has been possible because of enabling technologies that permit widespread deployment.

Wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires". The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications). Wireless communication is generally considered to be a branch of telecommunications.

It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, satellite television and cordless telephones.

Wireless communication can be via:

- Radio frequency communication
- Microwave communication, for example long-range line-of-sight via highly Directional antennas, or short-range communication or
- Infrared (IR) short-range communication, for example from remote controls or via Infrared Data Association (IrDA).

2.0 Objectives

At the end of this unit, you should be able to:

- Define wireless communication
- Mention examples of wireless communication equipment
- State the application area of wireless communication
- Discuss the history of radio communication
- Identify the use of wireless technology
- State the classes of wireless.

3.0 Main Content

3.1 Concept of Wireless Communication

Wireless is a term used to describe telecommunication in which electromagnetic waves (rather than some form of wire) carry the signal over part or the entire communication path.

3.1.1 Wireless Equipment

Among the common examples of wireless equipment in use today include:

- **Cellular phones and pagers**: these provide connectivity for portable and mobile applications, both personal and business
- **Global Positioning System (GPS):** allows drivers of cars and trucks, captains of boats and ships, and pilots of aircraft to ascertain their location anywhere on earth
- **Cordless computer peripherals**: the cordless mouse is a common example; keyboards and printers can also be linked to a computer via wireless
- **Cordless telephone sets**: these are limited-range devices, not to be confused with cell phones
- **Home-entertainment-system control boxes**: the VCR control and the TV channel control are the most common examples; some hi-fi sound systems and FM broadcast receivers also use this technology
- **Remote garage-door openers**: one of the oldest wireless devices commonly use by consumers which are usually operated at radio frequencies
- **Two-way radios**: this includes Amateur and Citizens Radio Service, as well as business, marine, and military communications
- **Baby monitors**: these devices are simplified radio transmitter/receiver units with limited range
- **Satellite television**: allows viewers in almost any location to select from hundreds of channels
- **Wireless LANs or local area networks**: provide flexibility and reliability for business computer users.

3.1.2 Examples of Wireless Communication and Control

More specialised and exotic examples of wireless communications and control include:

- **Global System for Mobile Communication (GSM):** a digital mobile telephone system
- **General Packet Radio Service (GPRS):** a packet-based wireless communication service that provides continuous connection to the Internet for mobile phone and computer users.
- **Enhanced Data GSM Environment (EDGE):** a faster version of the Global System for Mobile (GSM) wireless service.
- **Universal Mobile Telecommunications System (UMTS):** a broadband, packet-based system offering a consistent set of services to mobile computer and phone users no matter where they are located in the world.
- **Wireless Application Protocol (WAP):** a set of communication protocols to standardise the way that wireless devices, such as cellular telephones and radio transceivers, can be used for internet access.
- **i-Mode**: the world's first "smart phone" for Web browsing, first introduced in Japan; provides colour and video over telephone sets.

3.1.3 Uses of Wireless Technology

Wireless technology is rapidly evolving, and is playing an increasing role in the lives of people throughout the world. In addition, increasing numbers of people are relying on the technology directly or indirectly.

The following situations justify the use of wireless technology:

- to span a distance beyond the capabilities of typical cabling
- to avoid obstacles such as physical structures
- to provide a backup communications link in case of normal network failure
- to link portable or temporary workstations
- to overcome situations where normal cabling is difficult or financially impractical, or
- to remotely connect mobile users or networks.

3.1.4 Classification of Wireless

Wireless can be divided into the following classes:

- **fixed wireless**: the operation of wireless devices or systems in homes and offices, and in particular, equipment connected to the Internet via specialised modems
- **mobile wireless**: the use of wireless devices or systems aboard motorised, moving vehicles; examples include the automotive cell phone and PCS (personal communications services)
- **portable wireless**: the operation of autonomous, battery-powered wireless devices or systems outside the office, home, or vehicle; examples include handheld cell phones and PCS units
- **IR wireless**: the use of devices that convey data via IR (infrared) radiation; employed in certain limited-range communications and control systems

3.1.5 Applications of Wireless Technology

- **Security systems:** wireless technology may supplement or replace hard wired implementations in security systems for homes or office buildings.
- **Television remote control:** modern televisions use wireless (generally infrared) remote control units but now radio waves are also used.
- **Cellular telephony (phones and modems):** these instruments use radio waves to enable the operator to make phone calls from many locations world-wide. They can be used anywhere there is a cellular telephone site to house the equipment that is required to transmit and receive the signal that is used to transfer both voice and data to and from these instruments.
- **WiFi:** Wi-Fi (for wireless fidelity) is a wireless LAN technology that enables laptop PC's, PDA's, and other devices to connect easily to the internet. Wi-Fi is less expensive and nearing the speeds of standard Ethernet and other common wire-based LAN technologies.
- **Wireless energy transfer:** wireless energy transfer is a process whereby electrical energy is transmitted from a power source to an electrical load that does not have a built-in power source, without the use of interconnecting wires.

- **Computer interface devices:** answering the call of customers frustrated with cord clutter, many manufactures of computer peripherals turned to wireless technology to satisfy their consumer base. Originally these units used bulky, highly limited transceivers to mediate between a computer and a keyboard and mouse, however more recent generations have used small, high quality devices, some even incorporating Bluetooth

3.2 Brief History of Wireless Communications

Before the "Birth of Radio" 1867-1896

- 1867 - Maxwell predicts existence of electromagnetic (EM) waves
- 1887 - Hertz proves existence of EM waves; first spark transmitter generates a spark in a receiver several meters away
- 1890 - Branly develops coherer for detecting radio waves
- 1896 - Guglielmo Marconi demonstrates wireless telegraph to English telegraph office

"The Birth of Radio"

- 1897 – "The Birth of Radio" - Marconi awarded patent for wireless telegraph
- 1897 - First "Marconi station" established on Needles Island to communicate with English coast
- 1898 - Marconi awarded English patent no. 7777 for tuned communication
- 1898 - Wireless telegraphic connection between England and France established

Transoceanic Communication

- 1901 - Marconi successfully transmits radio signal across Atlantic Ocean from Cornwall to Newfoundland
- 1902 - First bidirectional communication across Atlantic
- 1909 - Marconi awarded Nobel Prize for physics

Voice over Radio

- 1914 - First voice over radio transmission
- 1920s - Mobile receivers installed in Police cars in Detroit
- 1930s - Mobile transmitters developed; radio equipment occupied most of Police car trunk
- 1935 - Frequency modulation (FM) demonstrated by Armstrong
- 1940s - Majority of Police systems converted to FM

Birth of Mobile Telephony

- 1946 - First interconnection of mobile users to public switched telephone network (PSTN)
- 1949 – Federal Communication Commission (FCC) recognises mobile radio as new class of service
- 1940s - Number of mobile users > 50,000
- 1950s - Number of mobile users > 500,000
- 1960s - Number of mobile users > 1,400,000
- 1960s - Improved Mobile Telephone Service (IMTS) introduced; supports full-duplex, auto dial, auto trunking

- 1976 - Bell Mobile Phone has 543 pay customers using 12 channels in the New York City area; waiting list is 3700 people; service is poor due to blocking

Cellular Mobile Telephony

- 1979 – NTT Communications Corporation Japan deploys first cellular communication system
- 1983 - Advanced Mobile Phone System (AMPS) deployed in US in 900 MHz band: supports 666 duplex channels
- 1989 - Groupe Spècial Mobile defines European digital cellular standard, GSM
- 1991 - US Digital Cellular phone system introduced
- 1993 - IS-95 code-division multiple-access (CDMA) spread- spectrum digital cellular system deployed in US
- 1994 - GSM system deployed in US, labelled "Global System for Mobile Communications"

PCS and Beyond

- 1995 - Federal Communication Commission (FCC) auctions off frequencies in Personal Communications System (PCS) band at 1.8 GHz for mobile telephony
- 1997 - Number of cellular telephone users in U.S. > 50,000,000
- 2000 - Third generation cellular system standards. Bluetooth standards.

3.3 Mobile Radio Communication

Radio is the technology and practice that enables the transmission and reception of information carried by long-wave electromagnetic radiation. Radio makes it possible to establish wireless two-way communication between individual pairs of transmitter and receiver, and it is used for one-way broadcasts to many receivers. Radio signals can carry speech, music, telemetry, or digitally-encoded entertainment.

Radio is used by the general public, within legal guidelines, or it is used by private business or governmental agencies. Cordless telephones are possible because they use low-power radio transmitters to connect without wires. Cellular telephones use a network of computer-controlled low power radio transmitters to enable users to place telephone calls away from phone lines.

Radio receivers recover modulation information in a process called demodulation or detection. The radio carrier is discarded after it is no longer needed. The radio carrier's cargo of information is converted to sound using a loudspeaker or headphones.

3.3.1 Evolution of Mobile Radio Communication

In the 19th Century, in Scotland, James Clerk Maxwell described the theoretical basis for radio transmissions with a set of four equations known ever since as Maxwell's Field Equations. Maxwell was the first scientist to use mechanical analogies and powerful mathematical modeling to create a successful description of the physical basis of the electromagnetic spectrum. His analysis provided the first insight into the phenomena that would eventually become radio.

Not long after Maxwell's remarkable revelation about electromagnetic radiation, Heinrich Hertz demonstrated the existence of radio waves by transmitting and receiving a microwave radio signal over a considerable distance. Hertz's apparatus was crude by modern standards but it was important because it provided experimental evidence in support of Maxwell's theory.

Guglielmo Marconi developed a wireless telegraphy which was able to send a long-wave radio signal across the Atlantic Ocean.

The first radio transmitters to send messages, Marconi's equipment included, used high-voltage spark discharges to produce the charge acceleration needed to generate powerful radio signals. Spark transmitters could not carry speech or music information. They could only send coded messages by turning the signal on and off using a telegraphy code similar to the landline Morse code.

Spark transmitters were limited to the generation of radio signals with very-long wavelengths, much longer than those used for the present AM-broadcast band in the United States. The signals produced by a spark transmitter were very broad with each signal spread across a large share of the usable radio spectrum. Only a few radio stations could operate at the same time without interfering with each other. Mechanical generators operating at a higher frequency than those used to produce electrical power were used in an attempt to improve on the signals developed by spark transmitters.

A technological innovation enabling the generation of cleaner, narrower signals was needed. Electron tubes provided that breakthrough, making it possible to generate stable radio frequency signals that could carry speech and music. Broadcast radio quickly became established as source of news and entertainment.

Continual improvements to radio transmitting and receiving equipment opened up the use of successively higher and higher radio frequencies.

Short waves, as signals with wavelengths less than 200m were found to be able to reach distant continents. International broadcasting on shortwave frequencies followed, allowing listeners to hear programming from around the world.

The newer frequency-modulation system, FM, was inaugurated in the late 1930s and for more than 25 years struggled for acceptance until it eventually became the most important mode of domestic broadcast radio. FM offers many technical advantages over AM, including an almost complete immunity to the lightning-caused static that plagues AM broadcasts. The FM system improved the sound quality of broadcasts tremendously, far exceeding the fidelity of the AM radio stations of the time. The FM system was the creation of E. H. Armstrong, perhaps the most prolific inventor of all those who made radio possible.

In the late 1950s, stereo capabilities were added to FM broadcasts along with the ability to transmit additional programmes on each station that could not be heard without a special receiver. A very high percentage of FM broadcast stations today carry these hidden programmes that serve special audiences or markets. This extra programme capability, called SCA for Subsidiary Communications Authorisation, can be used for stock market data, pager services, or background music for stores and restaurants.

3.3.2 Radio and the Electromagnetic Spectrum

Radio utilises a small part of the electromagnetic spectrum, the set of related wave-based phenomena that includes radio along with infrared light, visible light, ultraviolet light, x rays, and gamma rays. Radio waves travel at the velocity of electromagnetic radiation. A radio signal moves fast enough to complete a trip around the earth in about 1/7 second.

3.3.3 How Radio Signals Are Created

If you jiggle a collection of electrons up and down one million times a second, then a 1-MegaHertz radio signal will be created. Change the vibration frequency and the frequency of the radio signal will change. Radio transmitters are alternating voltage generators. The constantly changing voltage from the transmitter creates a changing electric field within the antenna. This alternating field pushes and pulls on the conduction electrons in the wire that are free to move. The resulting charge acceleration produces the radio signal that moves away from the antenna. The radio signal causes smaller sympathetic radio frequency currents in any distant electrical conductor that can act as a receiving antenna.

3.3.4 Radio Wavelengths, Frequencies and Antennas

Each radio signal has a characteristic wavelength just as it is in sound wave. The higher the frequency of the signal, the shorter will be the wavelength. Antennas for low-frequency radio signals are long. Antennas for higher frequencies are shorter; to match the length of the waves they will send or receive.

It is a characteristic of all waves, not just radio signals, that there is greater interaction between waves and objects when the length of the wave is comparable to the object's size. Just as only selected sound wavelengths fit easily into the air column inside a bugle, only chosen frequencies will be accepted by a given antenna length. Antennas, particularly transmitting antennas, function poorly unless they have a size that matches the wavelength of the signal presented to them. The radio signal must be able to fit on the antenna as a standing wave. This condition of compatibility is called resonance. If a transmitter is able to "feed" energy into an antenna, the antenna must be resonant or it will not "take power" from the transmitter. A receiver antenna is less critical, since inefficiency can be compensated by signal amplification in the receiver, but there is improvement in reception when receiving antennas are tuned to resonance.

If an antenna's physical length is inappropriate, capacitors or inductors may be used to make it appear electrically shorter or longer to achieve resonance.

3.3.5 Radio Signals and Energy

Energy is required to create a radio signal. Radio signals use the energy from the transmitter that accelerates electric charge in the transmitting antenna. A radio signal carries this energy from the transmitting antenna to the receiving antenna. Only a small fraction of the transmitter's power is normally intercepted by any one receiving antenna, but even a vanishingly-small received signal can be amplified electronically millions of times as required.

3.4 Differences between Wired and Wireless

- The main difference between wired and wireless data communication infrastructure is the existence of physical cabling.
- A wired network uses wires (cables) to connect devices whereas a wireless network uses radio waves.
- Wired networks are easy to set up and troubleshoot whereas wireless networks are comparatively difficult to set up, maintain and troubleshoot.
- Wired networks make you immobile while wireless ones provide you with convenience of movement.
- Wired network proves expensive when covering a large area because of the wiring and cabling while wireless network do not involve this cost.
- Wired networks have better transmission speeds than wireless ones.
- In wired networks, a user does not have to share space with other users and thus gets dedicated speed while in wireless networks the same connection may be shared by multiple users.

Self-Assessment Exercise

i. What is wireless communication?
ii. Why are antennas on cell phones smaller than antenna on your radio?

4.0 Conclusion

This unit has introduced you to the concept, applications and origination of wireless communication. You have also been informed on how radio signals are created.

5.0 Summary

The main points in this unit include the following:

- wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires"
- it encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), wireless networking, etc.
- radio is the technology and practice that enables the transmission and reception of information carried by long-wave electromagnetic radiation
- Marconi successfully transmits radio signal across Atlantic Ocean from Cornwall to Newfoundland
- the main difference between wired and wireless data communication infrastructure is the existence of physical cabling.

6.0 Self-Assessment Exercise

i. Discuss the evolution of radio communication
ii. Why are car antennas about the same size as TV antenna?
iii. Mention five examples of wireless communication equipment.
iv. List five uses of wireless technology

v. Briefly explain the application area of wireless communication
vi. Outline the four classes of wireless

7.0 References/Further Reading

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Unit 2 Modern Wireless Communication System

1.0 Introduction

As you have learnt in the previous unit, the field of mobile communications has experienced various advanced developments. In fact, it can be said that mobile radio communications industry has grown up during the last ten years. There are various factors which are responsible for speedy developments in mobile or wireless communications. These factors are digital and RF fabrication improvements, new large scale circuit integration and other miniaturisation technologies.

2.0 Objectives

At the end of this unit, you should be able to:

- explain a cellular system
- state the basic components of cellular system
- discuss the wireless communication generations.

3.0 Main Content

3.1 Introduction to Cellular System

A cellular system is a radio network made up of a number of radio cell (or just cells) each served by at least one fixed-location transceiver known as a cell site or base station. These cells cover different land areas to provide radio coverage over a wider area than the area of one cell, so that a variable number of portable transceivers can be used in any one cell and moved through more than one cell during transmission.

Cellular systems offer a number of advantages including but not limited to the following over alternative solutions:

- increased capacity
- reduced power usage
- larger coverage area
- reduced interference from other signals

3.1.1 Basic Cellular System

A basic cellular system is made up of three parts:

i. a mobile unit
ii. a cell site
iii. Mobile Telephone Switching Office (MTSO) and with connections to link the three subsystems:

- **Mobile Unit**: a mobile telephone unit contains a control unit, a transceiver and an antenna system

- **Cell Site:** the cell site provides interface between the MTSO and the mobile unit. It has control unit, radio cabinets, antennas, a power plant and data terminals.
- **MTSO:** the switching office, the central coordinating element for all cell sites, contains the cellular processor and cellular switch. It interfaces with telephone company zone offices; controls call processing and handle billing activities.
- **Connections:** as a matter of fact, the radio and high speed data links connect the three subsystems. Each mobile unit can only use one channel at a time for its communication link.

However, the channel is not fixed i.e. it can be any one in the entire band assigned by the serving area, with each site having multi-channel capabilities that can connect simultaneously to many mobile units.

In addition to the above:

- the MTSO is the heart of the cellular mobile system. Its processor provides central coordination and cellular administration.
- the cellular switch, which can be either analog or digital, switches calls to connect mobile subscribers to other mobile subscribers and to the nationwide telephone network. It uses voice trucks similar to telephone company interoffice voice trucks. It also contains data links providing supervision links between the processor and the switch and between the cell sites and the processor.
- the radio link carries the voice and signal between the mobile unit and the cell site.
- the high-speed data links cannot be transmitted over the standard telephone trucks and therefore must use either microwave links or T-carriers (wire lines).
- microwave radio links or T-carriers carry both voice and data between the cell site and the MTSO.

3.2 Wireless Communications Standards/Generations

3.2.1 First Generation Cellular Systems

The first generation (1G) wireless communications stems use frequency division multiple access (FDMA) as the multiple access technology.

FDMA is an analog transmission technique that is inherently narrowband. As a matter of fact, the first generation cellular systems make use of analog FM scheme for speech transmission. The individual calls use different frequencies and share the available spectrum through a particular multiple access technique known as frequency-division multiplexing access (FDMA).

3.2.2 Second Generation Cellular Systems

The second generation (2G) wireless systems use digital transmission. The multiple access technology is both time division multiple access (TDMA) and code division multiple access (CDMA). Although, the second generation wireless systems offer higher transmission rates with greater flexibility than the first generation systems, they are nevertheless narrowband systems. The service offered by both 1G and 2G system is predominantly voice. The digital technology allows greater sharing of the radio hardware in the base station among the multiple users, and provides a larger capacity to support more users per base station per

Megahertz (Mhz) of spectrum as compared to analog system. As a matter of fact, digital systems offer a number of advantages over analog system.

Digital systems provide:

- flexibility for supporting multimedia services
- flexibility for capacity expansion
- reduction in Radio Frequency (RF) transmit power
- encryption for communication privacy
- reduction in system complexity.

3.2.3 Third Generation Cellular Systems

The third generation (3G) standard is based on CDMA as the multiple access technology. With a transmission rate of up to 2 megabits per second (Mbps), 3G systems are wideband, and are expected to support multimedia services. It is likely that the third generation cellular systems will be equipped with the infrastructure to support Personal Communications Systems (PCS). The network infrastructure support will likely include the following:

- public land mobile networks (PLMNs)
- mobile Internet Protocol (Mobile IP)
- wireless asynchronous transfer mode (WATM) networks, and
- low earth orbit (LEO) satellite network

3.2.4 Fourth Generation Cellular Systems

During the last 20 years, wireless networks have evolved from an analog, single medium (voice), and low data rate (a few kilobits per second) system to the digital, multimedia, and high data rate (ten to hundreds of megabits per second) system of today. Future systems will be based on user's demands as the fourth-generation (4G) cellular system applications which need high speed data rates to achieve them.

In July 2003, the International Telecommunications Union (ITU) made requirements for 4G system which are:

i.at a standstill condition, the transmission data rate should be 1 Gbps.

ii.at a moving condition, the transmission data rate should be 100 Mbps.

Any proposed system that can meet these requirements with less bandwidth and higher mobile speed will be considered. A potential 4G system could be used in the family of OFDM (Orthogononal Frequency Division Multiplexing), because the Wireless Metropolitan Area Network (WMAN) using OFDM can have a transmission data rate of 54-70 Mbps, which is much higher than what the Code Division Multiple Access (CDMA) system can provide.

Self-Assessment Exercise

Write briefly on the Fourth Generation (4G) Systems.

4.0 Conclusion

In this unit, you have learnt the concepts of a cellular system and the generations/standard of wireless communications.

5.0 Summary

The main points in this unit are:

- a cellular system is a radio network made up of a number of radio cell (or just cells) each served by at least one fixed-location transceiver known as a cell site or base station
- a basic cellular system is made up of three parts: a mobile unit, cell site, and Mobile Telephone Switching Office (MTSO) and with connections to link the three subsystems
- wireless communications systems that have been in deployment for sometime are those of the first generation and second generation. Third generation systems are also currently under deployment, but continue to evolve.

6.0 Self-Assessment Exercise

i. Discuss on the first, second and third generation wireless communication networks
ii. What do you understand about a basic cellular system?

7.0 Reference/Further Reading

Sharma, S. (2006). *Wireless & Cellular Communications*. New Delhi: S. K. Kataria & Sons.

Unit 3 Wireless Data Network

1.0 Introduction

In this unit, we are going to discuss various issues related to wireless data networks in brief.

2.0 Objectives

At the end of this unit, you should be able to:

- discuss the wireless data network
- differentiate between PAN, LAN, MAN and WAN
- illustrate with diagram wireless data network.

3.0 Main Content

3.1 Wireless Data Networks

Wireless data network can be classified according to their coverage areas as: Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN).

3.1.1 Personal Area Network (PAN)

Personal Area Network – PAN – is a computer network organised around an individual person. It is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one's person. Personal area network typically involve a mobile computer, a cell phone and/or a handheld computing device such as a PDA. You can use these networks to transfer files including email and calendar appointments, digital photos and music. The smallest coverage area, where the network is called wireless personal area network (PAN), is limited to an office. A cell of such a small size would enable connection of computers or electronic input devices. A wireless PAN network can use Bluetooth. Personal area networks generally cover a range of less than 10 meters (about 30 feet).

The channel bandwidth is 200 kHz using Quadrature Amplitude Modulation (QAM). The data rate can be 1 Mbps. It is a short wire replacement for wireless. Today, most of cell phones are equipped with Bluetooth.

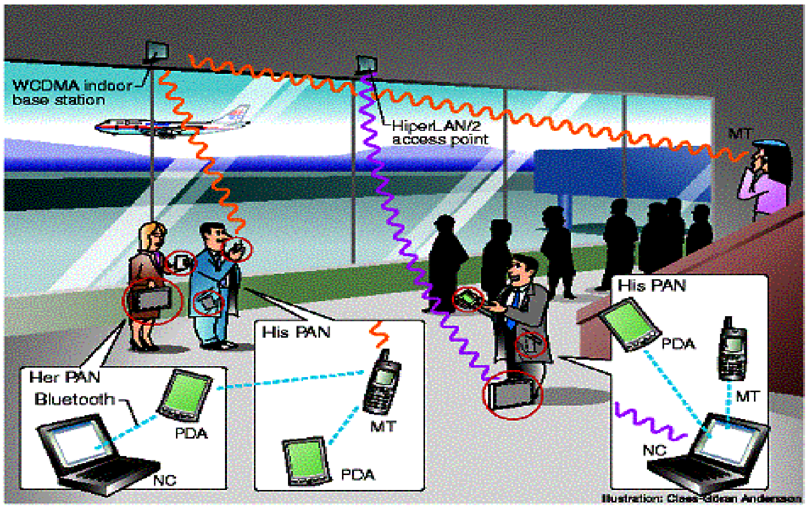


Fig.3.1: Personal Area Network

3.1.2 Local Area Network (LAN)

Local Area Network (LAN) is a computer network covering a small physical area, like a home, office, or small group of buildings, such as a school, or an airport. Wireless local area network (LAN) connects users on a particular floor of a building. For example, two computers linked together at home are the simplest form of a LAN while several hundred computers cabled together across several buildings at school form a more complex LAN. In 1990s, wireless LANs was divided into the radio-frequency (RF) systems and infrared (IR) systems specified by the Federal Communication Commission (FCC). The RF systems are divided into the licensed non-spread-spectrum (NSS) and the unlicensed spread spectrum (SS). In the unlicensed SS, it requires a minimum of 50 and 75 hopping frequency at 910MHz and 2.5GHz, respectively, or achieved by a spread-spectrum modulation exceeding a spreading factor of 10m in direct sequence systems. LANs are usually connected with coaxial or CAT5 cable.

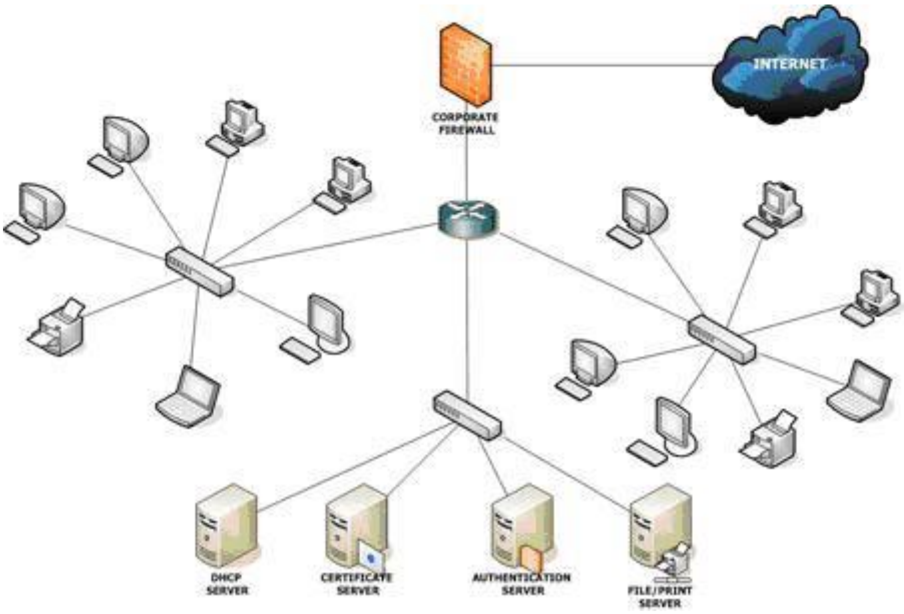


Fig.3.2: LAN illustration. Image Source: Network Elements

Source: **www.networkelements.co.uk/media/lan.jpg**

3.1.3 Metropolitan Area Network (MAN)

A Metropolitan Area Network (MAN) is a network that connects two or more local area networks or campus area networks together but does not extend beyond the boundaries of the immediate town/city. It connects the residents and visitors to a city. MANs, are large computer networks usually spanning a city. **MANs** connect multiple geographically nearby LANs to one another (over an area of up to a few dozen kilometers) at high speeds. Thus, a MAN lets two remote nodes communicate as if they were part of the same local area network Routers, switches and hubs are connected to one another with high speed links (usually fibre optic cables) to create a metropolitan area network. MANs are usually connected with fibre-optic cable, microwave transceivers or leased data landlines.

There are three important features which distinguish MANs from LANs or WANs:

- The network size falls intermediate between LANs and WANs. A MAN typically covers an area of between 5 and 50 km diameter. Many MANs cover an area the size of a city, although in some cases
- A MAN (like a WAN) is not generally owned by a single organisation. The MAN, its communications links and equipment are generally owned by either a consortium of users or by a single network provider who sells the service to the users. This level of service provided to each user must therefore be negotiated with the MAN operator, and some performance guarantees are normally specified.
- A MAN often acts as a high speed network to allow sharing of regional resources (similar to a large LAN). It is also frequently used to provide a shared connection to other networks using a link to a WAN.

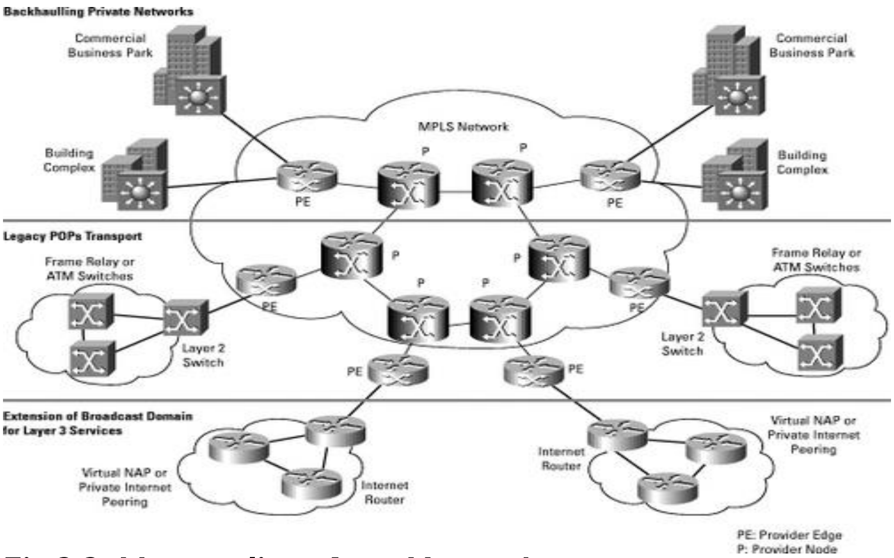
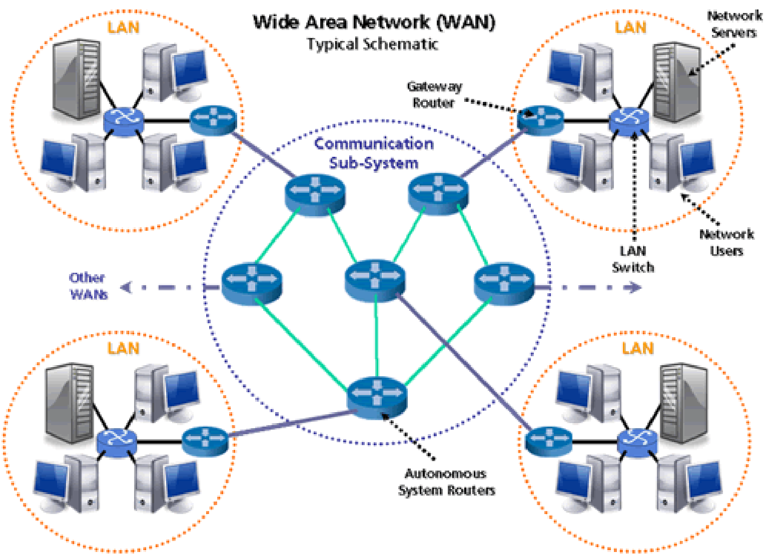


Fig.3.3: Metropolitan Area Network

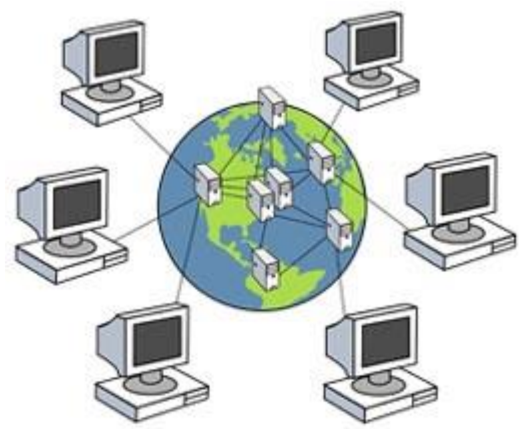
Source **[rkcablenet.tradeindia.com/Exporters_Suppliers]**

3.1.4 Wide Area Network (WAN)

Wide Area Network (WAN) is a computer network that covers a broad area (i.e., any network whose communications links cross metropolitan, regional, or national boundaries). WAN is a data communications network that covers a relatively broad geographic area (i.e. one city to another and one country to another country) and that often uses transmission facilities provided by common carriers, such as telephone companies. The largest and most well-known example of a WAN is the Internet. WANs are used to connect LANs and other types of networks together, so that users and computers in one location can communicate with users and computers in other locations**.** Typically, a WAN consists of two or more Local Area networks (LANs) connected by a communication sub-system, which is usually comprised of Autonomous System (AS) routers. For example, a national banking organisation may use a WAN to connect all of its branches across the country. WANs are usually connected using the Internet, ISDN landlines or satellite.



(a*)* ***Source: www.air-stream.org.au/wan***



(b) **Source:**
www.computernetworks.com/WAN.cfm

Fig.3.4 (a & b): Wide Area Network (WAN)

Self-Assessment Exercise

Mention four classifications of wireless data network.

4.0 Conclusion

The wireless data network can be classified according to their coverage areas as:

- Personal Area Network (PAN)
- Local Area Network (LAN)
- Metropolitan Area Network (MAN)
- Wide Area Network (WAN)

5.0 Summary

In this unit, you have learnt that:

- Personal Area Network (PAN) is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one's person
- LAN means Local Area Network, and is generally restricted to a single building
- Local Area Network (LAN) is a computer network covering a small physical area, like a home, office, or small group of buildings, such as a school, or an airport

- MAN means Metropolitan Area Network, and usually encompasses multiple sites in the same city. It connects the residents and visitors to a city

- WAN means Wide Area Network and can cover any area. It connects the entire country.

6.0 Self-Assessment Exercise

i. Discuss the wireless LAN
ii. Differentiate between MAN and WAN
iii. Illustrate with diagram a Local Area Network

7.0 References/Further Reading

Sharma, S. (2006). *Wireless & Cellular Communications*. New Delhi: S. K. Kataria & Sons.

Tse, D. & Viswanath, P. (2005). *Fundamentals of Wireless Communication*. Cambridge University Press.

Unit 4 The Cellular Concept

1.0 Introduction

Cellular systems are widely used today and cellular technology needs to offer very efficient use of the available frequency spectrum. With billions of mobile phones in use around the globe today, it is necessary to refuse the available frequencies many times over without mutual interference of one cell phone to another. It is this concept of frequency reuse that is at the heart of cellular technology.

2.0 Objectives

At the end of this unit, you should be able to:

- explain the cell concept
- discuss the use of frequency reuse concept
- mention different types of cell
- state the importance of hexagonal cell shape over other shapes.

3.0 Main Content

3.1 Concept of Cellular Communications

The limitation in spectral width and the maximum number of user (i.e. system capacity) that can be supported in a wireless mobile system is an important performance measure. If a single transmitter is used to cover a large geographical area (a single small area called a cell that is served by a single base station, or a cluster of cells), a very high power transmitter and very high antenna would be required. With a single high power transmitter, all users will share the same set of frequencies, or radio channels. If the same set of radio resources were assigned to serve a smaller geographical area and then reused to serve another small geographical area, it would be possible to expand the system capacity (i.e. the number of users).The geographical regions that use the same set of radio frequencies must be physically separated from each other so that the power level of the signal that spills out from one region to a neighbouring region does not produce unacceptable interference. This way of replicating identically structured and operated geographical regions gives rise to the concept of cellular communications.

3.1.1 Cell Fundamentals

A single small area is called a cell. The cell shape can be of only three types of regular polygons, equilateral triangle, square, and regular hexagon.

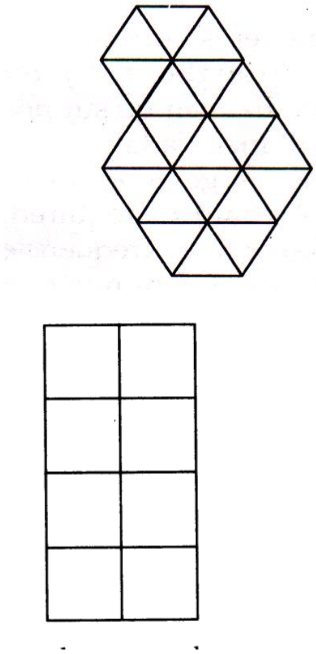


Fig.4. I: Triangular and Rectangular Cells

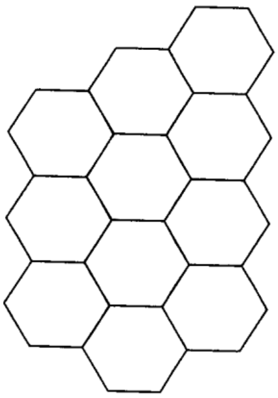


Fig. 4.2: Regular Hexagon

The hexagonal cell is the closest approximation to a circle among these three and has been used traditionally for system design. The reason being that among the three shapes mentioned, for a given radius (largest possible distance between the polygon center and its edge) the hexagon has the largest area. When using the hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell or on three of the six cell vertices.

3.1.2 Cell Size

Even though the number of cells in a cluster in a cellular system can help govern the number of users that can be accommodated, by making all the cells smaller, it is possible to increase the overall capacity of the cellular system. However a greater number of transmitter receiver or base stations are required if cells are made smaller and this increases the cost of the operator. Accordingly, in areas where there are more users, small low power base stations are installed.

The different types of cells are given different names according to their size and function:

- **Macro Cells**: are large cells that are usually used for remote or sparsely populated areas. These may be 10km or possibly more in diameter.
- **Micro Cells:** are those that are normally found in densely populated areas which may have a diameter of around 1km
- **Pico cells:** are generally used for covering very small areas such as particular areas of buildings, or possibly tunnels where coverage from a larger cell in the cellular system is not possible. Obviously for small cells, the power levels used by the base stations are much lower and the antennas are not positioned to cover wide areas. In this way the coverage is minimised and the interference to adjacent cell is reduced.
- **Selective Cells:** may be used where full 360 degree coverage is not required. They may be used to fill in a hole in the coverage in the cellular system, or to address a problem such as the entrance to a tunnel, etc.
- **Umbrella Cells:** is sometimes used in instances such as those where a heavily used road crosses an area where there are micro cells. Under normal circumstances this would result in a large number of handovers as people driving along the road would quickly cross the micro cells. An umbrella cell would take in the coverage of the micro cells (but use different channels to those allocated to the micro cells). However, it would enable those people moving along the road to be handled by the umbrella cell and experience fewer handovers than if they had to pass from one micro cell to the next.

Fig.4.3: Cell Size

Decreasing cell size gives:

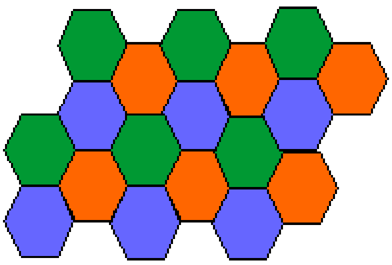
- increased user capacity
- increased number of handovers per call
- increased complexity in locating the subscriber
- lower power consumption in mobile terminal: so it gives longer talk time, safer operation.

3.1.3 Cellular Frequency Reuse

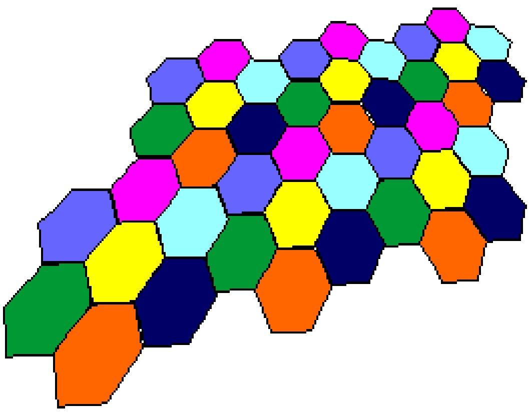
Frequency reuse is a technique of reusing frequencies and channels within a communications system to improve capacity and spectral efficiency. Frequency reuse is one of the fundamental concepts in which commercial wireless systems are based that involves the partitioning of an RF radiating area (cell) into segments of a cell. One segment of the cell uses a frequency that is far enough away from the frequency in the bordering segment that does not provide interference problems.

In the cellular concept, frequency allocated to the service are reused in a regular pattern of areas, called 'cells', each covered by one base station.

Every cellular base station is assigned a group of radio channels which are used within a small geographical area called a cell. The base station antennas are designed to achieve the desired coverage within a particular cell. In mobile-telephone system these cells are usually hexagonal. To ensure that the mutual interference between users remains below harmful level, adjacent cells use different frequencies. In fact, a set of C different frequencies ($f_1 \ldots f_c$) are used for each cluster of C adjacent cells. Cluster patterns and the corresponding frequencies are re-used in a regular pattern over the entire service area.

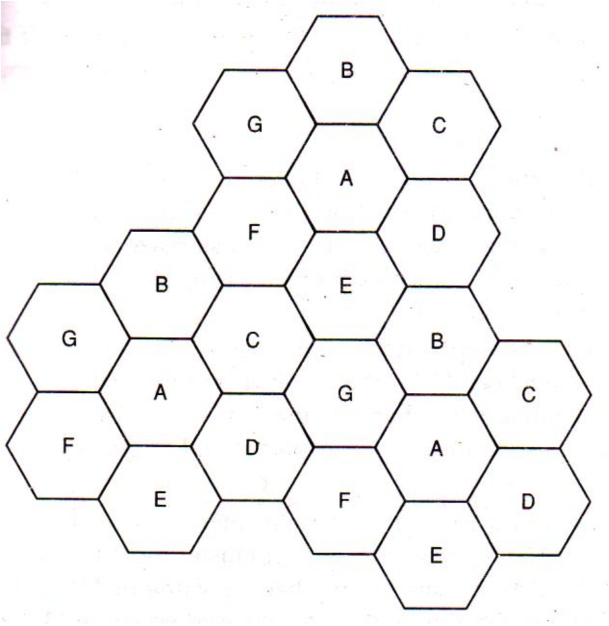


(a): Frequency reuse plan for *C* = 3, with hexagonal cells. (*i*=1, *j* =1)



(b): Frequency reuse plan for *C* = 7 (*i*=2, *j* =1).

The total bandwidth for the system is *C* times the bandwidth occupied by a single cell.



(c) Fig. 4.4 (a-c): Illustration of Cellular Frequency Reuse Concept

Source*: *Linnartz J.M.G (1997)

3.1.4 Cell Planning

In the practice of cell planning, cells are not hexagonal as considered in the theoretical studies. However, propagation over irregular terrain leads to quite different cell shapes and cell sizes. Computer methods are being used for optimised planning of base station locations and cell frequencies. Path loss and link budgets are computed from the terrain features and antenna data. This determines the coverage of each base station and interference to other cells.

In the initial phases of operating a cellular network, the planners typically aim at maximum coverage. Subscribers should be able to reach a base station anywhere. The map of the service coverage should not contain dark spots where the service is not available. Base stations are located such that they reach as many locations as possible, e.g. typically on hill tops.

Later on, when the number of subscribers increases, there is a need to optimse the capacity. Cell size should be as small as possible to accommodate as many different cell areas as possible. The effect that hills can shield on signals and avoid propagation into other valleys can be used as advantage. It allows that frequencies are reused in nearby valleys, particularly if base station are not located at the hill tops but in the valleys.

Effect of Traffic Density

An important aspect is the distribution of traffic. Cell sizes need to be smaller in areas with more traffic. The erlang theory addresses the amount of traffic that can be carried over a given number of channels, at a given blocking rate. If a GSM operator faces blocking rates that are too large in a certain area, he could for instance:

- split the cell into two cells with disjoint coverage areas, for instance by using two sectors from the same mast, or by using two separate base station locations
- install equipment for a second GSM carrier, for 8 telephone channels. The old and new carriers have the same coverage and together provide 16 voice channels.

The first option is more efficient from a frequency scarcity point of view. In both cells, the 8 channels can carry 3.13 erlang at a blocking rate of 1%. In the second case, the 16 channels can carry 8.8 erlang at 1% blocking rate. Note that this is significantly more than 2 times 3.13 erlang.

3.1.5 Mobile Phone Networks

The most common example of a cellular network is a mobile phone (cell phone) network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station), or transmitting tower. Radio waves are used to transfer signals to and from the cell phone.

Large geographic areas (representing the coverage range of a service provider) may be split into smaller cells to avoid line-of-sight signal loss and the large number of active phones in an area. In cities, each cell site has a range of up to approximately ½ mile, while in rural areas; the range is approximately 5 miles. Many times in clear open areas, a user may receive signals from a cell site 25 miles away. All of the cell sites are connected to cellular telephone exchanges "switches", which connect to a public telephone network or to another switch of the cellular company.

As the phone user moves from one cell area to another cell, the switch automatically commands the handset and a cell site with a stronger signal (reported by each handset) to switch to a new radio channel (frequency). When the handset responds through the new cell site, the exchange switches the connection to the new cell site.

With CDMA, multiple CDMA handsets share a specific radio channel.

The signals are separated by using a pseudonoise code (PN code) specific to each phone. As the user moves from one cell to another, the handset sets up radio links with multiple cell sites (or sectors of the same site) simultaneously. This is known as "soft handoff" because, unlike with traditional cellular technology, there is no one defined point where the phone switches to the new cell.

Modern mobile phone networks use cells because radio frequencies are limited and shared resource. Cell-sites and handsets change frequency under computer control and use low power transmitters so that a limited number of radio frequencies can be simultaneously used by many callers with less interference.

Since almost all mobile phones use cellular technology, including GSM, CDMA, and AMPS (analog), the term "cell phone" is used interchangeably with "mobile phone". However, satellite phones are mobile phones that do not communicate directly with a ground-based cellular tower, but may do so indirectly by way of a satellite.

There are different digital cellular technologies, including: Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Code Division Multiple

Access (CDMA), Evolution-Data Optimized (EV-DO), Enhanced Data Rates for GSM Evolution (EDGE), 3GSM, Digital Enhanced Cordless Telecommunications (DECT), Digital AMPS (IS-136/TDMA), and Integrated Digital Enhanced Network (iDEN).

3.1.6 Concept of Cell Cluster

When devising the infrastructure technology of a cellular system, the interference between adjacent channels is reduced by allocating different frequency bands or channels to adjacent cells so that their coverage can overlap slightly without causing interference. In this way cells can be grouped together in what is termed a cluster. A group of cells that use different set of frequencies in each cell is called a Cell Cluster. Let N be the cluster size in terms of the number of cells within it and K be the total number of available channels without frequency reuse. The N cells in the cluster would then utilise all K available channels. In this way, each cell in the cluster contains one-Nth of the total number of available channels. In this sense, N is also referred to as the frequency reuse factor of the cellular system.

Seven is a convenient number of cells that can be in a cluster, but there are number of conflicting requirements that need to be balanced when choosing the number of cells in a cluster for a cellular system:

- limiting interference levels
- number of channels that can be allocated to each cell site.

It is necessary to limit the interference between cells having the same frequency. The topology of the cell configuration has a large impact on this. The larger the number of cells in the cluster, the greater the distance between cells sharing the same frequencies. In the ideal world it might be good to choose a large number of cells to be in each cluster. Unfortunately there are only a limited number of channels available.

This means that the larger the number of cells in a cluster, the smaller the number available to each cell, and this reduces the capacity. This means that there is a balance that needs to be made between the number of cells in a cluster, and the interference levels and the capacity that is required.

(a)Capacity Increase by Frequency Reuse Concept

Let us consider that each is allocated J channels ($J \leq K$). If the K channels are divided among the N cells into unique and disjoint channel groups, each with J channels, then we have

$$K = J\,N$$

N cells in a cluster use the complete set of available frequencies while K is the total number of available channel. By decreasing the cluster size N, it is possible to increase the capacity per cell. The cluster can be replicated many times to form the entire cellular communication system.

Let M be the number of times the cluster is replicated and C be the total number of channels used in the entire cellular system with frequency reuse. C is then the system capacity and is given by

$$C = M\,J\,N$$

If M is increased, the system capacity C will increase.

Self-Assessment Exercise

Given a cellular system which has a total of 1001 radio channels available for handling traffic and given the area of a cell is 6 km^2 and the area of the entire system is 2100 km^2.

i. Calculate the system capacity if the cluster size is 7.
ii. How many times would the cluster of size 4 have to be replicated in order to approximately cover the entire cellular area?
iii. Calculate the system capacity if the cluster size is 4.
iv. Does decreasing the cluster size increase the system capacity? Explain

Solution: Given that

The total number of available channels K = 1001.

Cluster size N = 7.

Area of cell Acell = 6 km2

Area of cellular system A_{sys} = 2100 km^2

(i)The number of channels per cell is given by $J = \frac{K}{N}$

Then we have $J = \frac{1001}{7} = 143\, channels/cell$

Also, we know that the coverage area of a cluster is given by

$A_{cluster} = N \times A_{cell} = 7 \times 6 = 42 km^2$

The number of times that the cluster has to be replicated to cover the entire system will be

$M = \frac{A_{sys}}{A_{cluster}}$ or $M = \frac{2100}{42} = 50$

Hence, the system capacity C will be

C = M J N = 50 x 143 x 7 = 50,050 channels.

(ii)For N = 4, $A_{cluster}$ = 4 x 6 = 24 km^2

Hence $M = \frac{A_{sys}}{A_{cluster}} = \frac{2100}{24} = 87.5 \approx 87.$

(iii) With N = 4,

$J = \frac{1001}{4} \cong 250\, channels/cell.$

The system capacity is then

C = 87 x 250 x 4 = 87,000 channels.

From (i) and (iii), it is obvious that a decrease in N from 7 to 4 is accompanied by an increase in M from 50 to 87, and the system capacity is increased from 50,050 channels to 87,000 channels.

Hence, decreasing the cluster size does increase the system capacity.

(ii)**Cellular Layout for Frequency Reuse**

Rule to Determine the Nearest Co-channel Neighbours

The following two-step rule can be used to determine the location of the nearest co-channel cell:

Step I: Move i cells along any chain of hexagons;
Step 2: Turn 60 degrees counter clockwise and move j cells. Figure 4.5 shows the method of locating co-channel cells in a cellular system using the preceding rule for i = 3 and j= 2, where the co-channel cells are the shaded cells.

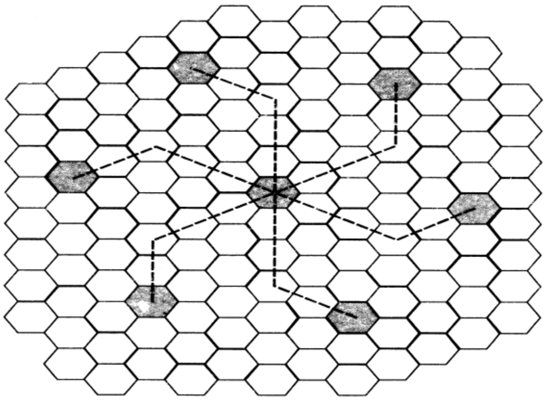


Fig. 4.5: Locating co-channel Cells in a Cellular System

Figure 4.6 illustrates the cluster concept and frequency reuse in a cellular network where cells with the same number use the same set of frequencies. These are co-channel cells that must be separated by a distance such that the co-channel interference is below a prescribed threshold. The parameters i and j measure the number of nearest neighbours between co-channel cells; the cluster size, N, is related to i and j by the following expression:

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

For example, if i = 1 and j = 2, then, N = 7. With a cluster size N = 7, the frequency reuse factor is seven since each cell contains one-seventh of the total number of available channels.

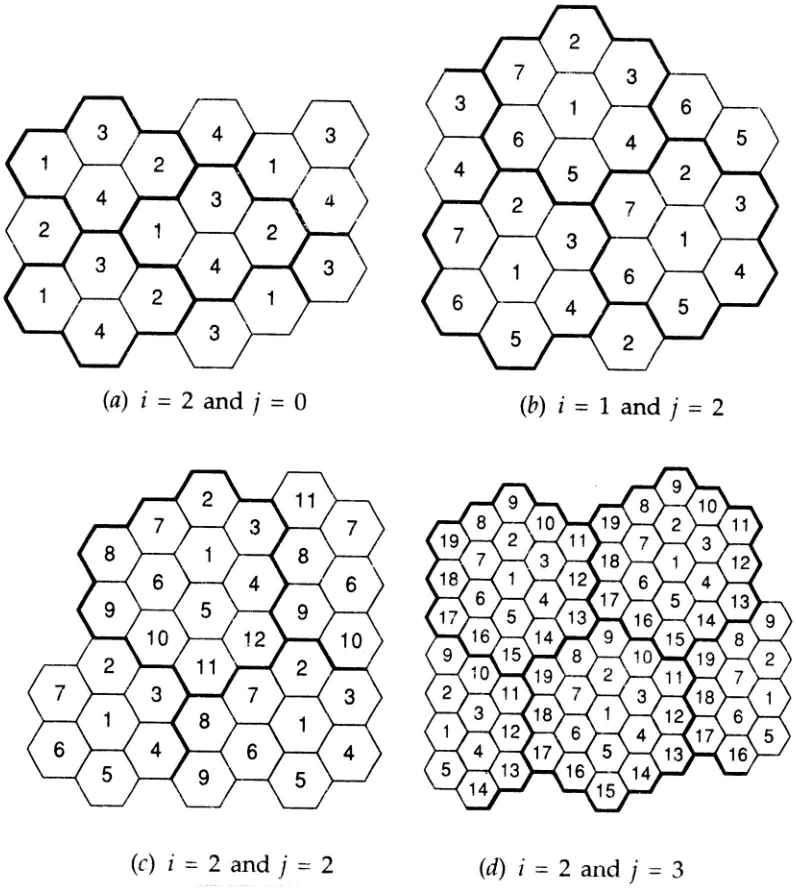


Fig. 4.6:Illustrations of Cell Clusters

3.1.7Geometry of Hexagonal Cells

Figure 4.7 shows the geometry of an array of hexagonal cell where R is the radius of the hexagonal cell (from the center to a vertex). A hexagonal has exactly six equidistant neighbours. In the cellular array the line joining the centers of cell and each of its neighbours are separated by multiples of 60^0. It may be noted that angle 60^0 is bounded by the vertical line and the 30^0 line, which join centers of hexagonal cells. The distance between the centers of two adjacent hexagonal cells is $\sqrt{3}R$.

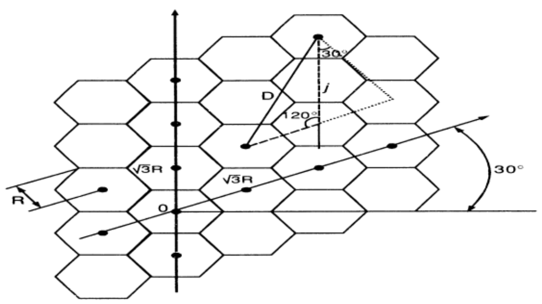


Fig. 4.7: Distance between Nearest co-channel Cells

The actual distance between the center of the candidate cell (the cell under consideration) and the other nearest co-channel cell is expressed as

$$D = D_{norm} \times \sqrt{3}R \qquad or$$
$$D = \sqrt{3}R$$

For hexagonal cells, there are six nearest co-channel neighbours to each cell. Co-channel cells are located in tiers. In general, a candidate cell is surrounded by 6k cells in tier k. For cells with the same size, the co-channel cells in each tier lie on the boundary of the hexagon that chains all the co-channel cell in that tier.

Self-Assessment Exercise

What do you understand by hexagonal cell concept?

4.0 Conclusion

Any cellular radio system mainly depends upon an intelligent assignment and reuse of channel (i.e. frequency) throughout a coverage region. Every cellular base station is assigned a group of radio channels which are used within a small geographical area called a cell.

5.0 Summary

In this unit, you have learnt that:

- cell is a single small area
- cell shape can be of only three types of regular polygons equilateral triangle, square, and regular hexagon.
- computer methods are being used for optimised planning of base station locations and cell frequencies
- a group of cells that use different set of frequencies in each cell is called a Cell Cluster
- frequency reuse is a technique of reusing frequencies and channels within a communications system to improve capacity and spectral efficiency
- the increase in system capacity comes from the use of smaller cells, reuse of frequencies and antenna sectoring
- the actual distance between the center of the candidate cell (the cell under consideration) and the other nearest co-channel cell is expressed as

$$D = D_{norm} \times \sqrt{3}R \qquad or$$
$$D = \sqrt{3}R$$

6.0 Self-Assessment Exercise

i. What do you understand by cell
ii. Mention the different types of cell
iii. In the radio cell layout, in addition to the hexagonal topology, a square or an equilateral triangle topology can also be used. Given the same distance between the cell center and its farthest perimeter points, compare the cell coverage areas among the three regular polygons (hexagon, square and triangle).

iv. Discuss the advantages of using the hexagonal cell shape over the square and triangle cell shape.

7.0 References/Further Reading

Linanartz, J. M. G (1997). *Wireless Communication*. (Online) Available at: http://wireless.per.nl/reference/about.htm

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Unit 5 Improving Capacity in Cellular System

1.0 Introduction

In this unit, you will be exposed to the concept of cell cluster and the advantage of cellular system.

2.0 Objectives

At the end of this unit, you should be able to:

- enumerate the advantages of cellular system
- discuss the mechanism for increasing the capacity of a cellular system
- compute the size and number of cells cluster in a service area
- compute the maximum number of user in service.

3.0 Main Content

3.1 Advantages of Cellular Systems

The advantages of operating in a cellular arrangement are listed below:

- the use of low power transmitter, and
- an allowance for frequency reuse

Frequency reuse needs to be structured so that co-channel interference is kept at an acceptable level. As the distance between co-channel cells increases co-channel interference will decrease. If the cell size is fixed, the average signal-to-co-channel interference ratio will be independent of the transmitted power of each cell. The distance between any two co-channel cells can be examined by making use of the geometry of hexagonal cells.

Self-Assessment Exercise

Given a cellular system with a total bandwidth of 30 MHz which uses two 25 kHz simplex channels to provide full duplex voice and control channels. Assuming that the system uses a nine-cell reuse pattern and 1 MHz of the total bandwidth is allocated for control channels. (i) calculate the total available channels (ii) determine the number of control channels (iii) determine the number of voice channels per cell, and (iv) determine an equitable distribution of control and voice channels in each cell.

Solution: Given that

Total bandwidth = 30 MH

Channel bandwidth = 25 kHz x 2 = 50 kHz/duplex channel

i. The total number of available channels = $\frac{30000}{50} = 600$

ii. The number of control channels = $\frac{1000}{50} = 20$

iii. The number of voice channels per cell = $\frac{600-20}{9} \cong 64.$

iv. Since, only a maximum of 20 channels can be used as control channels, for N = 9, one way is to allocate 7 cells with 2 control channels and 64 voice channels each, and 2 cells with 3 control channels and 66 voice channels each. It may be noted that the allocation performed in part (iv) is not unique.

3.2 Interference and System Capacity

Interference is the major limiting factor in the performance of the cellular radio systems. Sources of the interference include the following cases:

- another mobile in the same cell
- a call in progress in the neighbouring cell
- other base stations operating in the same frequency band
- any non-cellular system which inadvertently leaks energy into cellular frequency band.

Interference on the voice channels causes crosstalk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked call due to errors in the digital signaling. Interference is more severe in urban areas due to the greater radio frequency (RF) noise floor and the large number of base stations and the mobiles. Interference has been recognised as a major bottleneck in increasing capacity.

The two major types of system generated cellular interference are:

- co-channel interference
- adjacent channel interference.

3.2.1 Co-channel Interference

Frequency reuse implies that in a given coverage areas there are several cells that use the same set of frequencies. These cells are called co-channel cells and the interference between the signals from these cells is called co-channel interference. Co-channel interference or CCI is from two different radio transmitters using the same frequency.

Co-channel radio interference is caused by the following:

- **Adverse weather conditions**: during periods of abnormally high-pressure weather, VHF signals which would normally exit through the atmosphere can instead be reflected by the troposphere. This troposphere ducting will cause the signal to travel much further than intended; often causing interference to local transmitters in the areas affected by the increased range of the distant transmitter.

- **Poor frequency planning**: poor planning of frequencies by broadcasters can cause CCI, although this is rare. A very localised example is Listowel in the south-west of Ireland. The RTÉNL UHF television transmitter systems in Listowel and Knockmoyle (near Tralee) are on the same frequencies but with opposite polarization. However in some outskirts of Listowel town, both transmitters can be picked up causing heavy CCI. This problem forces residents in these areas to use alternative transmitters to receive RTÉ programming.

- **Overly-crowded radio spectrum**: in many populated areas, there is no much room in the radio spectrum. Stations are jam-packed, sometimes to the point that one can hear loud and clear two, three, or more stations on the same frequency, at once.

Co-channel interference cannot be combated by simply increasing the carrier power of transmitter. This is because an increase in carrier transmitter power increases the interference to neighbouring co-channel cells. To reduce co-channel interference co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

When the size of the cell is approximately the same and the base station transmit the same power the co-channel interference ratio is independent of the transmitted power and becomes a function of radius of cell and the distance between the centers of the nearest co-channel cells. By increasing the ratio of D/R the spatial separation between co-channel cells relative to the coverage distance of the cell is increased. Thus the interference is reduced from the improved isolation of the RF energy from the co-channel cell. The parameter Q called the co-channel reuse ratio is related to the cluster size. For a hexagonal geometry

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

A small value of Q provides larger capacity since the cluster size N is small, whereas a larger value of Q improves the transmission quality due to the smaller capacity.

Self Assessment Exercise

The acceptable signal-to-co-channel interference ratio in a certain cellular communications situation is $\frac{S}{I} = 20$ dB or 100. Also, from measurements, it is determined that k = 4. What will be the minimum cluster size?

Solution:

The frequency reuse ratio can be calculated as $q = (6 \times 100)^{1/4} = 4.9494$

The cluster size is given by $N = \frac{q^2}{3} = 8.165 \cong 9$

In this case, a 9-reuse pattern is required for an S/I ratio of at least 20 dB. Since $q = \frac{D}{R}$ or $D = qR$

D can be determined, given the cell radius R, and vice versa. It may be noted that if N is less than 9, the S/I value would be below the acceptable level of 20 dB.

3.2.2 Adjacent Channel Interference (ACI)

Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference. Adjacent channel interference results from the imperfect receiver filters which allow nearby frequency to leak into the passband.

Let us consider the uplink transmission from two mobile users using adjacent channels, one very close to the base station and the other very close to the cell boundary. Without proper transmission power control, the received power from the mobile close to the base station is much larger than that from the other mobile far away. This near-far effect can significantly increase the ACI from the strong received signal to the weak received signal. Adjacent channel interference can be minimised by:

- using modulation schemes which have low out-of-band radiation (e.g., MSK is better than QPSK and GMSK is better than MSK)
- carefully designing the bandpass filter at the receiver front end
- using proper channel interleaving by assigning adjacent channels to different cells
- avoiding using adjacent channels in adjacent cells to further reduce ACI if cell cluster size is large enough and
- separate the uplink and downlink properly by Time Division Duplex (TDD) or Frequency Division Duplex (FDD)

3.3 Channel Assignment Strategies

In Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) based cellular radio systems and wireless networks, channel allocation schemes are required to allocate channels to base stations and access points and to avoid co-channel interference among nearby cells. Different approaches have been tried to assign bandwidth to users in an efficient manner while minimising interference to other users.

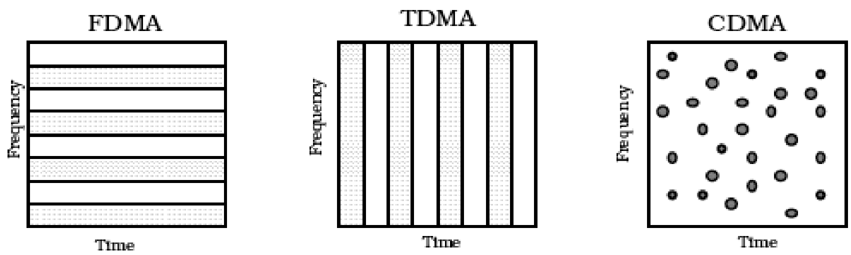
The two approaches to channel assignment are: (i) fixed channel assignment, and (ii) dynamic channel assignment.

3.3.1 Fixed Channel Assignment (FCA)

In a fixed channel assignment, each cell is allocated a predetermined set of a voice channel. Any call attempt within the cell only is served by the unused channels in that particular cell. To improve utilisation, a borrowing strategy may be considered. With the borrowing option, a cell is allowed to borrow channels from a neighbouring cell if all of its own channels are already occupied (the call is blocked and the subscriber does not receive) and the neighbouring cell has spare channels. Borrowing is supervised by the Mobile Switching Centre (MSC) because it has full knowledge of the capacity usage of the cluster of cells within its jurisdiction. Hence, the MSC is the natural subsystem to oversee function such as channel borrowing.

Three basic methods can be used to combine customers on to fixed channel radio links:

- FDMA - (frequency division multiple access) analog or digital. In analog transmission, signals are commonly multiplexed using frequency-division multiplexing (FDM), in which the carrier bandwidth is divided into sub-channels of different frequency widths, each carrying a signal at the same time in parallel.
- TDMA - (time division multiple access) three conversation paths are time division multiplexed in 6.7 m/sec time slots on a single carrier.
- CDMA - (code division multiple access) this uses spread spectrum techniques to increase the subscriber density. The transmitter hops through a pseudo-random sequence of frequencies. The receiver is given the sequence list and is able to follow the transmitter. As more customers are added to the system, the signal of noise will gradually degrade. This is in contrast to AMPS where customers are denied access once all of the frequencies are assigned code division multiple access (digital only).



Drawback of TDMA and FDMA Systems with FCA

- Fixed Channel Allocation or Fixed Channel Assignment (FCA) requires manual frequency planning, which is an arduous task in TDMA and FDMA based systems, since such systems are highly sensitive to co-channel interference from nearby cells that are reusing the same channel.
- Another drawback with TDMA and FDMA systems with FCA is that the number of channels in the cell remains constant irrespective of the number of customers in that cell. This result in traffic congestion and some calls being lost when traffic gets heavy in some cells, and idle capacity in other cells.

3.3.2 Dynamic Channel Assignment (DCA)

The more efficient way of channel allocation would be Dynamic Channel Allocation or Dynamic Channel Assignment (DCA). In DCA, voice channels are not allocated to different cells on a permanent basis.

Each time a call request is made, the serving base station requests a channel from MSC. The MSC determine (dynamically) the availability of a channel and executes its allocation procedure accordingly. The MSC only allocates a given frequency (radio channel) if that frequency (radio channel) is not presently in use in the cell, or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference.

Dynamic channel assignment reduces the likelihood of call blocking, which increases the trucking capacity of the system, since all available channels under the control of the MSC are accessible to all of the cells.

Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution and radio signal quality of all channels on a continuous basis.

Merit

- Dynamic Channel Assignment (DCA) and Dynamic Frequency Selection (DFS) eliminate the tedious manual frequency planning work.
- DCA also handles busty cell traffic and utilises the cellular radio resources more efficiently.
- DCA allows the number of channels in a cell to vary with the traffic load, hence increasing channel capacity with little costs.

3.4 Mechanisms for Capacity Increase in Cellular System

The capacity of a cellular system can be enlarged through frequency and it can also be improved based on cellular layout and antenna design. Basically, the following are the three popular mechanisms for increasing the capacity of a cellular system:

- **Cell Splitting**

One way to perform cell splitting is to subdivide a congested cell into smaller cells, each with its own base station and corresponding reduction in antenna height and transmission power. With more cells, there will be more clusters in the same coverage area. Hence cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused. In Figure 5.1 the central area is assumed to be saturated with traffic. The original large cell with radius R in the center is split into the medium cells with radius R/2 and the medium cell in the center is further split into the small cells with radius R/4. The cell splitting reduces the call blocking probability in the area, and increases the frequency with which mobiles hand off from cell to cell.

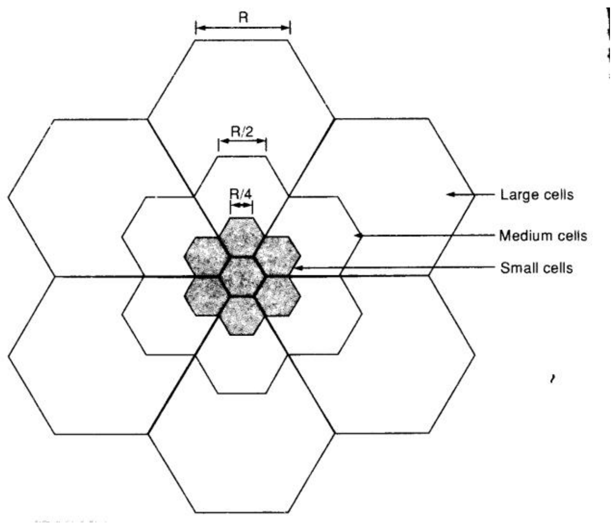


Fig.5.1: Illustration of Cell Splitting from Radius R to R/2 and to R/4

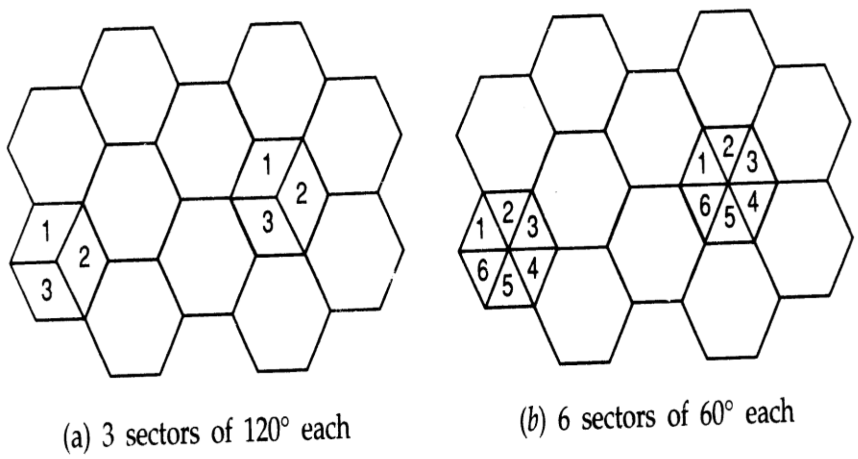
- **Directional Antennas (Sectoring)**

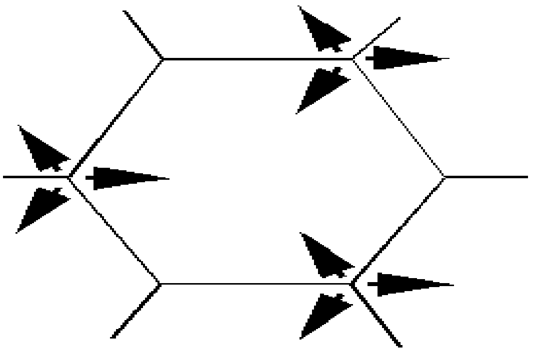
One way to increase the subscriber capacity of a cellular network is replace the omni-directional antenna at each base station by three (or six) sector antennas of 120 (or 60) degrees opening. Each sector can be considered as a new cell, with its own (set of) frequency channel(s).

The base station can either be located at:

- the centre of the original (large) cell, or
- the corners of the original (large) cell.

The use of directional sector antennas substantially reduces the interference among co-channel cells. This allows denser frequency reuse. Sectoring is less expensive than cell-splitting, as it does not require the acquisition of new base station sites.





(c)

Fig.5.2(a,b,c): Antenna Sectorisation

- **Microcell Zone**

The microcell concept is based on the seven cell reuse, in which three or more zone sites are connected to a single base station and share the same radio equipment. As mobile travels within the cell, it is served by the zone with the strongest signal. As a mobile travels from one zone to another within the cell, it retains the same channel. The base station simply switches the channel to different zone site. In this way, a given channel is active only in the particular zone in which the mobile is traveling and hence the base station radiation is localised and interference is reduced.

Self-Assessment Exercise

i. How can you increase the capacity of cellular system with the help of frequency reuse concept?
ii. What are the advantages of cellular systems?

4.0 Conclusion

If different cells in the entire cellular system were to use different set of frequencies, inter cell interference would be kept at minimum. However, the system capacity would be limited. In fact deployment of frequency reuse is necessary to enlarge the system capacity.

5.0 Summary

In this unit, you have learnt that:

- interference is the major limiting factor in the performance of the cellular radio systems
- the two major types of system generated cellular interference are: Co-channel interference and adjacent channel interference
- co-channel interference or CCI is crosstalk from two different radio transmitters using the same frequency
- interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference
- channel allocation schemes are required to allocate channels to base stations and access points and to avoid co-channel interference among nearby cells
- the two approaches to channel assignment are: fixed channel assignment, and dynamic channel assignment
- in a fixed channel assignment, each cell is allocated a predetermined set of a voice channel
- in DCA, voice channels are not allocated to different cells on a permanent basis
- the three popular mechanisms for increasing the capacity of a cellular system are: cell splitting, directional antennas and microcell zone.

6.0 Self-Assessment Exercise

A cellular system has a total of 500 duplex voice channels (without frequency reuse). The service area is divided into 150 cells. The required signal-t-co-channel interference ratio is 1dB. Consider the path loss exponent k equal to 3, 4 and 5 respectively. Determine:

i. the cell cluster size
ii. the number of cell clusters in the service area and
iii. the maximum number of users in service at any instant. Discuss effects of the path loss exponent on the frequency reuse and on the transmit power (when the cell size is fixed).

7.0 References/Further Reading

Linanartz, J. M. G (1997). *Wireless Communication*. (Online) Available at: http://wireless.per.nl/reference/about.htm

Sharma, S. (2006). *Wireless & Cellular Communications*, New Delhi: S. K. Kataria & Sons.