UNIT-1

Wireless communication systems are classified based on coverage, range, and technology.

The main types are:

1. **Satellite Communication:**
    - Uses satellites to transmit signals over long distances.
    - Covers large areas, including remote regions.
    - Example: GPS, satellite TV.
2. **Cellular Communication (Mobile Networks):**
    - Divides coverage area into cells, each served by a base station.
    - Efficient frequency reuse, supports many users.
    - Example: 4G, 5G networks.
3. **Wi-Fi (Wireless LAN):**
    - Short-range communication, typically in homes or offices.
    - High data rates, limited range.
    - Example: Wireless internet at home or office.
4. **Bluetooth:**
    - Very short-range, low power communication between devices.
    - Used for connecting peripherals like headphones, keyboards.
5. **Microwave Communication:**
    - Point-to-point line-of-sight communication using microwave frequencies.
    - Used for long-distance telephony and data links.

Comparison:

Type	Range	Data Rate	Example	Power/Cost
Satellite	Very long	Medium	GPS, TV	High
Cellular	Medium	High	4G, 5G	Medium
Wi-Fi	Short	High	Home/Office Internet	Low
Bluetooth	Very short	Low	Headphones, Keyboard	Very low
Microwave	Long	Medium	Long-distance links	Medium

Wireless communication systems allow transmission of information without physical wires. Three important types are:

1. **Satellite Communication:**
   - Uses satellites in orbit to relay signals between distant locations.
   - Can cover very large areas, including oceans and remote regions.
   - Applications: GPS navigation, satellite TV, weather monitoring.
   - Advantages: Wide coverage, reliable.
   - Disadvantages: Expensive, signal delay due to long distance.
2. **Cellular Communication:**
   - Divides a large area into smaller cells, each with a base station.
   - Allows many users to share frequencies efficiently.
   - Applications: Mobile phones, 4G/5G internet.
   - Advantages: High capacity, supports mobility.
   - Disadvantages: Requires many base stations, interference possible.
3. **Wi-Fi (Wireless Local Area Network):**
   - Provides wireless connectivity in small areas like homes, offices, or campuses.
   - Uses radio waves to connect devices to the internet or each other.
   - Applications: Wireless internet at home, office networking.
   - Advantages: High data rates, easy to install.
   - Disadvantages: Limited range, affected by walls and obstacles.

Advantages of Wireless Communication:

1. **Mobility:** Users can communicate anywhere without cables.
2. **Easy Installation:** No need for laying physical wires.
3. **Cost-effective for Remote Areas:** Ideal for difficult terrains.
4. **Scalability:** Easy to add new users or devices.

Disadvantages of Wireless Communication:

1. **Interference:** Signals can be affected by weather, obstacles, or other devices.
2. **Security Issues:** Easier for hackers to intercept data.
3. **Limited Range:** Some systems (Wi-Fi, Bluetooth) have short coverage.
4. **Signal Quality:** Can degrade over distance or due to obstacles.

Generations of Cellular Systems (Any Two):

1. **1G – First Generation:**
   - **Technology:** Analog.
   - **Purpose:** Only voice communication.
   - **Features:**
     - Large cell size, low capacity.
     - Poor security; calls could be easily intercepted.
     - Limited coverage and poor voice quality.
   - **Example:** AMPS (Advanced Mobile Phone System).
2. **2G – Second Generation:**
   - **Technology:** Digital.
   - **Purpose:** Voice communication and basic data services like SMS.
   - **Features:**
     - Higher capacity compared to 1G.
     - Improved voice quality and security (encryption used).
     - Supports text messaging and limited internet access.
   - **Example:** GSM (Global System for Mobile Communications).

Summary:

- **1G → Analog, only voice, low security.**
- **2G → Digital, voice + SMS, better security and quality.**

3G – Third Generation Cellular System:

- **Technology:** Digital, based on **packet switching** for data.
- **Purpose:** Provides **high-speed voice, data, and multimedia services**.
- **Data Rate:** Up to **2 Mbps** for stationary users and ~384 kbps for mobile users.
- **Features:**
  1. Supports **voice, video calls, and mobile internet**.
  2. Enables services like **video streaming, video conferencing, and mobile TV**.
  3. Improved **security and network capacity** compared to 2G.
  4. Uses **CDMA (Code Division Multiple Access) and WCDMA** technologies for better spectrum utilization.
- **Example:** UMTS (Universal Mobile Telecommunications System).

Summary:

3G allows **fast data transfer and multimedia services**, making mobile communication more than just voice and SMS.

Answer (Comparison of 1G, 2G, 3G – 5 marks):

Feature	1G (First Generation)	2G (Second Generation)	3G (Third Generation)
Technology	Analog	Digital	Digital, packet-switched
Services	Voice only	Voice + SMS	Voice + Data + Multimedia (video, internet)
Data Rate	Very low (~2 kbps)	Up to 64 kbps	Up to 2 Mbps (stationary)
Security	Poor	Better (encryption)	High security (encryption, authentication)
Example	AMPS	GSM	UMTS
Coverage & Capacity	Large cells, low capacity	Smaller cells, higher capacity	Smaller cells, high capacity, better spectrum use

Summary:

- **1G:** Analog, voice only, low security.
- **2G:** Digital, voice + SMS, better security.
- **3G:** Digital, high-speed data, multimedia services, improved network efficiency

4G – Fourth Generation Cellular System:

- **Technology:** Digital, IP-based network.
- **Purpose:** High-speed mobile internet, voice, and multimedia services.
- **Data Rate:** Up to **100 Mbps** for mobile users, 1 Gbps for stationary users.
- **Features:**
  1. Supports HD video streaming, online gaming, and VoIP.
  2. Better spectral efficiency and network capacity than 3G.
- **Example:** LTE (Long Term Evolution).

Comparison: 4G vs 5G

Feature	4G	5G
Data Speed	Up to 1 Gbps (stationary)	Up to 10–20 Gbps
Latency	~50 ms	~1 ms
Technology	LTE, IP-based	NR (New Radio), advanced radio tech
Applications	HD video, gaming, VoIP	IoT, smart cities, AR/VR, autonomous vehicles
Network Capacity	Medium	Very high, supports massive devices

Summary:

- **4G** → Fast internet and multimedia.
- **5G** → Ultra-fast, low latency, massive connectivity for advanced applications.

Satellite Communication:

Satellite communication allows information to be transmitted over **long distances** using satellites orbiting the Earth.

Types of Satellite Communication:

1. **Geostationary Satellites (GEO):**
    - Orbits at ~36,000 km above Earth.
    - Appears stationary relative to Earth.
    - Covers large area, used for TV, weather monitoring.
2. **Low Earth Orbit Satellites (LEO):**
    - Orbits at 500–2000 km above Earth.
    - Moves quickly relative to Earth, needs a constellation for continuous coverage.
    - Used for mobile satellite phones, internet.
3. **Medium Earth Orbit Satellites (MEO):**
    - Orbits at 2,000–36,000 km.
    - Used mainly for navigation systems like GPS.
4. **Communication Satellites by Function:**
    - **Telecommunication satellites:** For voice, data, and video transmission.
    - **Broadcast satellites:** For TV and radio broadcasting.
    - **Navigation satellites:** For GPS and navigation.

Working of Satellite Communication:

1. **Transmission:**
    - Earth station transmits the signal to the satellite using a **uplink** frequency.
2. **Satellite Processing:**
    - The satellite receives the signal, amplifies it, converts it to a different frequency to avoid interference, and retransmits it back to Earth (**downlink**).
3. **Reception:**
    - The receiving Earth station (or user terminal) captures the downlink signal using a satellite dish or antenna.
4. **Key Points:**
    - Signals travel as **electromagnetic waves**.
    - **Line-of-sight** communication is required between Earth station and satellite.
    - Delay occurs due to the large distance of GEO satellites (~250 ms).

Importance of Satellite Communication in Wireless Communication:

1. **Global Coverage:**
    - Can provide communication to **remote and rural areas** where terrestrial networks are not available.

2. **Long-Distance Communication:**
    - Enables transmission over **thousands of kilometers**, connecting different countries and continents.
3. **Broadcast Services:**
    - Supports **TV, radio, and internet broadcasting** to a wide audience.
4. **Disaster Management:**
    - Useful in **emergencies and natural disasters** when ground networks fail.
5. **Navigation and GPS:**
    - Satellites provide **positioning, timing, and navigation** services worldwide.

Summary:
Satellite communication is crucial for **global connectivity, reliable broadcasting, emergency communication, and navigation**, making it an essential part of wireless communication systems.

Working of Infrared (IR) Communication:
Infrared communication uses **infrared light waves** (wavelength 700 nm – 1 mm) to transmit data wirelessly over short distances.

1. Components:

- **Transmitter:**
    - Converts electrical signals (voice or data) into infrared light pulses.
    - Uses an **LED or IR laser diode** to emit light.
- **Receiver:**
    - Detects incoming IR light using a **photodiode or phototransistor**.
    - Converts the light pulses back into electrical signals.
- **Medium:**
    - Infrared waves travel through **air** and require **line-of-sight** between transmitter and receiver, although reflection off surfaces is sometimes possible.

2. Working Steps:

1. The transmitter **modulates the data** onto IR light, creating pulses representing binary 0s and 1s.
2. IR light is **emitted toward the receiver**.
3. The receiver **detects the light pulses** and **demodulates** them to recover the original data.
4. The electrical signal is sent to the output device (e.g., TV, computer).

3. Key Points:

- **Short-range communication:** Usually within a few meters.
- **Line-of-sight needed:** Direct path or reflected signals.
- **Low interference:** Does not interfere with radio signals.

4. Applications:

- Remote controls for TVs, air conditioners.
- Wireless keyboards and mice.

- Data transfer between mobile devices.

Microwave Communication:
Microwave communication is a type of **wireless communication** that uses **microwave frequency waves** (1 GHz – 300 GHz) to transmit information such as voice, data, and video over long distances.

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1. Components:

- **Transmitter:** Converts electrical signals into microwave signals.
- **Receiver:** Receives microwave signals and converts them back into electrical signals.
- **Antennas:** Highly directional antennas (parabolic dishes) are used for point-to-point communication.
- **Repeater Towers:** Used for long-distance communication to amplify and retransmit signals.

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2. Working Principle:

1. The **transmitter** modulates the data onto microwave signals.
2. The microwaves are transmitted in a **line-of-sight (LOS)** path toward the receiver.
3. For very long distances, **relay/repeater towers** are placed at intervals to boost and forward the signals.
4. The **receiver** demodulates the microwave signals to retrieve the original data.

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3. Types of Microwave Communication:

- **Terrestrial Microwave:** Point-to-point communication using towers on the ground.
- **Satellite Microwave:** Uses satellites as relay stations to transmit microwaves over very long distances.

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4. Features:

- Supports **high data rates**.
- Requires **line-of-sight**, can be blocked by obstacles.
- Suitable for **long-distance communication** (up to hundreds of kilometers).

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5. Applications:

- Long-distance telephone and television transmission.
- Wireless broadband and internet.
- Radar systems and satellite communication.

<u>UNIT-2</u>

Concept of Cellular System
A **cellular system** is a wireless communication network where the coverage area is divided into smaller geographical areas called **cells**.

Each cell has its own **Base Station (BS)** with a transmitter and receiver that communicates with **mobile users** in that cell.

Key Concepts

1. **Cell Structure**
   - The total coverage area is split into **hexagonal-shaped cells** for better frequency reuse.
   - Each cell is served by a **base station**.
2. **Frequency Reuse**
   - Same radio frequencies are reused in non-adjacent cells to increase capacity.
3. **Handoff**
   - When a mobile user moves from one cell to another, the call or data session is transferred automatically to the next cell's base station without interruption.
4. **Centralized Control**
   - A **Mobile Switching Center (MSC)** connects base stations and manages call setup, routing, billing, and mobility.
5. **Advantages**
   - Better spectrum efficiency.
   - Large coverage with limited frequencies.
   - Scalability by adding more cells.

Concept of a Cell in Cellular Communication:

- A **cell** is the **basic geographic unit** of a cellular communication system.
- Each cell has a **base station** that transmits and receives signals within a small geographic area.
- The shape of a cell is generally considered **hexagonal**, though in practice it may not be a perfect hexagon.
- Hexagonal cells are used because they allow **efficient coverage** without overlapping or leaving gaps and make analysis manageable.

Key Points about a Cell:

1. **Coverage Area:** The region where the signal from the base station is strong enough for reliable communication.
2. **Footprint:** The actual radio coverage of a cell, which can be measured or predicted.
3. **Frequency Reuse:** The same set of channels can be used in different cells without interference if cells are adequately spaced.
4. **Advantages:** High capacity, local interference only, robust against single component failures.

Hexagonal Geometry Cell Structure in Cellular System:

- In cellular systems, the **coverage area** is divided into smaller regions called **cells**.

- Each cell is served by a **base station** that transmits and receives signals within that area.
- **Hexagonal shape** is used for cells instead of circular because:
    1. Hexagons cover the entire area **without gaps or overlaps**.
    2. They are the **closest shape to a circle** for uniform distance from center to edges.
    3. Simplifies **frequency planning** and **cell layout**.
- Neighboring cells use **different frequencies** to avoid interference, and **frequency reuse** is done for distant cells.

Advantages of Hexagonal Cells:

1. Efficient coverage of area.
2. Easy to calculate and plan network.
3. Supports frequency reuse effectively.

Summary:

- A **cell** is the **smallest unit** of a cellular system.
- **Hexagonal geometry** provides **efficient coverage**, allows **frequency reuse**, and avoids ambiguous areas.
- Base stations in each cell manage **local communication** and link to the wider network.

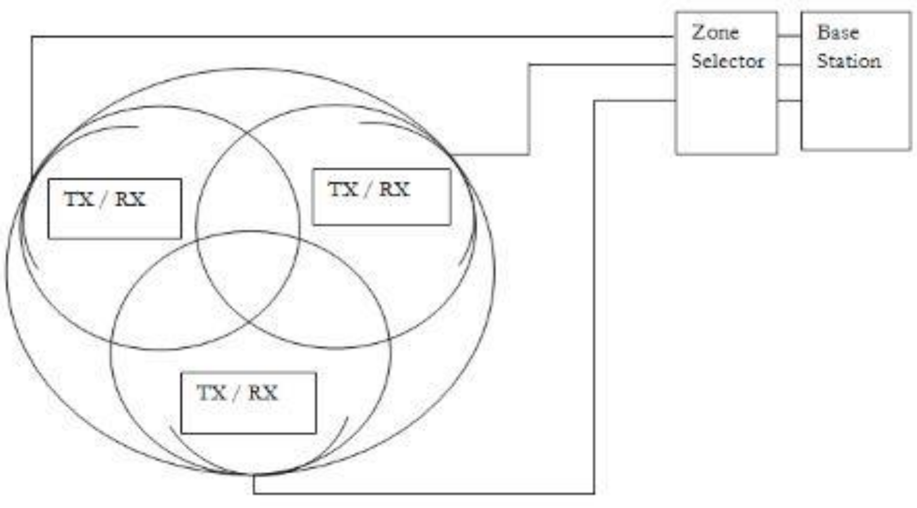

Fig: Microcell zone

Microcell Zone Concept:

- The **microcell zone concept** is used in cellular systems to **increase capacity and improve coverage**, especially in areas with **high traffic density** such as cities, shopping malls, and crowded streets.
- Instead of one large coverage area, a **cell** is divided into **multiple smaller zones**.
- Each **zone** has its own **transmitter/receiver (TX/RX)** unit, but **all zones share the same radio channel** for that cell.

- The **zone selector** in the base station continuously monitors the signal strength of the mobile user and **automatically switches** the call to the zone where the user is present.
- This switching between zones is **fast** and does **not require a formal handoff**, which improves **call quality** and **reduces dropped calls**.

Working:

1. Mobile moves from one zone to another within the same cell.
2. The **zone selector** detects the movement and changes the serving zone.
3. Base station remains the same for all zones, avoiding full handoff procedures.

Advantages:

1. **Improved coverage** in dense or obstructed areas.
2. **Lower interference** due to smaller coverage area per zone.
3. **No frequent handoffs** inside the cell, reducing network load.
4. **Better voice quality** and reliability.

Handoff Scenario at the Cell Boundary:

- **Handoff** is the process of **transferring an active call or data session** from one cell's base station to another without disconnecting the call.
- It occurs when a **mobile user moves from the coverage area of one cell to another**, usually at the **cell boundary**.
- It ensures **continuous connectivity** and prevents call drops.
- Controlled by the **Mobile Switching Center (MSC)**.

Working:

1. The mobile station continuously measures the **signal strength** from its serving cell and neighboring cells.
2. As the user approaches the **cell boundary**, the signal from the current base station becomes **weak**, and the signal from the neighboring cell becomes **stronger**.
3. When the signal drops below a certain **threshold**, the system decides to **initiate handoff**.
4. The **Mobile Switching Center (MSC)** coordinates with both base stations to transfer the call.
5. The mobile is **switched** to the new base station's frequency/channel without noticeable interruption.

Example:

- If a user is on a call while traveling in a car, when they move from **Cell A** to **Cell B**, the call is handed over from **Base Station A** to **Base Station B** seamlessly.

Importance:

- Ensures **uninterrupted communication**.
- Maintains **call quality** and prevents dropped calls.

Types of Handoff Strategies:

1. Hard Handoff – *Break-before-make*

- The connection with the current base station is **broken** before establishing a new one.
- Common in **FDMA** and **TDMA** systems.
- **Advantage:** Simple and requires less hardware.
- **Disadvantage:** Short interruption may occur.

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2. Soft Handoff – *Make-before-break*

- The mobile connects to the **new base station before leaving the old one**.
- Common in **CDMA** systems.
- **Advantage:** No call drop and smooth transition.
- **Disadvantage:** Requires more complex hardware and resources.

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3. Forced Handoff

- Initiated by the network when **signal quality drops suddenly** or cell resources are needed for high-priority users.

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4. Delayed Handoff

- Handoff is **intentionally delayed** to avoid unnecessary switching when the mobile is moving back and forth between cell boundaries.

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5. Mobile-Assisted Handoff (MAHO)

- The **mobile station measures** the signal strength from nearby base stations and sends the data to the network, which then decides the best time for handoff.

1. Cell Sectoring

- The process of **dividing a cell into smaller sectors** (usually 3 or 6) using **directional antennas** instead of an omnidirectional antenna.
- Each sector has its **own set of frequencies** and antenna beam.

Advantages:

- Reduces **co-channel interference**.
- Increases **capacity** as frequencies can be reused more efficiently.
- Improves **signal quality**.

Example: A 360° cell is split into 3 sectors of 120° each.

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2. Cell Splitting

- The process of **subdividing a large cell into smaller cells** with **lower transmit power** and smaller coverage radius.
- Done when traffic in an area increases beyond capacity.

Advantages:

- Increases the number of channels available in the same area.
- Handles **more users** by adding new base stations in smaller cells.

Performance Improvement in Cellular Systems:

- **More capacity**: Both techniques allow more users to be served.
- **Better coverage**: Reduces dead zones and improves signal strength.
- **Less interference**: Sectoring especially reduces co-channel interference.

Frequency Reuse – Concept

- In a cellular system, the **total available radio frequency spectrum is divided into groups of channels**.
- These channel groups are **reused** in different cells that are **separated by a certain distance** to avoid interference.
- Each cell has its own **set of frequencies**, and the same set can be used in another cell far enough to prevent signal overlap.

Example: If a system has 100 channels, and each cell uses 10 channels, then the same 10 channels can be reused in many other cells using a proper reuse pattern.

Advantages of Frequency Reuse:

1. **Efficient Spectrum Utilization** – Maximizes use of limited frequency bands.
2. **Increases System Capacity** – More users can be served without requiring extra spectrum.
3. **Supports Mobility** – Users can move across cells without losing connectivity.
4. **Scalability** – New cells can be added easily using the same frequencies.

Problems of Frequency Reuse:

1. **Co-Channel Interference (CCI)** – Interference between cells using the same frequency set.
2. **Cell Planning Complexity** – Requires careful placement of base stations.
3. **Handoff Requirements** – More frequent handoffs when cells are small.

Fixed Network Transport Protocols

These are protocols used for **data transmission** in fixed (wired) communication networks like LAN, WAN, and the internet. They ensure **reliable, efficient, and error-free delivery** of data between devices.

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1. TCP (Transmission Control Protocol)

- **Connection-oriented** protocol.
- Provides **reliable** delivery using acknowledgments, retransmissions, and error checking.
- Used for applications like **web browsing, emails, file transfer**.

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2. UDP (User Datagram Protocol)

- **Connectionless** protocol.
- **Faster** than TCP but **no guarantee** of delivery.

- Used in **real-time applications** like video streaming, VoIP, and gaming.

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3. IP (Internet Protocol)

- Responsible for **addressing and routing** data packets between devices.
- Works with both TCP and UDP.
- Ensures packets reach the correct destination.

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4. Other Examples

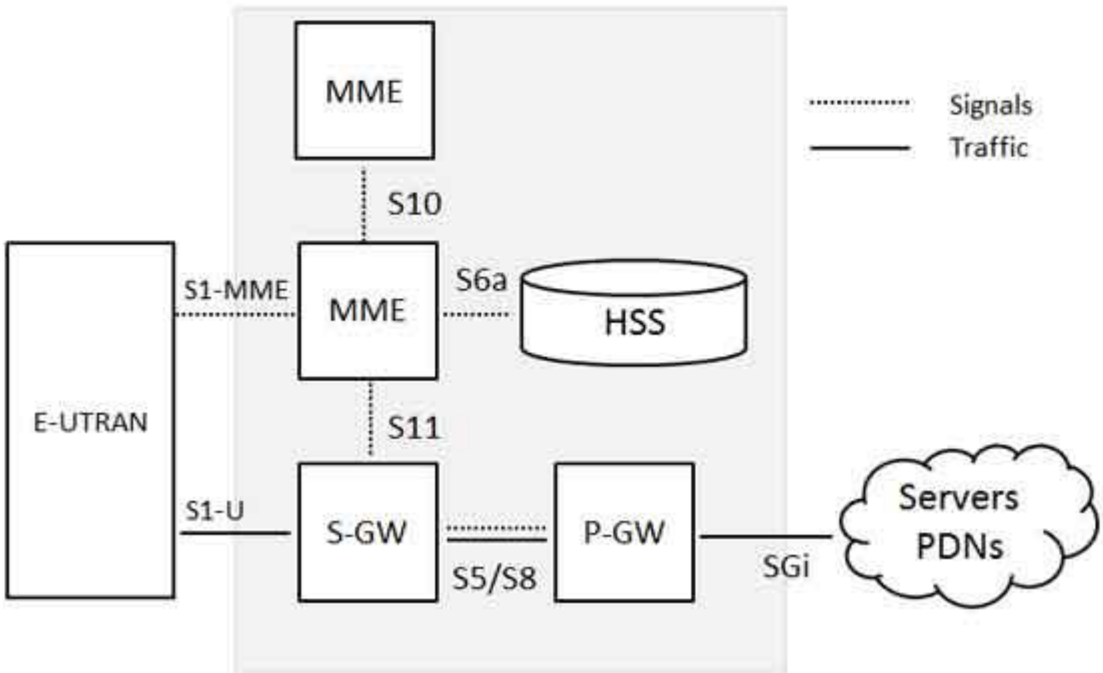
- **FTP** – File transfer protocol.
- **SMTP** – Sending emails.
- **HTTP/HTTPS** – Web communication.

Need for LTE (Long Term Evolution)

LTE was developed to overcome the limitations of **3G networks** and to meet the growing demand for **high-speed mobile internet**.

Key Needs:

1. **Higher Data Rates** – Support up to 100 Mbps (downlink) and 50 Mbps (uplink).
2. **Lower Latency** – For real-time applications like video calling, gaming, and IoT.
3. **Better Spectrum Efficiency** – Use available frequency more effectively.
4. **Support for IP-based Traffic** – Designed for all-IP networks (voice, video, data over IP).
5. **Global Roaming** – Standardized worldwide for smooth user mobility.



Architecture of LTE

LTE architecture is divided into **two main parts**:

1. **E-UTRAN (Evolved UMTS Terrestrial Radio Access Network)**
    - **Contains eNodeB** (Base stations) that provide radio access to mobile devices.
    - Handles **radio resource management, mobility, and scheduling**.
    - Connected to EPC via **S1 interface**.
2. **EPC (Evolved Packet Core)** – Main IP-based core network.
   Components:
    - **MME (Mobility Management Entity):**
        - Control plane node.
        - Handles authentication, session management, handover.
    - **HSS (Home Subscriber Server):**
        - Database storing subscriber information and authentication data.
    - **S-GW (Serving Gateway):**
        - Routes and forwards user data packets between eNodeB and P-GW.
        - Acts as an anchor for mobility.
    - **P-GW (Packet Data Network Gateway):**
        - Connects LTE network to external IP networks like the internet and PDNs.
        - Assigns IP addresses to devices.

Interfaces in LTE Architecture:

- **S1-MME** – Between eNodeB and MME (signaling).
- **S1-U** – Between eNodeB and S-GW (user data).
- **S5/S8** – Between S-GW and P-GW.
- **S6a** – Between MME and HSS.
- **S10** – Between MMEs for mobility.

Diagram Explanation (based on given image):

- **E-UTRAN** on the left connects to the EPC core through S1 interfaces.
- **MME & HSS** handle control signaling.
- **S-GW & P-GW** manage data traffic flow.
- External servers/PDNs are accessed via **SGi interface**.

Features of LTE Technology

1. **High Data Rates**
    - Downlink speed up to **100 Mbps**.
    - Uplink speed up to **50 Mbps**.
    - Supports bandwidths from **1.4 MHz to 20 MHz**.
2. **Low Latency**
    - End-to-end delay reduced to **less than 10 ms** for data transfer.
    - Improves real-time applications like VoIP and video calls.
3. **All-IP Network**

    - Uses **IP-based architecture** for both voice and data.
    - Simplifies integration with other internet services.
4. **Improved Spectrum Efficiency**
    - Uses **OFDMA** (Downlink) and **SC-FDMA** (Uplink).
    - Allows more users in the same frequency band.
5. **Mobility Support**
    - Provides seamless handovers between cells and networks.
    - Supports mobility up to **350 km/h** (for high-speed trains).

Signaling Protocols in LTE

In LTE, signaling protocols handle **control information exchange** between the user device (UE), E-UTRAN, and EPC. They are divided into **Control Plane Protocols** and **User Plane Protocols**.

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1. Control Plane Protocols (For signaling)

Used for **session control, mobility, and authentication**.

- **RRC (Radio Resource Control)**
    - Between **UE and eNodeB**.
    - Manages radio bearers, mobility, handover, and measurement reports.
- **NAS (Non-Access Stratum)**
    - Between **UE and MME**.
    - Handles authentication, security control, session management, and mobility management.
- **S1-AP (S1 Application Protocol)**
    - Between **eNodeB and MME**.
    - Used for UE context setup, paging, and handover signaling.
- **Diameter Protocol**
    - Between **MME and HSS/P-GW**.
    - Used for authentication, authorization, and accounting (AAA).

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2. User Plane Protocols (For data transfer)

Although mainly for data, some signaling is embedded here.

- **GTP-U (GPRS Tunneling Protocol – User Plane)**
    - Between **eNodeB → S-GW → P-GW**.
    - Encapsulates user data packets and transports them

LTE Protocol Model

The **LTE Protocol Model** is divided into two main planes:

1. Control Plane

- Handles signaling and control messages between **User Equipment (UE)** and **Evolved Packet Core (EPC)**.

- Used for connection setup, authentication, mobility management, and session management.

Protocols in Control Plane:

- **NAS (Non-Access Stratum):**
  - Runs between UE and MME.
  - Handles mobility management (MM) and session management (SM).
- **RRC (Radio Resource Control):**
  - Between UE and eNodeB.
  - Manages radio bearers, handover, and connection control.

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2. User Plane

- Transfers actual **user data (voice, video, browsing)**.
- Ensures fast, efficient delivery with minimal delay.

Protocols in User Plane:

- **PDCP (Packet Data Convergence Protocol):**
  - Header compression, encryption, integrity protection.
- **RLC (Radio Link Control):**
  - Segmentation/reassembly, error correction.
- **MAC (Medium Access Control):**
  - Multiplexing, scheduling, HARQ.
- **PHY (Physical Layer):**
  - Modulation, coding, signal transmission over air.

Summary Diagram for Exam

```
        Control Plane                 User Plane
  UE <---- NAS, RRC ----> MME      UE <--- PDCP/RLC/MAC/PHY ---> eNodeB ---> S-GW/P-GW
```

- Control plane handles **signaling**,
- User plane handles **actual data flow**.