CHAPTER 3

Cellular and Satellite Communication

Objectives...

- To learn cellular telephony and 4G, 5G architectures.
- To understand working principles of dipole and patch antenna.
- To know about the importance of MINO and its concept.
- To study block diagram and applications of satellite communication.

3.1 INTRODUCTION

- The cellular concept was developed by AT and T Bell Laboratories of United States in 1947, but the first tests were conducted in 1962 to explore commercial applications.
- Cellular technology is a communication system that divides a geographic area into smaller regions called *cells*, each served by its own base station or transmitter. This structure allows efficient frequency reuse, enabling a large number of users to communicate simultaneously without interference.
- The technology forms the foundation of modern mobile communication systems, supporting voice, data and multimedia transmission. Evolving through generations, from 1G analog systems to the advanced 5G networks, cellular technology has revolutionized global connectivity by offering high-speed internet, enhanced capacity, low latency and seamless mobility across vast areas.
- In this chapter, cellular telephony, smart antennas and satellite communication concepts are discussed.

3.2 CELL AND CELLULAR TELEPHONY

- A small geographic coverage area of a base station with the diameter of 2 to 50 km, each of which allocated a number of RF channels is called a cell. Thus, a cell represents the coverage area of a base station.
- The base stations in adjacent cells are assigned channel group which contain completely different channels than neighbouring cells.
- The base station antennas are designed to achieve the desired coverage within the particular cell.

- In this technique, for limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within the tolerable limits.
- What should be the geometric shape of a cell? While deciding the geometric shape of a cell, a geometric shape of a cell has to be considered which covers the entire region of radio coverage of a base station without overlap and has equal area of radio coverage.
- By considering these two factors, there are three sensible choices for the geometric shape of a cell: (1) a circle, (2) an equilateral triangle and (3) a hexagon.
- A cell must be designed to serve the weakest mobiles within the foot prints which are typically located at the edge of the cell. It might seem natural to choose a circle to represent the coverage area of a base station, but adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions. So, the circle cannot be a suitable choice. Also, an equilateral triangle does not fulfill the required design conditions of a cell.
- For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area as that of a circle and an equilateral triangle.
- Thus, by using the hexagon geometry, the fewest members of cells can cover a geometric region of a base station and also the hexagon closely approximates a circular radiation pattern, which would occur for an Omni-directional base station antenna and free space propagation. So, the hexagon is a best choice for the geometric shape of a cell.
- The hexagonal shape of a cell shown in below Fig. 3.1 is a conceptual and a simplest model for a cell of the radio coverage for each station. It has been universally adopted, since the hexagon permits easy and manageable analysis of a cellular measurements or propagation prediction models.

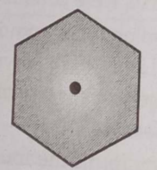


Fig. 3.1 : A hexagonal cell

- Fig. 3.2 shows Cellular telephone network with MTSO - Mobile Telephone Switching Office.
- As shown in the Fig. 3.2 each repeater in the cell is responsible for coverage in small cell.
- Although the cells are shown hexagons, in real situation the antenna patterns will now achieve this precision, hence the cells are more likely to be approximately circular, with some overlap.

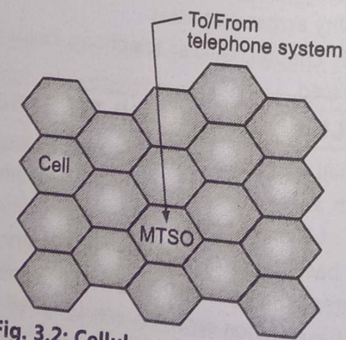


Fig. 3.2: Cellular telephone network

- Also the cells are not of same size. It depends on the population area, usage of telephone in that area like business area, school area, suburban places etc.
- All the cell sites in a region are connected by copper cable, fiber optics and now-a-days with microwave link to a central office called a Mobile Switching Center (MSC) or Mobile Telephone Switching Office (MTSO) and the MSC's are themselves interconnected so that the system can keep track of its mobile phones.
- The cellular system is connected at a point of presence to the landline telephone network.
- Thus, cellular phone customers can speak to landline customers and vice-versa.
- Here, there is no facility for direct mobile-to-mobile communication even though both mobile phones are in the same room.
- Every call from one to other mobile goes through a cell site and a MSC only. If it is landline communication then each cell will go through PSTN.

3.3 FREQUENCY REUSE AND HAND-OFF STRATEGIES

Frequency Reuse :

- Frequency reuse is the technique for using a specified range of frequencies more than once in the same radio system so that the total capacity of the system is increased without increasing its allocated bandwidth.
- In mobile communication system, use of space division multiplexing (SDM) allows frequency reuse.
- If one transmitter is far away from another, i.e., outside the interference range, it can reuse the same frequencies.
- Hence, in mobile phone systems, frequencies are assigned to certain users which are blocked for other users.
- The frequencies are a scarce resource and the number of concurrent users per cell is very limited. Huge cells do not allow for more users. On the contrary, they are limited to less possible users per square kilometer.
- This is also the reason for using very small cells in cities where many more people use mobile phones.

Handoff Strategies :

- Now, how the call is automatically transferred from one cell to other is discussed in below section.
- This is the most advantage of cellular phones since it provides mobility and still the call continues everywhere even a person carrying mobile is inside a car or on a vehicle.
- If a user walks around with a wireless station, the station has to move from one access point to another to provide uninterrupted service. This movement between access points is called 'roaming'.
- The term "handover" or "handoff" as used in the context of mobile or cellular phone systems would be more appropriate as it is simply a change of the active cell.

- The Mobile Telephone Switching Office (MTSO) controls all the cells and provides the interface between each cell and the main telephone office.
- As the owner of mobile phone is calling or receiving from a cell, it will be served by the cell transceiver.
- The telephone call will be routed through MTSO and through the standard telephone system.
- When the mobile phone owner crosses the cell with his vehicle, the system will automatically switch from one cell to the next.
- This transfer of a call in progress from one cell to another is called handling.
- The receiver in each cell base station continuously monitors the signal strength of the mobile unit.
- The optimum transmission and reception through paper selection of signal is monitored by the computer situated at MTSO.
- Cellular carriers and frequencies are allocated with channels. The control channels are used to allocate noise channels to mobile phones.
- When a user dials a phone number on a mobile, the phone scans all the control channel frequencies to find the strongest frequency.
- This control channel is associated with the closest cell site.
- The mobile phone transmits on its corresponding channel and once the call has been setup, the cell site assigns it a clear voice channel.
- The signal strength is continuously monitored to make available strongest signal while the conversation continues, similar procedure takes place for incoming calls.

3.3 OVERVIEW OF CELLULAR TELEPHONY GENERATIONS

- The first commercial mobile phone was introduced in 1983 by Motorola; mobile technology has come a long way.
- As evolution in technology, protocols, services offered or speed, the changes in mobile telephony which is named as generation of mobile communication.
- The evolution of cellular communication networks is commonly known by 1G, 2G, 3G and 4G, 5G designations.
- We are currently in the fifth generation with 6G emerging.
- The basic features of these generations that differentiate it from the previous generations are discussed below in brief.

3.3.1 Mobile Technology 1G to 5G

- 1G refers to the first generation of wireless mobile communication where analog signals were used to transmit data.
- It was introduced in the US in early 1980s and designed exclusively for voice communication.
- Some characteristics of 1G communication are speed up to 2.4 Kbps, poor voice quality, large size phones with limited battery life, no data security.

- 2G refers to the second generation of mobile telephony which used digital signals for the first time.
- 2G was launched in Finland in 1991 and used GSM technology.
- Some characteristics of 2G communication are data speed up to 64 Kbps, text and multimedia messaging possible, better quality than 1G.
- With introduction of GPRS technology it enabled web browsing, e-mail services and fast upload/download speeds. Hence, 2G with GPRS is also referred as 2.5G, a step short of next mobile generation.
- Third generation (3G) of mobile telephony began with the start of the new millennium and offered major advancement over previous generations.
- Some of the characteristics of this generation are data speed of 144 Kbps to 2 Mbps, high speed web browsing, running web based applications like video conferencing, multimedia e-mails, etc.
- Other enhanced developments in 3G are fast and easy transfer of audio and video files, 3D gaming facility, but this made mobile phones expensive with high infrastructure costs like licensing fees and mobile towers, trained personnel required for infrastructure set up for it.
- The intermediate generation, 3.5G grouped together dissimilar mobile telephony and data technologies.
- Fourth generation (4G) of mobile communication was introduced in 2011.
- It provides more facilities like speed of 100 Mbps to 1 Gbps, mobile web access, high definition mobile TV, cloud computing, IP telephony which we are using now a days.
- The 5th Generation (5G) mobile network technology was first introduced commercially in 2019. South Korea and the United States were among the earliest countries to deploy 5G services, followed by other countries such as China, Japan and parts of Europe.
- 5G brought significant improvements over 4G LTE, including higher data speeds, lower latency, massive device connectivity and enhanced support for IoT and multimedia applications.
- Today, the 5G (Fifth Generation) mobile network is the most widely deployed and utilized cellular technology worldwide.
- Over 2.6 billion 5G connections were reported globally by mid-2025, marking a 37% increase from the previous year.
- In India, 5G services were launched in October 2022, initially in major cities and have since expanded rapidly across the country.
- In India, 5G adoption is particularly notable, with over 360 million users and network coverage exceeding 80% of the population.
- 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects and devices.
- 5G wireless technology will provide higher multi-Gbps peak data speeds, ultra low latency, more reliability, massive network capacity, increased availability to more users.

- The country is also preparing for 6G trials, indicating a forward-looking approach to next-generation mobile technology.
- While 5G is the current standard, the industry is already laying the groundwork for 6G (Sixth Generation) networks.
- 6G (Sixth Generation) mobile networks have not yet been commercially launched. However, the industry is actively preparing for their introduction, with early trials and standardization efforts underway.
- Research and development are underway, with early trials expected around 2029–2030. However, 6G is still in the conceptual and experimental phase and widespread commercial deployment is not anticipated in the near term.
- While 6G is still in the development phase, its anticipated capabilities include ultra-fast data speeds, low latency and support for advanced applications such as AI, holographic communication and immersive augmented reality.
- The progression from 5G to 6G is expected to follow a similar trajectory, with initial deployments in select regions leading to broader global adoption in the early 2030s.

3.4 3G UMTS (UNIVERSAL MOBILE TELECOMMUNICATIONS SYSTEM)

- UMTS is a third-generation (3G) mobile communication technology based on the WCDMA (Wideband Code Division Multiple Access) air interface.
- It was developed to provide higher data rates and improved network capacity compared to 2G systems, enabling services such as mobile internet, video calling and multimedia applications.

Key Features of UMTS :

- Data rates are up to 384 Kbps for mobile users and up to 2 Mbps for stationary users.
- Frequency bands typically operates in the 1900 MHz and 2100 MHz bands, depending on the region.
- Network architecture comprises User Equipment (UE), Node B (base station), Radio Network Controller (RNC) and Core Network.
- Multiple Access Technique uses WCDMA, allowing multiple users to share the same frequency band simultaneously with unique spreading codes.
- UMTS marked the evolution from 2G (GSM) to 3G networks, providing faster data services and laying the foundation for later technologies like LTE (4G).

UMTS Architecture :

- UMTS (Universal Mobile Telecommunications System) is a 3G mobile communication technology developed based on 3GPP standards.
- The architecture of UMTS is shown in Fig. 3.3.

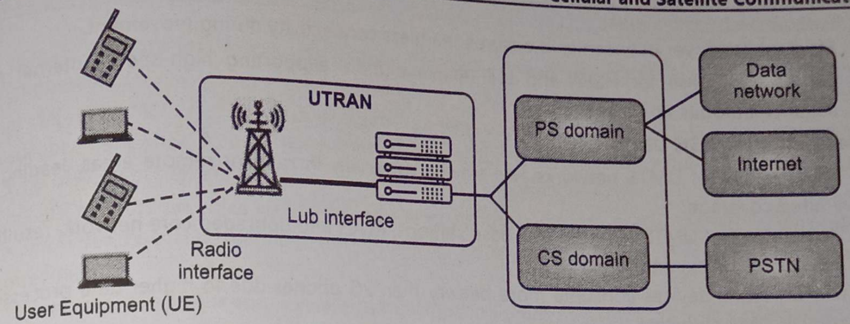


Fig. 3.3 : UMTS architecture

- As shown in Fig. 3.3, UMTS architecture is broadly divided into three main parts; UE (User Equipment), UTRAN (UMTS Terrestrial Radio Access Network) and CN (Core Network).
  1. **User Equipment (UE):** UE is the mobile device used by the end-user, e.g., smartphone or modem. It contains the USIM (Universal Subscriber Identity Module) for user identification.
  2. **UMTS Terrestrial Radio Access Network (UTRAN):** It consists of Node B (Base Station) and Radio Network Controller (RNC). Node B handles radio transmission/reception with mobile devices. RNC manages radio resources, handovers and controls multiple B nodes.
  3. **Core Network (CN):** CN provides switching, routing and connectivity to external networks. It has two main domains: Circuit-Switched (CS) domain which handles voice and traditional telephony and Packet-Switched (PS) domain which handles data services like internet access. Core elements include Mobile Switching Center (MSC), Gateway MSC (GMSC), Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN).
- The UE communicates with Node B via the air interface (Uu).
- Node B connects to RNC, which manages multiple base stations.
- The RNC forwards traffic to the Core Network, either to the CS domain for voice or the PS domain for data services.

Advantages of 3G UMTS :

- Supports data rates up to 384 Kbps for mobile users and up to 2 Mbps for stationary users, enabling faster internet access and multimedia services.
- UMTS allows international roaming, enabling users to access mobile services across different countries seamlessly.
- Supports video calling, mobile TV and streaming, which were not feasible on 2G networks.
- Uses WCDMA (Wideband Code Division Multiple Access), allowing multiple users to share the same frequency band simultaneously without significant interference.
- Offers clearer and more reliable voice calls compared to 2G networks due to better coding and transmission techniques.
- Provides voice, video and data services over a single network, reducing the need for multiple infrastructures.

- Efficient handover between cells ensures seamless connectivity during movement.
- Serves as a base for HSPA and LTE (4G) evolution, supporting high-speed internet and advanced mobile applications.

Disadvantages of 3G UMTS :

- Initial rollout of UMTS networks was slower, especially in rural or remote areas, leading to limited coverage.
- Deployment of UMTS required new base stations, RNCs and upgraded core network, resulting in high capital expenditure.
- UMTS mobile devices consume more battery than 2G phones due to higher data processing and WCDMA signaling.
- WCDMA, while efficient, is sensitive to interference in densely populated areas, which can affect call quality and data speeds.
- Although 3G offers high speeds theoretically, data rates decrease significantly for users moving at high speeds, such as in trains or highways.
- UMTS is not fully backward compatible with some 2G devices, requiring dual-mode phones for users who move between 2G and 3G networks.
- The required frequency bands for UMTS are not always available in all regions, restricting network expansion.

3.5 4G LTE (LONG TERM EVOLUTION)

- In telecommunications, Long-Term Evolution (LTE) is a standard for wireless broadband communication for mobile devices and data terminals.
- LTE is a 4th generation (4G) mobile communication technology designed to provide high-speed data, low latency and improved spectral efficiency compared to 3G systems like UMTS.
- It is widely used for mobile internet, video streaming, VoIP and other data-intensive applications.
- LTE is the upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks.
- The different LTE frequencies and bands used in different countries mean that, only multiband phones are able to use LTE in all countries where it is supported.
- In March 2008, the ITU Radio communication Sector (ITU-R) released new standards for 4G ("Fourth Generation") connectivity, including faster connection speeds and mobile hotspots.
- Advantages of 4G are allowing users to fully enjoy digital media on their mobile devices, including streaming video, rich multimedia apps and high-quality music.
- While using network in 4G, users can start watching a movie in seconds, without worrying about long load times and buffering.
- While 4G LTE is a major improvement over 3G speeds, it is technically not 4G.
- The difference between 4G and LTE is that, 4G is faster than LTE.
- The reason for this is that, 4G meets the technical standards designated for it whereas LTE data transfer speed standard is merely a stopgap measure standard devised until actual 4G speed is realized.

- 4G LTE is short for "fourth generation long-term evolution". So it is actually two terms combined.
- In 4G LTE, "4G" represents the fourth generation of mobile technology, the next big advancement after 3G and "long-term evolution", or "LTE", is used to describe the particular type of 4G that delivers the fastest mobile internet experience.
- 4G LTE network provides fast download speed i.e. larger files takes few second for download, it provides fast and seamless web browsing, provides HD quality, live video and music streaming.
- LTE represents a major step forward from 3G technologies by providing faster internet access, higher capacity and better support for multimedia services and it forms the foundation for LTE-Advanced and 5G evolution.

Key Features of LTE:

- Data rates are up to 100 Mbps for downlink and 50 Mbps for uplink in mobile environments; higher rates for stationary users.
- Multiple Access Technique uses OFDMA (Orthogonal Frequency Division Multiple Access) for downlink and SC-FDMA (Single Carrier FDMA) for uplink.
- Network Architecture is a simplified Evolved Packet System (EPS) architecture, consisting of User Equipment (UE), eNodeB (base station) and EPC (Evolved Packet Core).
- LTE is an all-IP network, supporting voice over LTE (VoLTE) and seamless data services.
- End-to-end latency is significantly reduced compared to 3G systems, enabling real-time applications.
- It increases the capacity and speed using a different radio interface together with core network improvements.

4G LTE Architecture :

- LTE (Long-Term Evolution) is a 4th generation (4G) mobile communication system designed to provide high-speed data, low latency and all-IP services.

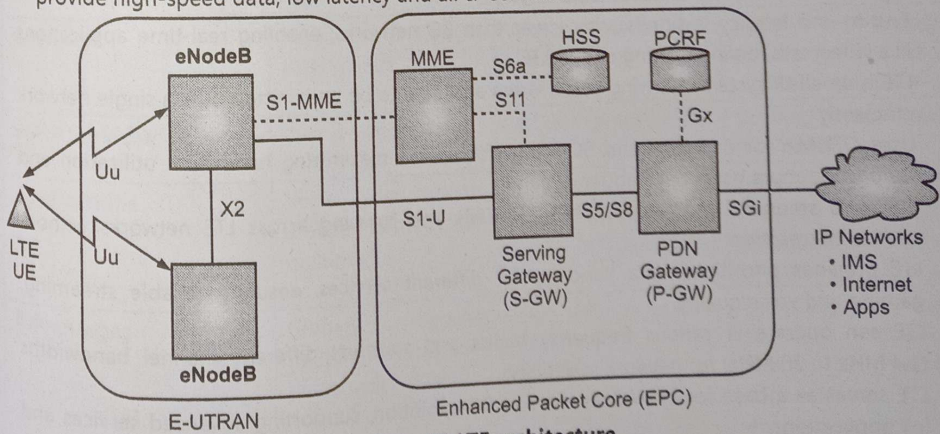


Fig. 3.4 : 4G LTE architecture

- Its architecture is simplified compared to 3G (UMTS), with fewer network nodes, making it more efficient.
- The LTE architecture is shown in Fig. 3.4.
- LTE architecture mainly consists of three components:
  1. **User Equipment (UE) :** UE is the mobile device used by the subscriber, e.g., smartphone, tablet, or LTE modem. It contains the SIM card (Subscriber Identity Module) for authentication and identification.
  2. **Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) :** It consists of eNodeB (evolved Node B) base stations, Functions of eNodeB are Radio resource management, Handover management, scheduling and packet routing between UE and core network. LTE does not use RNC; eNodeB performs most radio control functions locally, reducing latency.
  3. **Evolved Packet Core (EPC) :** EPC is the core network for LTE, responsible for routing, mobility and IP connectivity.
- The Key components of EPC are:
  1. **Mobility Management Entity (MME):** It handles signaling, mobility management, authentication and session setup.
  2. **Serving Gateway (SGW):** It routes and forwards user data packets between eNodeB and PDN Gateway.
  3. **Packet Data Network Gateway (PDN-GW / PGW):** It connects LTE network to external IP networks, e.g., the Internet handles IP address allocation and policy enforcement.
  4. **Home Subscriber Server (HSS):** It stores subscriber-related information such as profile, authentication and service access permissions.

Advantages of LTE :

- LTE provides up to 100 Mbps downlink and 50 Mbps uplink for mobile users, supporting high-speed internet and multimedia services.
- End-to-end latency is significantly lower than 3G networks, enabling real-time applications like video calls, online gaming and VoLTE.
- LTE is an all-IP system, allowing voice, video and data to be transmitted over a single network efficiently.
- Uses OFDMA for downlink and SC-FDMA for uplink, maximizing bandwidth utilization and supporting more users per frequency band.
- Supports smooth handover between eNodeBs and roaming across LTE networks without service interruption.
- LTE provides prioritized data handling for different services, ensuring reliable streaming, gaming and voice quality.
- LTE can operate in various frequency bands and supports different channel bandwidths (1.4 MHz to 20 MHz) for network scalability.
- LTE serves as a base for LTE-Advanced and 5G evolution, supporting advanced services and IoT applications.

Disadvantages of LTE :

- Deployment requires new infrastructure; rural and remote areas may have poor or no LTE coverage.
- Upgrading from 3G to LTE involves expensive base stations, core network upgrades and spectrum licensing.
- LTE devices consume more battery due to higher data processing and always-on connectivity.
- Older 3G or 2G devices cannot access LTE networks without dual-mode capability.
- High user density or poor spectrum management can cause interference and reduced data rates.
- Performance depends heavily on backhaul and core network quality, which may vary in developing regions.

Table 3.1 : Difference between UMTS and LTE

Feature	3G UMTS	4G LTE	5G
Generation	3rd Generation	4th Generation	5th Generation
Technology/Multiple Access	WCDMA (Wideband CDMA)	OFDMA (Downlink), SC-FDMA (Uplink)	NR (New Radio), OFDM, Massive MIMO
Data Rates	Up to 384 Kbps (mobile), 2 Mbps (stationary)	Up to 100 Mbps (mobile), 1 Gbps (stationary)	Up to 10-20 Gbps (peak)
Latency	~100-150 ms	~20-30 ms	~1 ms (ultra-low)
Network Type	Circuit and Packet Switched	All-IP Network	All-IP Network, Ultra-reliable low latency
Architecture Components	UE, Node B, RNC, MSC, SGSN, GGSN	UE, eNodeB, EPC (MME, SGW, PGW, HSS)	UE, gNodeB, 5G Core (AMF, SMF, UPF)
Coverage	Moderate, limited in early rollout	Wide, depends on LTE deployment	Initially limited, expected global coverage gradually
Voice Services	Circuit-switched voice	VoLTE (Voice over LTE)	VoNR (Voice over New Radio)
Applications	Voice, video calling, mobile internet, basic multimedia	High-speed internet, video streaming, VoLTE, IoT, gaming	Ultra-HD streaming, AR/VR, IoT/IIoT, autonomous vehicles, smart cities
Advantages	Global roaming, multimedia support, better voice quality	High data rates, low latency, all-IP, seamless mobility	Extremely high speed, ultra-low latency, massive connectivity, AI-enabled services

Feature	3G UMTS	4G LTE	5G
Disadvantages	Limited data rates, higher infrastructure cost, battery consumption	Initial coverage limitations, higher cost, battery usage	High deployment cost, early adoption challenges, requires new infrastructure
Deployment Timeline	Late 1990s - 2000s	2009 onwards	2019 onwards (commercially); full adoption ongoing

3.6 HANDOVERS IN 5G

- Handovers in 5G refer to the process of transferring an active user connection from one cell (or base station) to another without interrupting ongoing services like voice calls, video calls, or data sessions.
- Due to higher frequencies and smaller cells (especially in mmWave bands), seamless handover is critical in 5G to maintain ultra-reliable low-latency communication and continuous connectivity.

Types of Handovers in 5G :

1. **Intra-gNB Handover (Within the Same gNodeB):**
   - It occurs when a UE moves between sectors or cells controlled by the same gNodeB.
   - It requires minimal core network involvement, it is fast and seamless.
2. **Inter-gNB Handover (Between Different gNodeBs):**
   - It occurs when a UE moves from one gNodeB to another. It requires co-ordination between source and target gNodeBs and the 5G Core (AMF/UPF).
3. **Inter-RAT Handover (Between Different Radio Access Technologies):**
   - It is a switching between 5G NR and other RATs like LTE (4G) or UMTS (3G). It ensures service continuity in areas with weak 5G coverage.
4. **Dual Connectivity (DC) Handover:**
   - In this, UE simultaneously connects to two 5G cells (or a 5G and LTE cell) for load balancing and improved reliability.
   - This handover can occur on the secondary connection without interrupting the primary connection.
5. **Multi-RAT Dual Connectivity (MR-DC) Handover:**
   - In this, UE maintains simultaneous connections with multiple RATs, e.g., 5G NR + LTE. It supports seamless mobility when switching between 5G and 4G networks.
   - It ensures uninterrupted services during inter-RAT handovers and allows enhanced throughput.

Handover Process :

- A handover is "the seamless transfer of an active user connection from one cell to another without interrupting ongoing services like voice calls, video streaming or data sessions".

- In 5G, handovers are critical due to small cells, high frequencies and high-speed mobility.
- The handover process involves five main steps:

1. **Measurement :**
   - The User Equipment (UE) continuously measures the quality of the serving cell and neighboring cells.
   - Parameters such as Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) are monitored.
   - These measurements are reported periodically to the source gNodeB.
2. **Handover Decision :**
   - The network (source gNodeB and 5G Core, AMF) evaluates the UE reports.
   - A handover is triggered if:
     - Signal quality of the serving cell drops below a threshold.
     - Signal quality of a neighboring cell is better.
     - Load balancing or network optimization requires it.
   - The decision ensures seamless connectivity and service continuity.
3. **Handover Preparation :**
   - The source gNodeB communicates with the target gNodeB to reserve resources for the UE.
   - Necessary signaling is exchanged with the core network (AMF/UPF) for session continuity.
   - In DC or MR-DC scenarios, the secondary link may be prepared first to reduce interruption.
4. **Handover Execution :**
   - The UE switches from the source cell to the target cell.
   - Radio bearers are re-established and the data path may be updated via the Serving Gateway (SGW/UPF).
   - In dual connectivity, the UE can maintain the primary connection while switching the secondary connection, reducing service interruption.
5. **Handover Completion :**
   - The target gNodeB confirms successful connection establishment with the UE.
   - The source gNodeB releases the previously allocated resources.
   - The UE continues its ongoing services (voice, video, data) without interruption.

3.7 FUTURE GENERATION 6G

- 6G is the sixth generation of mobile communication technology, expected to be commercially launched around 2030.
- It will be the successor to 5G, designed to provide ultra-fast connectivity, low latency, massive device interconnection and deep integration of AI (Artificial Intelligence) and edge computing into the network infrastructure.

Key Features and Goals of 6G :

- Target speeds of up to 1 Tbps (terabit per second).
- Ultra-Low Latency, less than 1 millisecond, enabling real-time control and immersive experiences.
- Operates in 0.1-10 THz frequency range for massive bandwidth.
- Self-learning and self-optimizing networks that predict and adapt to user needs.
- Enables devices to sense their environment while communicating.
- Seamless coverage through terrestrial, aerial (UAVs) and satellite networks.
- Designed with green communication principles to reduce power usage.
- Supports holographic telepresence, VR/AR/XR with ultra-high resolution.
- AI-assisted security, quantum-resistant encryption and distributed trust systems.

- 6G will mark the era of intelligent, ultra-fast and ubiquitous communication, merging the physical, digital and biological worlds. It is not just an upgrade in speed, it is a leap toward fully connected intelligent societies.

3.8 ANTENNAS

- An antenna, or aerial as it is sometimes called is one or more electrical conductors of specific length that radiate radio waves generated by a transmitter or that collect radio waves at the receiver.
- There are different types of antennas used in communication system.

Working Principle of An Antenna :

- When a d.c. current flows through a conductor, a stationary magnetic field exists in the space surrounding the conductor. When the conductor carries a.c. current, a time varying magnetic field is produced.
- This field will induce a voltage in adjacent conductor. The voltage induced will drive a current through the conductor if the circuit is complete.
- An electric field will be developed by the varying magnetic field between any two points in the space. Hence, a changing magnetic field is accompanied by an associated electric field.
- In the similar way, a changing electric field is accompanied by an associated magnetic field. An electromagnetic wave is formed due to the properties of electric field E and magnetic field H.
- The electric field E and magnetic field H are always perpendicular to each other in space and they are at right angles to the direction in which the electromagnetic wave is propagated; this is shown in the Fig. 3.5.
- The electromagnetic wave travels at the speed of light. The strength or intensity of the wave at a given point, away from the transmitter is basically a measure of the e.m.f. produced by the electric field component of the wave and is expressed in terms of µV/metre.

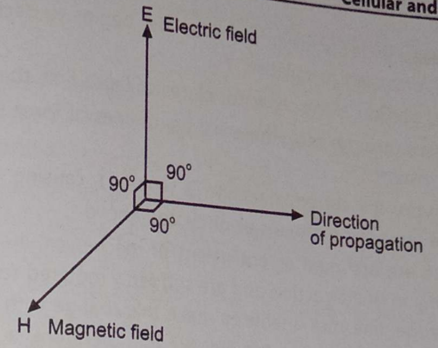


Fig. 3.5 : Relation between E, H

- Now to understand how the energy is radiated from an antenna, consider the LC circuit driven by RF generator as shown in the Fig. 3.6.
- The current flowing through the LC circuit will charge the capacitor with the polarity as shown in the Fig. 3.6, if the current for a certain instant is clockwise.

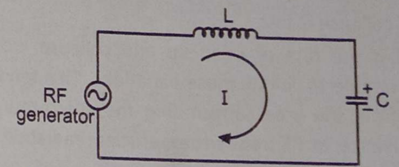


Fig. 3.6 : LC circuit driven by RF signal

- The electric lines of force will be created first between the central portions of the capacitor plates and progress towards the ends as the current increases during the positive half cycle. This situation is illustrated in the Fig. 3.7 below.

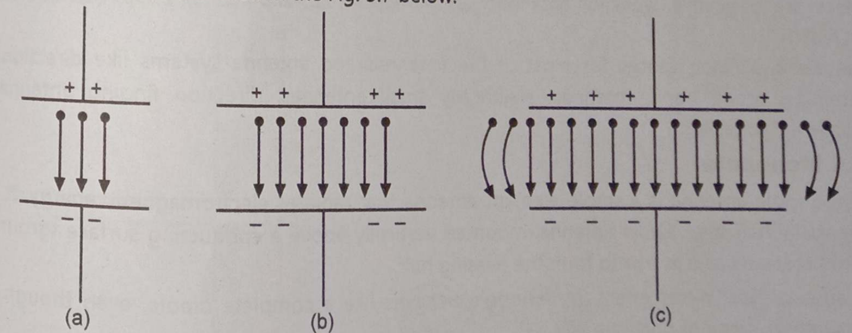


Fig. 3.7 : Field across the capacitor

- Now, the top plate of capacitor is positive with respect to bottom plate, hence the lines of force are directed from top plate to bottom plate as shown in the Fig. 3.7 (a).
- Since the lines are all in the same direction, they react on each other in the same way as like charges and they tend to repel each other as shown in the Fig. 3.7 (b).
- Now, a situation is arrived where some lines of force will ultimately extend beyond the space between the capacitor plates as shown in the Fig. 3.7 (c).

- Now, as the current reaches to its maximum value and begins to decrease towards negative half cycle, the lines of force start to collapse.
- The lines in the central portion of the capacitor plates collapse first, then adjacent.
- When the current passes through zero, there will be no lines of force between the two plates of capacitor for some instant.
- In the negative half cycle, the current direction is reversed, causing the lines of force from bottom to top and the same thing repeats as discussed above.
- Here the lines of force are assumed as equivalent of mechanical inertia. When the lines of force are moving rapidly in one direction and are suddenly required to reverse their direction, those at the extreme edge, lines are unable to make this change with sufficient speed, hence forced out of the system as shown in the Fig. 3.7 (c). Therefore, a certain amount of the energy stored in the capacitor is radiated during each cycle.
- The LC circuit is driven at RF frequency, causing the rate of lines of force build-up and collapse is fast.
- As the rate of build up and collapse increased more, the electromagnetic field becomes unable to follow these variations. This tends to disengage some of the electromagnetic field from the area surrounding the energized conductor and moves away from the conductor. Hence, at RF frequencies, efficient radiation is obtained from the conductor, which is called as an *antenna*.
- The antenna can function either a transmitting antenna or receiving antenna by virtue of properties of electromagnetic wave.

3.8.1 Types of Antenna

- There are basic five types of antenna : (1) Monopole, (2) Dipole, (3) Loop, (4) Slot and (5) Notch.
- These are building blocks for most of the antennas and antenna systems like directional antennas, broad band antennas, electrically small antennas, direction finding antennas, mobile antennas etc.

3.8.1.1 Monopole

- A monopole antenna is a single-element antenna that radiates electromagnetic energy. It is essentially half of a dipole antenna, mounted vertically above a conducting surface (ground plane) that acts as a mirror to form the missing half.
- Because of this mirror effect, a monopole behaves like a complete dipole, even though it physically consists of only one arm.
- In practice, monopole is not simply half a dipole, but this is true only when the ground plane is infinite and even very large ground planes give radiation patterns significantly different from that on an infinite plane.
- The monopole antenna consists of a metallic rod or wire connected to a transmission line (usually coaxial cable).
- The ground plane (either actual earth or a metal plate) serves as the reflecting surface.

- The most common type is the quarter-wave monopole antenna, whose length is:

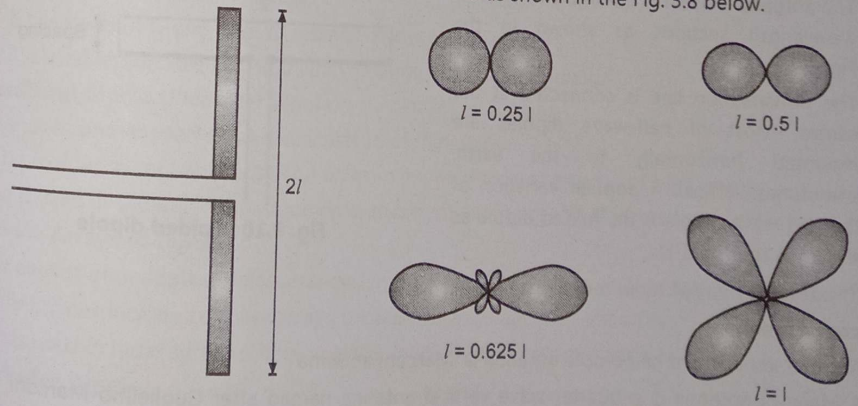
$$L = \frac{\lambda}{4}$$

where λ = wavelength of the signal.

- The ground plane creates a mirror image of the antenna, forming a virtual half-wave dipole.

3.8.1.2 Dipole Antenna

- A dipole antenna is a type of RF antenna that includes two conductive elements like wires or rods where the metal wire length is half of the highest wavelength approximately in free space at the operation of frequency.
- At the center of the antenna, the conductive materials are separated through an insulator which is called an antenna section.
- A Hertzian dipole, also known as an elementary dipole or short dipole, is the theoretical simplest form of an antenna.
- It was first proposed by Heinrich Hertz during his experiments on electromagnetic waves.
- It is mainly used as an idealized model to analyze and understand the radiation properties of antennas.
- A Hertzian dipole consists of a very short current-carrying conductor, usually much shorter than the wavelength of the signal it radiates.
- The length (l) of the antenna is much smaller than the wavelength (λ), i.e., $l << \frac{\lambda}{10}$.
- The antenna is assumed to have a uniform current distribution along its length.
- It is usually placed along the z-axis and the oscillating current produces time-varying electric and magnetic fields, which generate electromagnetic waves.
- Thus, the Hertzian dipole is a short linear antenna as shown in the Fig. 3.8 below.



(a) Vertical dipole (b) Radiation pattern of dipole

Fig. 3.8 : Dipole antenna

- The radiation is assumed to carry uniform current along its length as shown in the Fig. 3.8.

- The radiation patterns for thin dipole are shown. As the ratio of length/diameter is decreased, subsidiary nulls are blurred.
- The axial null appears to be unaltered but pattern changes, particularly for overall lengths of 1.25 λ, 2.5 λ etc. are very much dependent on diameter. Such antenna cannot be realised in practice, but longer antennas can be assumed to be made up of a number of dipoles connected in series.

Half Wave Dipole Antenna :

- A type of dipole antenna where the dipole length is half the wavelength at the operating frequency is called a half-wave dipole antenna. Sometimes, this antenna is also called the Hertz antenna.
- This antenna has a simple resonance structure as compared to other antennas, so used for transmission and reception purposes in different applications.
- A half-wave dipole antenna is shown in the Fig. 3.9 below.
- The ground plane affects the performance of the monopole not only because it is finite in size but because the capacitance between the base of the monopole and the ground plane differs from that between two halves of a dipole.
- This is also known as doublet; which is simply a piece of wire; rod or tubing that is one half wavelength long at the operating frequency.

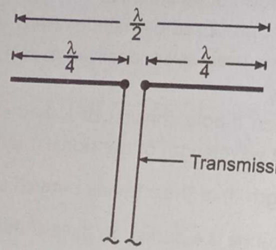


Fig. 3.9 : Half-wave dipole antenna

- The antenna is actually cut into two quarter wavelength sections as shown in the Fig. 3.9.
- The transmission line is connected at the centre. Most of half-wave dipoles are mounted horizontally to the earth; sometimes vertical. A popular variation of the half-wave dipole is the folded dipole as shown in the Fig. 3.10.

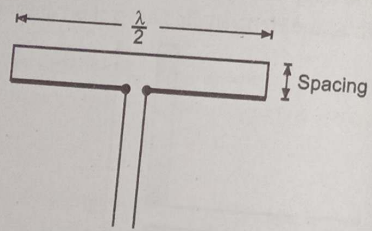


Fig. 3.10 : Folded dipole

- It is used in T.V., FM radio reception.

Marconi Antenna :

- Another variation of half dipole antenna is 'Marconi antenna'.
- A Marconi antenna is a quarter-wave vertical antenna named after Guglielmo Marconi, the pioneer of wireless communication.
- It is one of the earliest and simplest antennas used for radio broadcasting and communication systems.

- As shown in the Fig. 3.11 below for a vertical antenna, the arm of the dipole connected to the ground side of transmission line is driven into the earth.

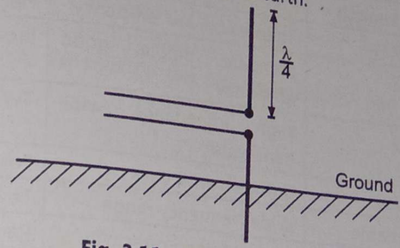


Fig. 3.11 : Marconi antenna

- Since the earth is a conductor, the arm of the antenna which is driven into the ground can be eliminated completely, such an antenna is called a 'quarter wave Marconi antenna'. This is used in UHF for mobile communication like a cartop antenna where the flat metal top of car provides the ground plane.

Folded Dipole Antenna :

- It is made by folding a half-wave dipole back on itself, creating two (or more) parallel conductors connected at the ends.
- Its Input impedance is four times that of a simple dipole ($\approx 300\ \Omega$).
- It provides broader bandwidth and better matching with transmission lines.
- It is used in TV antennas, FM broadcasting and antenna arrays.

Shortened Dipole Antenna :

- A dipole whose physical length is made shorter than $\lambda/2$ by adding loading coils (inductors).
- It is used when space is limited.
- It has lower efficiency due to resistive and reactive losses.
- It is used in portable radios, military communication equipment.

Broadband Dipole (Biconical Dipole) :

- It uses cone-shaped conductors instead of thin wires.
- It provides wider bandwidth and uniform impedance over a range of frequencies.
- It is used in wideband measurements, spectrum analyzers and EMC testing.

Antenna Arrays of Dipoles :

- It consist of multiple dipoles arranged in specific geometries to increase gain and directivity.
- Their types include collinear arrays, broadside arrays and end-fire arrays.
- It is used in radar systems, base stations, long-distance communication.

Inverted-V Dipole :

- It is formed by bending the dipole arms downward to form a "V" shape.
- It reduces required installation height and provides broader bandwidth.
- It is used in HF amateur radio and shortwave communication.

Table 3.2 : Summary of the types of antennas

Type	Length	Key Feature	Common Application
Short Dipole	$< \lambda/10$	Theoretical, low efficiency	Field analysis
Half-Wave Dipole	$\lambda/2$	Standard dipole, good efficiency	Broadcasting
Folded Dipole	$\lambda/2$	High impedance, wide bandwidth	TV/FM antennas
Shortened Dipole	$< \lambda/2$	Compact with coils	Portable radios
Broadband (Biconical)	Variable	Wide frequency range	Testing and measurement
Dipole Array	Multiple $\lambda/2$	High gain and directivity	Radar, base stations
Inverted-V	$\lambda/2$	Compact, wide coverage	Amateur radio

3.8.1.3 Patch Antenna

- A patch antenna (also known as a microstrip antenna) is a low-profile, lightweight and compact antenna widely used in modern wireless communication systems such as mobile phones, Wi-Fi routers, GPS devices and satellites.
- It consists of a flat metallic patch mounted over a ground plane, separated by a thin layer of dielectric substrate.
- The patch antenna is shown in Fig. 3.12.

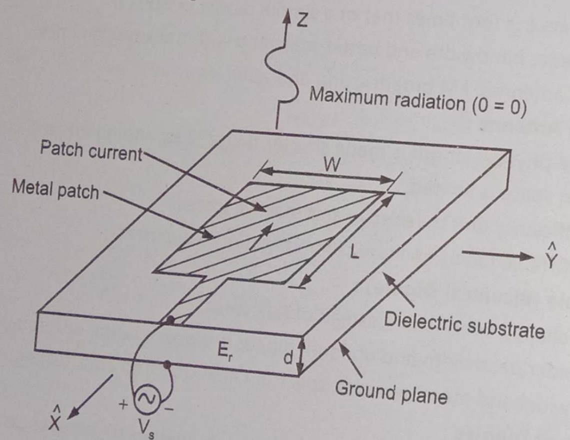


Fig. 3.12 : Patch antenna

- As shown in Fig. 3.12, a typical patch antenna has three main parts:
  1. Radiating metallic patch – a thin metallic layer (usually copper) that emits or receives electromagnetic waves.
  2. Dielectric substrate – an insulating material that separates the patch from the ground plane and affects antenna performance.
  3. Ground plane – a conducting layer below the substrate that acts as a reflector.

- When an RF signal is applied to the patch (via microstrip feed, coaxial probe, or aperture coupling), surface currents are induced on the patch.
- These currents create electromagnetic fields that radiate from the edges of the patch, producing the antenna's radiation pattern.
- The resonant frequency depends on the patch dimensions and dielectric constant of the substrate.

$$f_r = \frac{c}{2L\sqrt{\varepsilon_r}}$$

where, f_r = resonant frequency,

c = speed of light,

L = length of the patch,

ε_r = dielectric constant of substrate.

Working of Microstrip Patch Antenna :

- A microstrip patch antenna consists of a metallic conducting patch placed on a dielectric substrate, with the other side grounded using a metal layer.
- When the current from the feed line reaches the patch, it excites the structure and generates electromagnetic waves.
- These waves radiate from the edges of the patch, forming the antenna's radiation pattern.
- The thickness of the dielectric substrate affects the wave propagation; since the substrate is thin, some waves reflect back from the edges instead of radiating outward.
- The continuous metal surface of the patch does not radiate energy uniformly, radiation occurs primarily at discontinuities, i.e., at the patch edges.
- As only a small portion of the total energy is radiated, the antenna's efficiency is relatively low.
- Therefore, a patch antenna behaves more like a resonant cavity than a strong transmitter, which limits its use in applications requiring high radiation efficiency.

Types of Patch Antennas :

- A patch antenna, also known as a microstrip antenna, consists of a metallic patch placed over a ground plane, separated by a dielectric substrate.
- The shape of the patch determines the antenna's resonant frequency, polarization, bandwidth and radiation characteristics.
- Patch antennas are classified mainly based on the shape of the radiating patch and the feeding technique as listed below :

1. **Rectangular Patch Antenna :**
   - Most commonly used type due to simple design and analysis.
   - Easy to fabricate using PCB technology.
   - Resonant frequency depends mainly on the length (L) and dielectric constant (ε_r).
   - Supports linear or circular polarization.
   - It is used in mobile communication, GPS, WLAN, radar systems.

2. **Circular Patch Antenna :**
   - The patch is circular in shape.
   - Supports circular or linear polarization depending on feed type.
   - Compact in size compared to rectangular patches.
   - Offers narrow bandwidth but good symmetry in radiation pattern.
   - It is used in satellite and space communication, GPS receivers.
3. **Triangular Patch Antenna :**
   - The patch is equilateral or right-angled triangle.
   - Compact and lightweight.
   - Useful for array configurations due to small size.
   - Provides narrow bandwidth and moderate gain.
   - It is used in aerospace and defense communication systems.
4. **Elliptical Patch Antenna :**
   - Provides wideband performance compared to circular patches.
   - Supports dual polarization and wide-angle scanning.
   - Used in broadband and high-frequency applications.
   - It is used in wideband wireless communication systems.
5. **Ring or Annular Patch Antenna :**
   - Shaped like a ring (donut-shaped) patch with an inner and outer radius.
   - Offers dual-frequency operation and reduced surface wave losses.
   - Compact and suitable for multiband communication.
   - It is used in RFID, GPS and mobile satellite communication.
6. **Slot Patch Antenna :**
   - Has a slot or cut-out in the patch, such as an E, H, or U shape.
   - Provides enhanced bandwidth and multiple frequency bands.
   - Used where compact, wideband antennas are needed.
   - It is used in Wi-Fi routers, Bluetooth and IoT devices.
7. **Microstrip Line Feed :**
   - A conducting strip is directly connected to the patch.
   - Simple and easy to implement, but moderate bandwidth.
8. **Coaxial Probe Feed :**
   - The inner conductor of a coaxial cable is connected to the patch.
   - Provides good impedance matching but difficult to fabricate for arrays.
9. **Aperture Coupled Feed :**
   - Energy is coupled through a slot in the ground plane.
   - Offers high isolation between feed and radiating patch.

10. **Proximity Coupled Feed :**
    - Uses electromagnetic coupling between the feed line and patch.
    - Provides high bandwidth and low spurious radiation, but complex design.

Table 3.3 : Summary of the types of patch antenna

Type of Patch	Shape	Key Features	Typical Applications
Rectangular	Simple, λ/2 resonant	Easy design, linear/circular polarization	WLAN, GPS
Circular	Compact, symmetric	Circular polarization	Satellite, GPS
Triangular	Small, lightweight	Suitable for arrays	Aerospace
Elliptical	Wideband	Dual polarization	Broadband systems
Ring (Annular)	Donut-shaped	Dual-band operation	RFID, GPS
Slot (E, H, U-shaped)	Modified patch	Multiband, wideband	Wi-Fi, IoT

Advantages of Patch Antenna :
- Compact, low-profile and lightweight, easy to mount on flat or curved surfaces.
- Low fabrication cost and simple to manufacture using PCB technology.
- Supports both linear and circular polarization.
- Can be easily integrated with microwave circuits.
- Suitable for array configuration to achieve high gain.
- Ideal for aerospace, mobile and satellite communication due to small size and low weight.

Disadvantages of Patch Antenna :
- Low gain and low efficiency due to dielectric and conductor losses.
- Narrow bandwidth limits its frequency range of operation.
- Surface wave excitation may cause signal distortion and reduce efficiency.
- Power handling capacity is low.
- Performance is sensitive to fabrication tolerances and substrate parameters.

3.9 CONCEPT OF SMART ANTENNAS

- A Smart Antenna is an advanced antenna system that automatically adjusts its radiation pattern to improve signal quality and communication performance.
- Unlike traditional antennas that radiate or receive signals uniformly in all directions, smart antennas use signal processing algorithms to dynamically direct the beam toward desired users and suppress interference from unwanted directions.
- These antennas work by using multiple antenna elements and digital signal processing (DSP) techniques to analyze the signal environment and adapt their transmission or reception characteristics in real time.

3.9.1 Multiple Input Multiple Output (MIMO)

- MIMO is a key technology used in modern wireless communication systems like 4G LTE, 5G and Wi-Fi, which employs multiple transmitting and receiving antennas to improve communication performance.

Importance of MIMO :

1. MIMO allows the transmission of multiple data streams simultaneously over the same frequency band, significantly increasing throughput without requiring extra bandwidth.
2. It makes better use of the available spectrum by transmitting more bits per second per hertz (bps/Hz).
3. By using multiple antennas, MIMO provides spatial diversity, reducing the impact of fading and signal loss caused by multipath propagation.
4. Multiple signal paths strengthen the overall reception quality, improving coverage in dense urban or indoor environments.
5. Advanced MIMO techniques like beamforming help direct signals precisely toward users, minimizing interference with others.
6. Essential for LTE, 5G NR and modern Wi-Fi (802.11n/ac/ax) technologies, enabling higher capacity and better user experience.

Block Diagram of MIMO :

- Multiple Input Multiple Output (MIMO) communication uses multiple antennas and single radio channel to send the same information as several signals simultaneously.
- A simple MIMO system is shown in below Fig. 3.13.

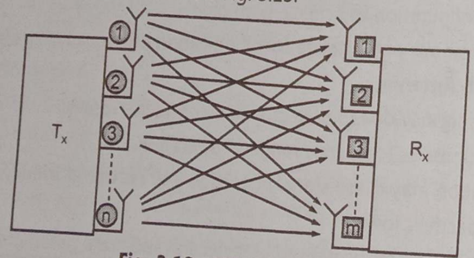


Fig. 3.13 : MIMO system

- As shown in Fig. 3.13, MIMO technology employs multiple antennas at both the transmitter and receiver ends to enhance the signal strength and quality of an RF communication link through antenna diversity.
- The transmitted data is divided into several independent data streams, each sent over a different antenna, allowing parallel transmission within the same frequency band.
- At the receiver end, the corresponding MIMO configuration with multiple antennas reassembles these data streams using advanced signal processing techniques, resulting in improved throughput, reliability and resistance to fading and interference.
- The block diagram of MIMO is shown in Fig. 3.14.

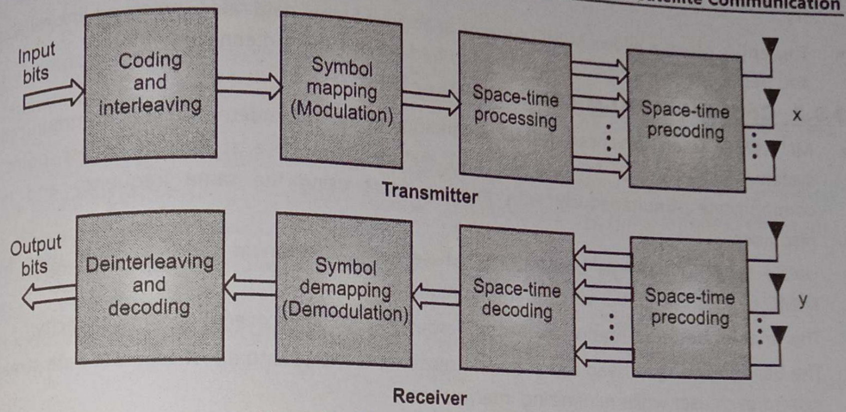


Fig. 3.14 : Block diagram of MIMO

- As shown in Fig. 3.14, a MIMO system consists of multiple antennas at both the transmitter and receiver ends.
- The basic block diagram includes the following components:

1. **Transmitter Section :**
   - The process begins with the original digital data or information bits to be transmitted.
   - The bits are encoded using a channel encoder (e.g., convolutional or turbo code) to add redundancy and enable error detection and correction at the receiver.
   - The encoded bits are interleaved to minimize the effect of burst errors during transmission.
   - The interleaved bits are mapped into modulation symbols (e.g., QAM or PSK symbols).
   - These modulation symbols are then processed by a space-time encoder, which generates one or more spatial data streams for parallel transmission.
   - The spatial data streams are mapped to multiple transmit antennas using a precoding technique to improve diversity and reduce interference.
   - The signals are transmitted simultaneously through multiple antennas and they propagate through different paths in the wireless channel.
2. **Receiver section :**
   - Multiple antennas receive the signals, each carrying versions of the transmitted data affected differently by the channel.
   - The receiver applies space-time signal processing to combine and separate the received signals effectively.
   - The combined signals are decoded to recover the original spatial data streams.
   - The decoded symbols are demapped to retrieve the corresponding bit sequences.
   - The bit sequences are deinterleaved to restore the original order of bits.
   - Finally, error correction decoding is performed to obtain the original transmitted information bits.

- This entire process allows MIMO systems to achieve higher data rates, improved link reliability and better spectral efficiency compared to traditional single-antenna systems.

3.9.2 Concept of MU-MIMO (Multi-User MIMO)

- MU-MIMO is an advanced MIMO technology used in modern wireless communication systems (like 4G LTE, 5G and Wi-Fi 6) that allows a base station or access point to communicate simultaneously with multiple users using the same frequency and time resources.
- Unlike SU-MIMO (Single-User MIMO), where multiple antennas serve a single user, MU-MIMO divides the spatial streams among multiple users.
- This enables better utilization of spectral resources and higher overall network capacity.
- The base station uses beamforming and precoding techniques to direct separate data streams toward each user while minimizing interference.

Working Principle :

- The base station has multiple transmit antennas and each user device may have one or more receive antennas.
- Data intended for different users is processed using space-division multiplexing.
- Beamforming ensures that each user receives their own data stream with minimal interference from streams intended for other users.
- The receiver extracts the signal intended for it using signal processing techniques.

Advantages of MU-MIMO :

- It has higher network capacity, as multiple users served simultaneously increases throughput.
- Through MU-MIMO, more data transmitted per unit frequency.
- It reduces waiting times and improved data rates.
- It is efficient for dense networks and ideal for areas with many active users (stadiums, offices, urban hotspots).

3.9.3 Concept of Massive MIMO

- Massive MIMO is an advanced extension of MIMO technology used in 5G and beyond wireless communication systems, where the base station is equipped with a very large number of antennas (tens or even hundreds) to serve multiple users simultaneously.
- It uses hundreds of antennas at the base station to spatially multiplex many users on the same time-frequency resources.
- By exploiting beamforming and spatial diversity, massive MIMO significantly increases spectral efficiency, throughput and link reliability.
- Each antenna element contributes to narrower and highly directed beams, reducing interference and enhancing signal strength for individual users.
- The word 'massive' refer to the number of antennas and not the physical size.

Working Principle :

- Hundreds of antennas transmit and receive signals simultaneously.
- Multiple users are served with independent data streams on the same frequency and time slots.
- Narrow beams are formed for each user to maximize signal quality and minimize interference.
- Advanced algorithms (e.g., precoding, channel estimation) manage many antennas efficiently.

Advantages of Massive MIMO :

- It supports more users on the same bandwidth.
- It can communicate with many users which increases throughput.
- It reduces fading and interference through spatial diversity.
- Its' focused beams reduce transmission power requirements which increase its angry efficiency.
- It is ideal for dense urban environments and 5G high-capacity networks.

Applications :

- 5G cellular networks and future 6G systems.
- High-capacity Wi-Fi networks.
- IoT networks with massive device connectivity.
- Urban, stadium and enterprise networks.

3.10 SATELLITE COMMUNICATION

- Satellite communication is "a modern communication technology that enables the transfer of information between distant locations on Earth using an artificial satellite placed in orbit".
- The satellite, known as a communication satellite, is specifically designed to establish a communication link by receiving, amplifying and retransmitting signals between a transmitter and a receiver on the ground.
- This system provides an efficient means of communication over vast geographical areas, making it ideal for global connectivity.
- In satellite communication, the orbiting satellite functions as a repeater or relay station in space, it receives signals from one Earth station (uplink), processes them and transmits them back to another station (downlink).
- Typical applications of satellite communication include television broadcasting, GPS navigation, weather monitoring, remote sensing and global internet connectivity, enabling seamless communication across the world.

3.10.1 Segments Satellite Communication System

(a) Space Segment :

- It consists of the satellite(s) in orbit.
- The satellite has transponders, antennas, solar panels and control systems.
- It receives uplink signals from earth, amplify and change their frequency and retransmit them as downlink signals back to earth.

(b) Earth Segment (Ground Segment) :

- It comprises earth stations that transmit and receive data to/from the satellite.
- It includes transmitters, receivers, parabolic antennas and tracking systems.
- It is responsible for uplink (sending) and downlink (receiving) signals.

3.10.2 Satellite Orbits

- Satellites are placed in orbits depending on their purpose and coverage area. Common types are:

1. **Geostationary Earth Orbit (GEO):**
   - Its altitude is ~35,786 km above Earth.
   - It appears stationary relative to Earth; ideal for TV broadcasting, weather monitoring.
   - Its coverage is large, typically one-third of the Earth's surface.
2. **Medium Earth Orbit (MEO):**
   - Its altitude is 2,000 to 35,786 km.
   - It is used for navigation systems like GPS.
3. **Low Earth Orbit (LEO):**
   - Its altitude is 500 to 2,000 km.
   - It provides low latency and high data rates; used for communication constellations (e.g., Starlink).

3.10.3 Uplink and Downlink

- **Uplink:** The transmission of signals from an Earth station to a satellite.
  Example: Sending TV broadcast signals or data to the satellite.
- **Downlink:** The transmission of signals from the satellite back to the Earth station or user terminals.
  Example: Receiving the relayed broadcast or communication signal from the satellite.

3.10.4 Block Diagram of Satellite Communication

- The satellite communication system enables wireless transmission of signals between two or more distant Earth stations through a satellite acting as a relay in space.
- The system mainly consists of two parts, the Earth segment and the space segment as shown in below Fig. 3.15.

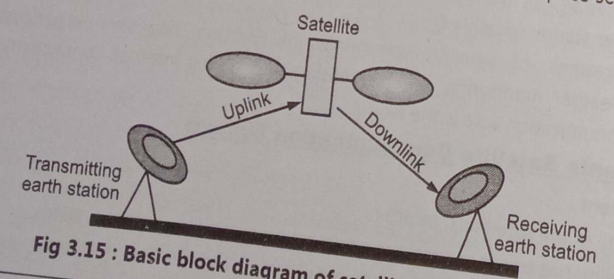


Fig 3.15 : Basic block diagram of satellite communication

- As shown in Fig. 3.15, the basic blocks of satellite communication are as follows :

1. **Earth Segment (Ground Segment) :** This segment includes the transmitting and receiving earth stations on the ground.

   (a) Transmitting Earth Station :
   - The information signal (voice, video or data) is first processed, encoded and modulated into a suitable carrier signal.
   - The high-power amplifier (HPA) boosts the signal power for long-distance transmission.
   - The parabolic dish antenna directs the signal toward the satellite, this is known as the uplink.

   (b) Receiving Earth Station :
   - The downlink signal transmitted from the satellite is received by a large parabolic antenna.
   - The signal is then amplified by a low-noise amplifier (LNA) to improve its strength.
   - It is demodulated and decoded to recover the original information.

2. **Space Segment (Satellite Segment) :**
   - The satellite acts as a repeater or transponder in space.
   - It receives the uplink signal from the transmitting earth station through its antenna.
   - The transponder performs three main functions:
     - It receives uplink signals.
     - It converts the received signal to a different frequency (to avoid interference between uplink and downlink).
     - It amplifies the signal and retransmits it toward the receiving earth station via the downlink.

3. **Communication Links :**
   - Uplink: The path from the transmitting earth station to the satellite.
   - Downlink: The path from the satellite to the receiving earth station.

Working :

- The earth station transmits signals to the satellite (uplink).
- The satellite's transponder amplifies and retransmits them back to earth on a different frequency (downlink).
- The receiving earth station then demodulates and decodes the signal to recover the original data.
- This process enables long-distance, reliable and high-capacity communication across continents and oceans.

- Frequency bands used for satellite communication are given in below table :

Band	Uplink (GHz)	Downlink (GHz)	Application
C-Band	5.925 - 6.425	3.7 - 4.2	Television and data links
Ku-Band	14 - 14.5	10.95 - 12.75	DTH, VSAT communication
Ka-Band	27.5 - 31	17.7 - 21.2	High-speed internet
X-Band	7.9 - 8.4	7.25 - 7.75	Military applications

3.10.5 Applications

1. Television Broadcasting.
2. Weather Forecasting.
3. Global Positioning System (GPS).
4. Internet and Data Communication.
5. Military and Defense Communication.
6. Disaster Management and Emergency Communication.
7. Remote Sensing and Earth Observation.
8. Telecommunication and Teleconferencing.
9. Radio Broadcasting.

Exercise

[A] Multiple Choice Questions:

[I] Choose the most correct alternative for each of the following and rewrite the sentence.

1. The basic unit of a cellular system is called a ....
   (a) Sector (b) Cell
   (c) Cluster (d) Channel
2. The process of reusing the same frequencies in different cells is known as ....
   (a) Frequency division (b) Frequency reuse
   (c) Frequency allocation (d) Frequency sharing
3. Handoff in cellular communication refers to ....
   (a) Allocating frequency to a user
   (b) Transferring an ongoing call to a new cell without disconnecting
   (c) Disconnecting a call automatically
   (d) Increasing call volume
4. UMTS stands for ....
   (a) Universal Mobile Telephone System
   (b) Universal Mobile Telecommunication System
   (c) Unified Mobile Transmission System
   (d) Universal Multichannel Telecommunication System

5. LTE is mainly designed for ....
   (a) Voice communication only (b) High-speed data transmission
   (c) Broadcasting TV channels (d) Satellite communication
6. Which generation of mobile network introduced IP-based core architecture?
   (a) 2G (b) 3G
   (c) 4G (d) 5G
7. In 5G networks, handovers like Dual Connectivity (DC) and Multi-RAT DC (MR-DC) are used to ....
   (a) Increase the cost of devices
   (b) Ensure seamless data transfer between networks
   (c) Limit mobility
   (d) Reduce signal strength
8. 6G technology aims to offer data rates up to ....
   (a) 1 Gbps (b) 10 Gbps
   (c) 1 Tbps (d) 100 Mbps
9. A dipole antenna consists of ....
   (a) Two conductors placed end-to-end (b) A single metal plate
   (c) A circular loop (d) A dielectric rod
10. The operating principle of a dipole antenna is based on ....
    (a) Transmission line theory (b) Resonance and radiation of current
    (c) Optical reflection (d) Refraction of waves
11. A patch antenna mainly radiates due to ....
    (a) Surface current (b) Edge fringing fields
    (c) Magnetic coupling (d) Dielectric losses
12. One of the main advantages of a patch antenna is ....
    (a) High cost (b) Bulky design
    (c) Compact and low-profile (d) Heavy structure
13. MIMO stands for ....
    (a) Multiple Input Multiple Output (b) Multi Interface Multi Output
    (c) Multi Integrated Multiple Operation (d) Multiple Intelligent Modular Output
14. The main function of MIMO is to ....
    (a) Reduce frequency reuse (b) Increase data rate and reliability
    (c) Increase antenna size (d) Reduce number of antennas
15. In MU-MIMO, multiple users ....
    (a) Share the same frequency at the same time (b) Are connected sequentially
    (c) Use different base stations (d) Use different frequency bands

16. The three main segments of satellite communication are ....
    (a) Space, Ground, User
    (b) Uplink, Downlink, Orbit
    (c) Space, Control, User
    (d) Transmitter, Receiver, Antenna
17. The uplink frequency is .... than the downlink frequency.
    (a) Lower
    (b) Equal
    (c) Higher
    (d) Variable
18. Typical C-band satellite communication frequencies are ....
    (a) 4-8 GHz
    (b) 10-15 GHz
    (c) 1-2 GHz
    (d) 20-30 GHz
19. The satellite acts as a .... between transmitting and receiving earth stations.
    (a) Receiver
    (b) Repeater
    (c) Transmitter only
    (d) Amplifier
20. Which of the following is not an application of satellite communication?
    (a) Weather forecasting
    (b) Television broadcasting
    (c) Internet access
    (d) Fiber optic communication

Answers

1. (b)	2. (b)	3. (b)	4. (b)	5. (b)
6. (c)	7. (b)	8. (c)	9. (a)	10. (b)
11. (b)	12. (c)	13. (a)	14. (b)	15. (a)
16. (c)	17. (c)	18. (a)	19. (b)	20. (d)

[II] True or False :

1. The basic unit of a cellular communication system is called a cell.
2. Frequency reuse allows the same frequency to be used in all adjacent cells.
3. A handoff occurs when a mobile user moves from one cell to another without interruption in service.
4. UMTS is a 2G mobile communication technology.
5. LTE is designed primarily for high-speed voice communication only.
6. 4G networks are based on IP (Internet Protocol) technology.
7. 5G networks provide ultra-low latency and enhanced data rates compared to 4G.
8. Dual Connectivity (DC) and Multi-RAT Dual Connectivity (MR-DC) are advanced handover techniques used in 5G networks.
9. 6G aims to provide data rates up to 1 Tbps and support AI-integrated wireless systems.
10. A dipole antenna consists of a single wire and a ground plane.
11. The radiation from a dipole antenna is maximum along its axis.
12. A patch antenna radiates due to fringing fields at the edges of the patch.
13. Patch antennas are bulky and expensive.

14. The main limitation of a patch antenna is its low radiation efficiency.
15. MIMO stands for Multiple Input Multiple Output.
16. MIMO technology uses multiple antennas at both transmitter and receiver to increase capacity and reliability.
17. In MU-MIMO, a base station communicates with only one user at a time.
18. Massive MIMO uses a large number of antennas (tens or hundreds) at the base station.
19. Smart antennas help reduce interference and improve signal quality.
20. A satellite communication system consists of three main segments: Space segment, Control segment and User segment.
21. The uplink frequency is lower than the downlink frequency.
22. The satellite acts as a repeater that receives, amplifies and retransmits signals back to Earth.
23. A geostationary satellite orbits the Earth once every 24 hours.
24. The C-band frequency range used in satellite communication is 4-8 GHz.
25. Satellite communication cannot be used for weather monitoring.

Answers

1. True	2. False	3. True	4. False	5. False
6. True	7. True	8. True	9. True	10. False
11. False	12. True	13. False	14. True	15. True
16. True	17. False	18. True	19. True	20. True
21. True	22. True	23. True	24. True	25. False

[III] Fill in the blanks :

1. The basic building block of a cellular communication system is called a ....
2. In a cellular network, the technique used to reuse frequencies in different cells is called ....
3. The process of transferring an active call from one cell to another is known as ....
4. UMTS stands for ....
5. LTE stands for ....
6. The 4G network is based on .... architecture.
7. 5G provides .... and ....
8. In 5G, Dual Connectivity (DC) and Multi-RAT Dual Connectivity (MR-DC) help in achieving .... between networks.
9. 6G is expected to provide data rates up to .... and integrate AI-driven communication systems.
10. A .... consists of two conductive elements placed end-to-end.
11. The radiation from a dipole antenna is .... to its axis.
12. A .... consists of a conducting patch on one side of a dielectric substrate and a ground plane on the other.
13. A major limitation of patch antennas is their ....
14. MIMO stands for ....

15. The ……… is the communication path from earth to satellite, while the ……… is from satellite to earth.
16. The uplink frequency is always ……… than the downlink frequency to avoid interference.
17. The satellite acts as a ………, which receives, amplifies and retransmits signals.
18. The ……… frequency range used in satellite communication is approximately 4-8 GHz.

Answers

1. Cell	2. frequency reuse	3. handoff (or handover)
4. Universal Mobile Telecommunication System		5. Long Term Evolution
6. IP (Internet Protocol)		
7. enhanced data rate, ultra-low latency and massive connectivity		
8. seamless handover	9. 1 Tbps	10. dipole antenna
11. maximum perpendicular	12. patch antenna	13. low radiation efficiency
14. Multiple Input Multiple Output		15. Uplink, downlink
16. Higher	17. repeater	18. C-band

[B] Short Answer Questions :

1. What is a cell in cellular communication?
2. Define cellular telephony.
3. What is frequency reuse in cellular networks?
4. Explain the concept of handoff (handover).
5. Expand UMTS and mention its generation.
6. What is LTE and what is its main objective?
7. List the main features of 4G technology.
8. Mention any two key features of 5G technology.
9. State any two expected features of 6G technology
10. What is a dipole antenna?
11. Explain the working principle of a dipole antenna.
12. Define a patch antenna.
13. Why does a patch antenna radiate electromagnetic waves?
14. Mention one advantage and one disadvantage of a patch antenna.
15. What is MIMO?
16. State the main advantage of using MIMO systems.
17. What is MU-MIMO?
18. What is Massive MIMO?
19. Mention any two benefits of smart antennas.
20. What are the main segments of a satellite communication system?
21. Define uplink and downlink.
22. Why is the uplink frequency higher than the downlink frequency?

23. What is the function of a satellite transponder?
24. What is the frequency range of the C-band used in satellite communication?
25. Mention any two applications of satellite communication.

[C] Long Answer Questions :

1. Explain the concept of a cellular communication system with neat diagrams.
2. Describe the structure of a cell and explain the concept of frequency reuse.
3. Explain the process of handoff in cellular communication systems.
4. Write a detailed note on the architecture and working of UMTS.
5. Explain the architecture and main features of LTE.
6. Compare 3G (UMTS) and 4G (LTE) technologies in terms of speed, architecture and performance.
7. Describe the architecture and working of 5G networks with a neat block diagram.
8. Explain the different types of handovers used in 5G networks including DC and MR-DC.
9. Discuss the key features, technologies and potential applications of 6G communication systems.
10. Explain the working principle and radiation pattern of a dipole antenna with a neat diagram.
11. Describe the construction and working of a patch antenna with neat diagrams.
12. Compare the dipole and patch antennas based on design, performance and applications.
13. Write short notes on different types of dipole antennas.
14. Explain the types and characteristics of patch antennas used in wireless systems.
15. Explain the concept of smart antennas and their importance in modern wireless communication.
16. Draw and explain the block diagram of a MIMO system.
17. Describe the working of a MIMO system and explain how it improves communication reliability.
18. Explain the concept of MU-MIMO and discuss its advantages in wireless networks.
19. Describe the concept and working of Massive MIMO with a neat block diagram.
20. Compare SU-MIMO, MU-MIMO and Massive MIMO in terms of configuration and performance.
21. Draw and explain the block diagram of a satellite communication system.
22. Describe the three main segments of satellite communication: space segment, ground segment and user segment.
23. Explain the different types of satellite orbits used in communication systems (GEO, MEO and LEO).
24. Discuss the concept of uplink and downlink with frequency ranges used in satellite communication.
25. Write a detailed note on the applications of satellite communication in various fields.

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Syllabus ...

1. Introduction to Communication System (6 Hours)

- **Introduction to Communication System:** Elements of digital communication system (block diagram and explanation).
- **Characteristics of Communication Channel:** Signal, Signal types, Signal bandwidth, Channel bandwidth, Signal to noise ratio, Noise figure, Data rate, Baud rate, Channel capacity, Shannon-Hartley theorem. (Definition only).
- **Signal encoding:** Types of signal encoding formats, M-ary coding (Concept level),
- **Error Handling Codes:** Necessity of error control codes, Types of error handling codes, Hamming code (Error detection and correction).
- **Modulation and Demodulation:** Definition of modulation and demodulation, Need of modulation, Classification of Modulation.

2. Digital Modulation, Multiplexing and Spread Spectrum Techniques (8 Hours)

- **Pulse Modulation:** Nyquist sampling theorem, PCM (Transmitter and receiver block diagram, Advantages, disadvantages and application), Concept of Delta modulation and Adaptive delta modulation.
- **Digital Modulation Techniques:** ASK, PSK (Concept, waveform and application), FSK, QPSK, (Transmitter end block diagram, working, waveforms, application), 4-QAM (Phaser Diagram, constellation diagram and application.)
- **Multiplexing Techniques:** Necessity of signal multiplexing, FDM, TDM, CDM, OFDM (Conceptual diagram and working).
- **Spread Spectrum Techniques:** Introduction to Spread Spectrum (SS), Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS), Pseudo-random (PN) sequence.

3. Cellular and Satellite Communication (8 Hours)

- **Cellular Communication:** Cell and cellular telephony, Frequency reuse and hand-off, LTE, UMTS, 4G, 5G architecture network, Handovers in 5G, Future generation 6G.
- **Types of Antennas:** Working principle of dipole antenna and patch antenna.
- **Concept of Smart Antennas:** Importance and block diagram of MIMO, Concept of MU-MIMO and Massive MIMO.
- **Satellite Communication:** Segments, Orbits, Uplink and downlink (Block diagram and frequencies), and Applications.

4. Modern Communication Technology (8 Hours)

- **Wireless Sensor Network:** Sensing & Actuation (Concept only), WSN Architecture, WSN topologies, Types of nodes (Co-ordinator, Router and End Device).
- **Wireless Communication Protocols:** Bluetooth, Wi-Fi & RFID.
- **Data Acquisition**: Basic of Arduino platform (Pin diagram and significance of each pin), I/O control and data acquisition using Arduino.
- **Introduction of IoT:** Definition, Characteristics, Challenges and IoT applications.

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