1.Introduction to Wireless Communication

1. Wireless communication

- Wireless communication is the transmission of data or information between two or more devices without the use of physical wires or cables.
- It uses electromagnetic waves like radio waves, microwaves, or infrared for data transfer.
- It is widely used in **telecommunication, networking, IoT devices, satellite communication, and mobile systems.**
- Wireless communication, also known as **Unguided Media or Unbounded Transmission Media**, is a method of transmitting electromagnetic signals without the use of any physical medium like cables or wires.
- The transmission occurs through the **air, water, or even vacuum**, using technologies such as **Infrared, Radio waves, and Microwaves**.

Features of Wireless Communication

- **No physical medium required** – Signals are transmitted without wires or cables.
- **Supports multiple mediums** – Can carry signals through air, water, or even vacuum.
- **Long-distance capability** – Signals can travel large distances depending on the technology.
- **Less secure –** More prone to interception and unauthorized access compared to wired communication.

Advantages of Wireless Communication

- Flexibility and mobility
- Ease of installation
- Cost-effective for large areas
- Supports multiple devices
- Remote access
- Scalability

Disadvantages of Wireless Communication

- Less secure
- Signal interference
- Limited bandwidth
- Lower data transfer rate
- High power consumption
- Range limitations

2. Types Wireless communication

S.no	Infrared	Radio Waves	Microwaves
1	Infrared is used for short-range communication like TV remotes, mobile phones, personal computers, etc. In science, the Infrared is part of a spectrum that is not visible to the human eye	Radio waves are the type of wireless communication that can travel large distances as well as can penetrate any wall	Microwaves are a line of sight transmission, meaning both the antennas sending and receiving should be properly aligned.
2	The frequency range of infrared rays 300GHz – 400THz	The frequency range of radio waves:3KHz – 1GHz.	Microwaves have a frequency Range between 1GHz – 300GHz.
3	The limitation of infrared rays is that they cannot penetrate any obstacles and can only use for short-range. Also, Infrared is used in night vision cameras as it has thermal properties. The frequency range of infrared rays 300GHz – 400THz	It can travel large distances as well as can penetrate any wall (Omni-directional,	They are unidirectional, as they can move in only one direction, and therefore it is used in point-to-point communication or unicast communication such as radar and satellite.
4	Infrared is one of the secure wireless communication mediums as it is used for short-range. Also, unlike other wireless mediums, infrared is quite inexpensive, and this is some reason it is used in many electronic devices.	Radio waves can travel to long distances so it is used for long distance communication and there is no need of digging and spreading wires.	Advantages of microwaves then we say that it is a very fast way of communication, that can carry 25000 voice channels at the same time. Also, it is a wireless communication medium so there is no need of digging and spreading wires.
5	Infrared waves are used in TV remotes, mobile phones, personal computers	Radio waves are used in AM and FM radios, and cordless phones.	Microwaves are used in mobile phones communication and television distribution.

Ad	- High security due to line-of-sight (LOS) communication - Low interference - Low power consumption	- Long-distance coverage - Can penetrate walls - Widely used (TV, radio, Wi-Fi)	- High bandwidth - Suitable for long-distance and satellite communication - Faster data transmission
Dis ad	- Requires LOS - Short range (a few meters) - Cannot penetrate walls	- Prone to interference - Less secure (easily intercepted) - Limited bandwidth	- Expensive setup - Requires LOS - Affected by rain (rain fade)

4. Bluetooth Communication

- Short-range wireless technology.
- Operates at **2.4 GHz ISM band**.
- Used for connecting peripherals (wireless keyboards, headphones).
- **Range:** Typically up to 100 meters.

5. Wi-Fi Communication

- Uses **radio waves (2.4 GHz/5 GHz/6 GHz bands)**.
- Provides wireless internet access for local area networks (WLAN).
- **Range:** 30–100 meters indoors.

6. Satellite Communication

If the communication takes place between any two earth stations through a satellite, then it is called as **satellite communication**. In this communication, electromagnetic waves are used as carrier signals.

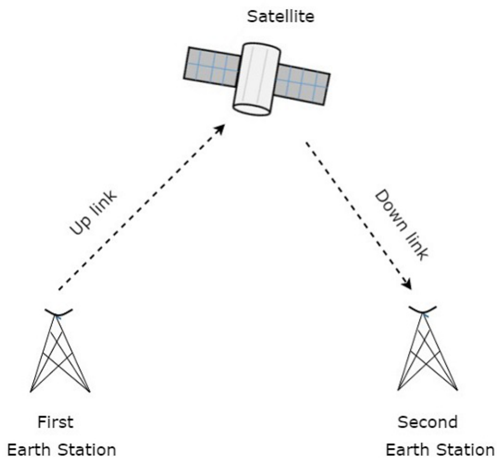
These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

A **satellite** is an object that moves around another object (such as Earth) in a fixed path known as an orbit.

A **communication satellite** acts as a **microwave repeater station in space**, enabling telecommunications, television, radio, and internet services.

Basic Concept

- A **repeater** strengthens a received signal and retransmits it.
- In satellites, this repeater is called a **transponder**, which not only amplifies the signal but also **changes its frequency** to avoid interference between the incoming (uplink) and outgoing (downlink) signals.



Key Terms

- **Uplink Frequency:**
  The frequency at which signals are transmitted from the **first earth station** to the satellite.
- **Downlink Frequency:**
  The frequency at which the satellite sends signals back to the **receiving earth station**.
- **Satellite Footprint:**
  The area on Earth where the satellite signal is strong enough to be received effectively.

Working Process of a Communication Satellite

1. **Transmission from Earth Station (Uplink)**
   - An earth station sends high-power, high-frequency (GHz range) signals to the satellite.
2. **Reception by Satellite**
   - The satellite receives the uplink signal using its antenna.
3. **Signal Processing by Transponder**
   - The transponder amplifies the signal.
   - Changes its frequency to the downlink frequency.
   - Prepares it for retransmission.
4. **Transmission to Second Earth Station (Downlink)**
   - The processed signal is transmitted back to Earth.
5. **Reception by Ground Station/Users**
   - The receiving earth station or user device decodes the signal for further use (TV, internet, radio, etc.).

- Uses satellites for **long-distance communication**.
- Operates using microwaves.
- Used for GPS, TV broadcasting, weather forecasting, and space communication.

7. Mobile Cellular Communication

- Uses cellular networks (2G, 3G, 4G, 5G).
- Based on radio frequencies.
- Enables voice calls, text messaging, and internet.

3.Generation of Cellular network

0th Generation:

- Pre-cell phone mobile telephony technology, such as radio telephones some had in cars before the arrival of cell phones.
- Communication was possible through voice only.
- These mobile telephones were usually mounted in cars or trucks.

1G (1st Generation):

- First-time calling was introduced in mobile systems.
- It used analog signals.
- It used an FDD scheme and typically allocated a bandwidth of 25 Mhz.
- The coverage area was small.
- No roaming support between various operators.
- Low sound quality.
- Speed:- 2.4 kbps.

2G (2nd Generation) :

- Shifted from analog to digital.
- It supported voice and SMS both.
- Supported all 4 sectors of the wireless industry namely Digital cellular, Mobile Data, PCS, WLAN,
- Moderate mobile data service.
- 2G WLAN provided a high data rate & large area coverage.
- Speed:- 64 kbps.

2.5G came after **2G** which used the concept of GPRS. Streaming was also introduced and mail services too. Then came **2.75G** or EDGE which was faster in providing services than 2.5G. It gave faster internet speed up to 128kbps and also used edge connection.

3G (3rd Generation) :

- The Internet system was improved.
- Better system and capacity.
- Offers high-speed wireless internet.
- The connection used was UMTS and WCMA.
- Speed:- 2mbps.

4G (4th Generation) :

- IP-based protocols.
- LTE (Long term evaluation) was mainly for the internet.
- Vo-LTE (Voice over LTE) is for both voice and the internet.
- Freedom and flexibility to select any desired service with reasonable QoS.
- High usability.
- Supports multimedia service at a low transmission cost.
- HD Quality Streaming.
- Speed:-100mbps.

5G (5th Generation):

It is yet to come in many countries but here are some notable points about 5G.

- Higher data rates.
- Connectivity will be more fast and more secure,
- Data Latency will be reduced to a great level.
- Massive network capacity.
- It is 30 times faster than 4G.
- There would be more flexibility in the network.

6G (Sixth Generation) (Upcoming)

6G refers to the sixth generation of mobile/cellular technology and is in the early stages of standardization.

Commercial rollouts are anticipated around **2030–2035**

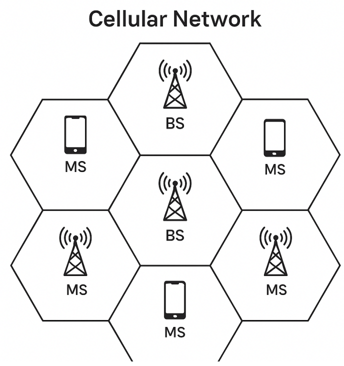
- Ultra-high speed and microsecond latency
- Terahertz frequency and AI-driven networks
- Supports holographic communication, XR, and digital twins
- Expected Speed: **Up to 1 Tbps**

2.Fundamentals of Cellular and LTE Technology

1.Cellular System

A **cellular system** is a wireless communication network that divides a large geographical area into smaller regions called **cells**, each served by its own **base station (BS)**.

This concept allows efficient use of frequencies, supports a large number of users, and provides seamless communication.



Key Components

1. **Cell** – A hexagon-shaped region where radio coverage is provided.
2. **Base Station (BS)** – Contains antennas and transceivers to communicate with mobile devices.
3. **Mobile Station (MS)** – User's device (mobile phone, tablet, etc.).
4. **Mobile Switching Center (MSC)** – Controls multiple base stations and manages call routing, handovers, and connections to external networks.

Working Principle

1. The total service area is divided into **multiple cells** (typically hexagonal).
2. Each cell operates on a **specific frequency band** to avoid interference.
3. As a user moves from one cell to another, a process called **handover (handoff)** ensures uninterrupted service.
4. The cellular system **reuses frequencies** in non-adjacent cells, increasing capacity.

Features of Cellular System

- Frequency reuse for efficient spectrum utilization.
- Handoff mechanism for uninterrupted mobility.
- Increased network capacity.
- Coverage over large areas using small cells.
- Scalability and flexibility.

Applications

- Mobile telephony (2G–5G and beyond)
- Wireless internet services
- IoT (Internet of Things) devices
- Vehicle tracking and navigation

2.Concept of Cell and Hexagonal Geometry in Cellular Systems

Cell Concept

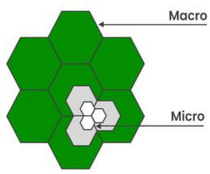
- A **cell** is the basic geographic unit of a cellular network.
- The entire service area is divided into smaller regions called **cells**, each served by a **Base Station (BS)**.
- Each base station consists of an antenna, transmitter, and receiver to facilitate communication between mobile users and the network.
- The purpose of using cells is to enable **frequency reuse**, allowing multiple users to share the same frequency without interference.

Hexagonal Geometry of a Cell

- Cells are represented by hexagons for simplicity in design and analysis.
- **Hexagons are preferred** because:
    - They cover the area without overlapping or leaving gaps (better than circles).
    - They allow **uniform frequency reuse planning**.
    - Each cell has **six neighboring cells**, making frequency allocation efficient.

Diagram of Hexagonal Cell Geometry

Key Components:

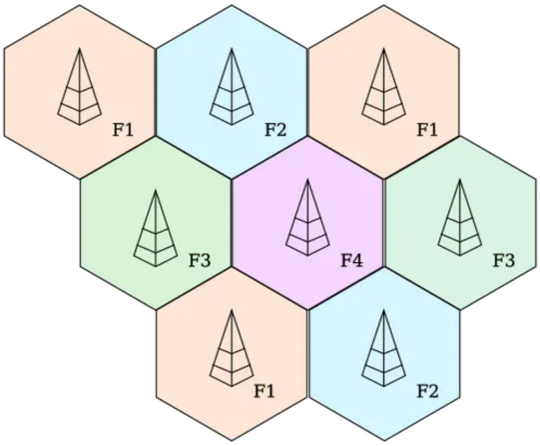


1. **Hexagonal cells** representing the coverage area.
2. **Base Station (BS)** located at the center of each hexagon.
3. **Mobile Stations (MS)** distributed within cells.
4. **Neighboring** cells sharing edges for seamless handover.

3.Explain concept of frequency reuse, its advantages and problems.

Frequency reuse means using the same set of frequencies in different areas (cells) of a mobile network to serve more users without needing more spectrum.

- The entire area is divided into small regions called **cells** (shaped like hexagons usually).
- Each cell gets a group of frequencies.
- The same frequencies can be used again in another cell that is far enough away to avoid interference.



Advantages

1. **Saves frequencies** – You don't need new frequencies for each cell.
2. **More users served** – The same limited spectrum can handle many users.
3. **Cost-effective** – No need to buy extra spectrum repeatedly.
4. **Easy expansion** – New cells can be added as demand grows.

Problems

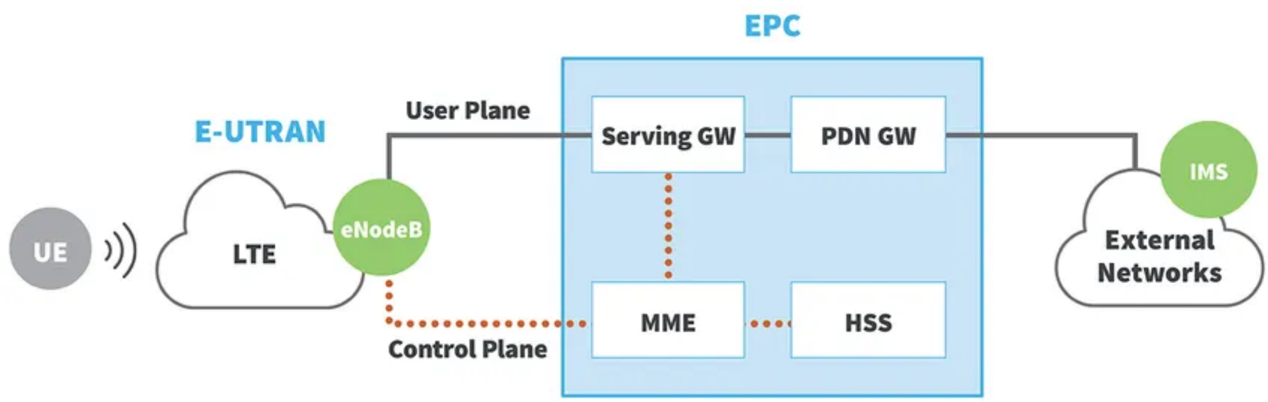
1. **Signal interference** – If cells using the same frequency are too close, signals disturb each other.
2. **Planning difficulty** – The distance between cells and power levels must be planned carefully.
3. **Handover challenges** – Managing calls or data when users move between cells becomes more complex.

4. Architecture of LTE:-

LTE was introduced to overcome the limitations of older mobile communication technologies (2G and 3G) and meet the growing demand for high-speed data and better quality communication.

Why is LTE needed?

1. **Higher Data Rates:** Supports download speeds up to 100 Mbps and upload speeds up to 50 Mbps.
2. **Low Latency:** Reduces delay in data transfer, making it suitable for real-time applications like video calls and gaming.
3. **Improved Spectrum Efficiency:** Uses available frequency bands more effectively.
4. **Better User Experience:** Provides faster internet and smoother multimedia streaming.
5. **Supports All-IP Network:** Voice, data, and multimedia all operate over an IP-based network.
6. **Future Ready:** Provides a path toward 5G.



1. User Equipment (UE)

- Represents the mobile device (smartphone, tablet, etc.).
- Communicates wirelessly with the LTE network.

2. E-UTRAN (Evolved UMTS Terrestrial Radio Access Network)

- **LTE Cloud:** Represents the radio access network.
- **eNodeB (Evolved Node B):**
  - Works as the base station.
  - Manages radio communications with UE.
  - Handles handovers, scheduling, and radio resource control.

3. EPC (Evolved Packet Core)

The main core network that handles data and signaling. It consists of:

User Plane (for data transfer):

- **Serving Gateway (SGW):** Routes and forwards user data between the eNodeB and PDN Gateway.
- **PDN Gateway (PGW):** Connects the LTE network to external networks (e.g., Internet, IMS).

Control Plane (for signaling and management):

- **MME (Mobility Management Entity):** Handles user authentication, mobility management, and session control.
- **HSS (Home Subscriber Server):** Stores user profiles, subscription details, and authentication information.

4. External Networks

- Connects to the internet or IMS (IP Multimedia Subsystem) for services like VoIP and video calls.

Key Features of LTE (Long Term Evolution)

1. High Data Rates
2. Low Latency
3. All-IP Network
4. High Spectral Efficiency
5. Scalable Bandwidth
6. Improved Capacity
7. Better Mobility
8. Improved QoS (Quality of Service)
9. Simplified Network Architecture
10. Smooth Evolution Path

5. Microcell Zone Concept

A **Microcell Zone** is used in cellular systems to improve coverage and capacity, especially in urban or high-density areas.

What is it?

- A microcell zone divides a regular cell (macrocell) into **smaller zones**.
- Each zone has its own **directional antenna**, but they are all connected to the same **Base Station (BTS)**.
- Zones share the same radio equipment and frequency allocation.

Why use it?

- To **reduce interference**.
- To **increase system capacity**.
- To **improve signal quality** at the edges.
- To reduce frequent handovers within a small area.

How it works?

- When a user moves from one zone to another within the same cell, the base station just switches the signal to the next zone's antenna.
- **No actual handoff is required** because it's still within the same cell.

Features of Microcell Zone Concept

1. Improved coverage
2. Less interference
3. Better capacity
4. No frequent handoffs within a cell
5. Cost-effective
6. Efficient for urban areas
7. Flexible expansion

6. Handoff Scenario at the Cell Boundary

Handoff (or Handover) is the process of transferring an ongoing call or data session from one cell to another as the user moves.

Cell Boundary Handoff Steps

1. **Signal Measurement:**
   - The mobile device continuously measures the signal strength of the serving cell and nearby cells.
2. **Threshold Reached:**
   - As the user moves towards the cell boundary, the signal of the current cell becomes weak.
3. **Handoff Decision:**
   - The network compares the signal strength of the current cell with neighboring cells.
   - If a neighboring cell's signal is stronger, the handoff process starts.
4. **Handoff Request:**
   - The current base station (BTS) requests the network to prepare a handoff to the target cell.
5. **Resource Allocation:**
   - The target base station reserves a channel or resources for the incoming connection.
6. **Switching:**
   - The call or data link is switched to the new cell without disconnecting the ongoing session.
7. **Completion:**
   - The old connection is released, and the new connection becomes active.

Types of Handoff

- **Hard Handoff:** "Break-before-make" – disconnects the old cell before connecting to the new one (used in GSM/CDMA).
- **Soft Handoff:** "Make-before-break" – connects to the new cell while still connected to the old one (used in CDMA).

Features of Handoff (at Cell Boundary)

1. Seamless communication
2. Automatic process
3. Based on signal strength
4. Maintains Quality of Service (QoS)
5. Supports hard and soft handoffs
6. Minimizes call drops
7. Occurs at cell boundaries

7.Protocol

1. Air Interface Transport Protocols (UE ↔ eNodeB)

These work over the **radio link** between the mobile device (UE) and the base station (eNodeB).

- **PDCP:** Encrypts data, compresses headers, ensures data is in the correct order.
- **RLC:** Splits or combines data, retransmits lost packets.
- **MAC:** Allocates radio resources and schedules data transmission.
- **PHY (Physical Layer):** Sends data as radio waves using OFDMA (downlink) and SC-FDMA (uplink).
- **RRC:** Controls connection setup, handovers, and security (control plane).

2. Fixed Network Transport Protocols (eNodeB ↔ EPC/Core Network)

These work in the **backhaul and core network** to carry data and control messages.

- **S1-U:** GTP-U (User Plane) – carries user data between eNodeB and Serving Gateway (SGW).
- **S1-MME:** S1-AP over SCTP – carries control messages between eNodeB and MME.
- **X2:** X2-AP – used between eNodeBs for handover and coordination.
- **S5/S8:** GTP-U (data) and GTP-C (control) between SGW and PGW.
- **S6a:** Diameter protocol between MME and HSS for authentication.

3. User Plane Protocols

These carry **actual user data (internet, video, voice over IP)** through the network.

- Uses **IP packets** at the top (e.g., TCP/UDP/RTP).
- Data travels through **PDCP → RLC → MAC → PHY** on the air side.
- In the core, data is tunneled using **GTP-U** (on S1-U, S5/S8).
- Ensures proper **Quality of Service (QoS)** via EPS bearers.

4. Signalling Protocols (Control Plane)

These manage and control the network connections (not the actual user data).

- **RRC:** Manages radio connections between UE and eNodeB.
- **NAS (EMM & ESM):** Handles attach, authentication, location update, and bearer setup (UE ↔ MME).
- **S1-AP:** Manages signaling between eNodeB and MME.
- **X2-AP:** Manages handover signaling between eNodeBs.
- **GTP-C:** Controls bearer tunnels in the core network (MME ↔ SGW, SGW ↔ PGW).
- **Diameter:** Manages subscriber info, authentication, and policy rules (MME ↔ HSS, PGW ↔ PCRF).

8. LTE Protocol Model

The LTE protocol model features a layered architecture with both a user plane for user data and a control plane for signaling, split into three main layers: Physical Layer (PHY), Layer 2 (MAC, **RLC, **PDCP), and Layer 3 (**RRC and **NAS).

These layers process data from the top down for transmission and bottom up for reception, with the user plane handling user traffic and the control plane managing network configuration and states.

1.Physical Layer (PHY):

The lowest layer, responsible for the actual transmission of data over the air interface between the user equipment (UE) and the eNodeB base station.

2.Layer 2 (Data Link Layer):

This layer consists of three sublayers:

Medium Access Control (MAC): Handles medium access and shares the radio channel among users. It includes procedures like Hybrid Automatic Repeat Request (HARQ) for error correction.

Radio Link Control (RLC): Performs segmentation, reassembly, and error correction for data packets.

Packet Data Convergence Protocol (PDCP): Responsible for header compression, ciphering, and integrity protection of data packets.

3.Layer 3 (Network Layer):

The highest layer in the radio network architecture:

Radio Resource Control (RRC): Manages the UE's connection and configuration, including moving the UE between idle and connected states.

Non-Access Stratum (NAS): Handles control signaling between the UE and the core network's Mobility Management Entity (MME), managing user authentication and session management.

The **LTE protocol model** shows how data and signaling flow through different layers in LTE. It is divided into two main parts:

1. **User Plane** – Carries user data like internet, video, and calls.
2. **Control Plane** – Manages connections, authentication, mobility, and session control.

LTE Protocol Model

User Plane	Control Plane
Application Layer	NAS
IP Layer	RRC
PDCP	S1-AP
RLC	X2-AP
MAC	GTP-C
PHY	Diameter

User Plane Control Plane

Layers of LTE Protocol Model

A) User Plane

- **Application Layer:** User applications (e.g., YouTube, WhatsApp).
- **IP Layer:** IPv4 or IPv6 packets carrying user data.
- **PDCP (Packet Data Convergence Protocol):**
    - Encrypts user data
    - Compresses IP headers (ROHC)
    - Ensures data is in the right order
- **RLC (Radio Link Control):**
    - Splits and joins data packets
    - Retransmits lost data
- **MAC (Medium Access Control):**
    - Allocates radio resources
    - Handles scheduling and priority
- **PHY (Physical Layer):**
    - Converts data into radio waves (OFDMA downlink, SC-FDMA uplink)

B) Control Plane

- **NAS (Non-Access Stratum):**
    - Between UE and MME
    - Handles attach, authentication, bearer setup, and mobility
- **RRC (Radio Resource Control):**
    - Between UE and eNodeB
    - Controls connection states, security activation, handovers

- **Other Control Protocols in Core:**
    - **S1-AP:** eNodeB ↔ MME (signaling messages)
    - **X2-AP:** eNodeB ↔ eNodeB (handover control)
    - **GTP-C:** Controls tunnels for user data (MME ↔ SGW, SGW ↔ PGW)
    - **Diameter:** Authentication and subscriber info (MME ↔ HSS)