Unit II

Mobile Network Protocols and Services: Introduction to 5G and emerging mobile technologies, Bluetooth and Wi-Fi, Mobile IP and GPRS, LTE (4G) architecture overview, 5G features and architecture introduction, Mobile communication protocols

Evolution of Cellular Systems

Generation	Key Features	Data Rate	Technology
1G	Analog voice	~2.4 kbps	FDMA
2G	Digital voice/SMS (GSM, CDMA)	up to 64 kbps	TDMA/CDMA
3G	Voice + data + video calls	2 Mbps	W-CDMA/UMTS
4G	High-speed data (IP based)	up to 1 Gbps	LTE, OFDMA
5G	Ultra-high speed + low latency + mass IoT	>10 Gbps	NR (New Radio), mmWave

📘 Introduction

5G (Fifth Generation Mobile Network) is designed to deliver:

- **Extremely high data rates** (up to 10–20 Gbps)
- **Ultra-low latency** (<1 ms)
- **Massive device connectivity** (IoT, sensors, autonomous systems)
- **Improved reliability, security, and energy efficiency**

Emerging 5G Technologies

- **Massive MIMO:** multiple antennas for higher throughput.
- **mmWave Spectrum:** 24–100 GHz for ultra-fast data.
- **Network Slicing:** virtual networks for specific services.
- **Edge Computing:** data processing near users → lower latency.
- **IoT Integration:** supports billions of connected devices.

1. Millimeter Wave (mmWave) Communication

- Uses **frequency bands between 24 GHz and 100 GHz**.
- Offers **huge bandwidth** → supports multi-Gbps data rates.
- Short range and easily blocked by obstacles → requires small cells.
- Used for dense urban areas, stadiums, and high-speed hotspots.

📊 *Advantages:* High capacity, low interference

⚠️ *Challenges:* Propagation loss, blockage, and coverage limits.

2. Massive MIMO (Multiple-Input Multiple-Output)

- Employs **dozens to hundreds of antennas** at base stations.
- Increases capacity and reliability through **spatial multiplexing**.
- Improves **energy efficiency** and **beam directivity**.
- Supports multiple users simultaneously in the same frequency band.

📊 *Advantage:* 10×–20× higher spectral efficiency

⚠ *Challenge:* Complex signal processing and hardware cost.

3. Beamforming

- A **signal-focusing technique** that directs radio energy toward specific users.
- Reduces interference and improves range, especially with mmWave.
- Works together with **massive MIMO** to dynamically steer beams.

📊 *Advantage:* Increased coverage and signal quality

⚠ *Challenge:* Requires precise user tracking.

4. Network Slicing

- Allows creation of **multiple virtual networks** on a shared physical infrastructure.
- Each slice serves a specific purpose:
  - **eMBB (Enhanced Mobile Broadband)** – video, VR/AR
  - **URLLC (Ultra-Reliable Low Latency Communication)** – autonomous vehicles, robotics
  - **mMTC (Massive Machine-Type Communication)** – IoT sensors
- Enables **customized QoS** for different applications.

📊 *Advantage:* Flexibility, efficient resource use

⚠️ *Challenge:* Complex management and orchestration.

5. Edge Computing (Multi-Access Edge Computing – MEC)

- Moves data processing **closer to users** (at network edge, near base stations).
- Reduces **latency** and **core network congestion**.
- Enables real-time applications (autonomous driving, AR/VR, industrial automation).

📊 *Advantage:* Lower delay, improved performance

⚠️ *Challenge:* Security and distributed management.

6. Cloud-Native Core Network (5GC)

- The **5G Core (5GC)** uses **cloud computing and virtualization** principles.
- Built on **Service-Based Architecture (SBA)** using **microservices.**
- Supports **software-defined networking (SDN)** and **network function virtualization (NFV).**
- Enables scalable, flexible, and programmable networks.

📊 *Advantage:* Dynamic scaling, faster deployment

⚠️ *Challenge:* Integration and interoperability with legacy systems.

7. Ultra-Reliable Low-Latency Communication (URLLC)

- Designed for **mission-critical** applications:
  - Remote surgery
  - Industrial robotics
  - Vehicle-to-everything (V2X) communication
- Provides **latency < 1 ms** and **reliability > 99.999%.**

📊 *Advantage:* Real-time response, high reliability

⚠️ *Challenge:* Requires precise synchronization and QoS control.

8. Massive Machine-Type Communication (mMTC)

- Supports **billions of IoT devices** with low power and small data needs.
- Used in **smart cities, agriculture, energy grids, environment monitoring.**
- Optimized for **energy efficiency** and **low-cost communication.**

📊 *Advantage:* Large-scale IoT connectivity

⚠️ *Challenge:* Managing network congestion.

9. Full Duplex Communication

- Enables **simultaneous transmission and reception** on the same frequency.
- Doubles spectral efficiency.
- Requires advanced **self-interference cancellation** techniques.

📊 *Advantage:* Higher throughput

⚠️ *Challenge:* Complex hardware and signal cancellation.

10. AI and Machine Learning Integration

- Used for **network optimization, predictive maintenance**, and **resource allocation.**
- Helps in **dynamic spectrum management** and **anomaly detection.**
- Enables **self-organizing networks (SON).**

📊 *Advantage:* Automation, efficiency, adaptive control

⚠️ *Challenge:* Data privacy and real-time training requirements.

Technology	Purpose	Benefit	Challenge
mmWave	High-frequency data transfer	Gbps speed	Short range
Massive MIMO	Many antennas	High capacity	Processing cost
Beamforming	Signal steering	Better coverage	User tracking
Network Slicing	Virtual networks	Flexibility	Management
Edge Computing	Local data processing	Low latency	Security
Cloud-Native Core	Virtualized 5G core	Scalability	Integration
URLLC	Critical communication	Reliability	Sync accuracy
mMTC	IoT connectivity	Energy-efficient	Congestion
Full Duplex	Simultaneous TX/RX	Double capacity	Interference
AI/ML	Intelligent control	Automation	Data privacy

Wi-Fi (Wireless Fidelity)

Wi-Fi is a **Wireless Local Area Network (WLAN)** technology based on **IEEE 802.11** standards.

It allows devices such as smartphones, laptops, and IoT systems to connect wirelessly to the internet or local networks.

Provides high-speed data transfer within a limited area — homes, offices, campuses, and hotspots.

Wi-Fi operates mainly on:

Band	Frequency Range	Usage
2.4 GHz	2.400 – 2.4835 GHz	Wider range, more interference
5 GHz	5.150 – 5.825 GHz	Higher speed, shorter range
6 GHz (Wi-Fi 6E)	5.925 – 7.125 GHz	Very high capacity, minimal interference

4. Wi-Fi Architecture

Components

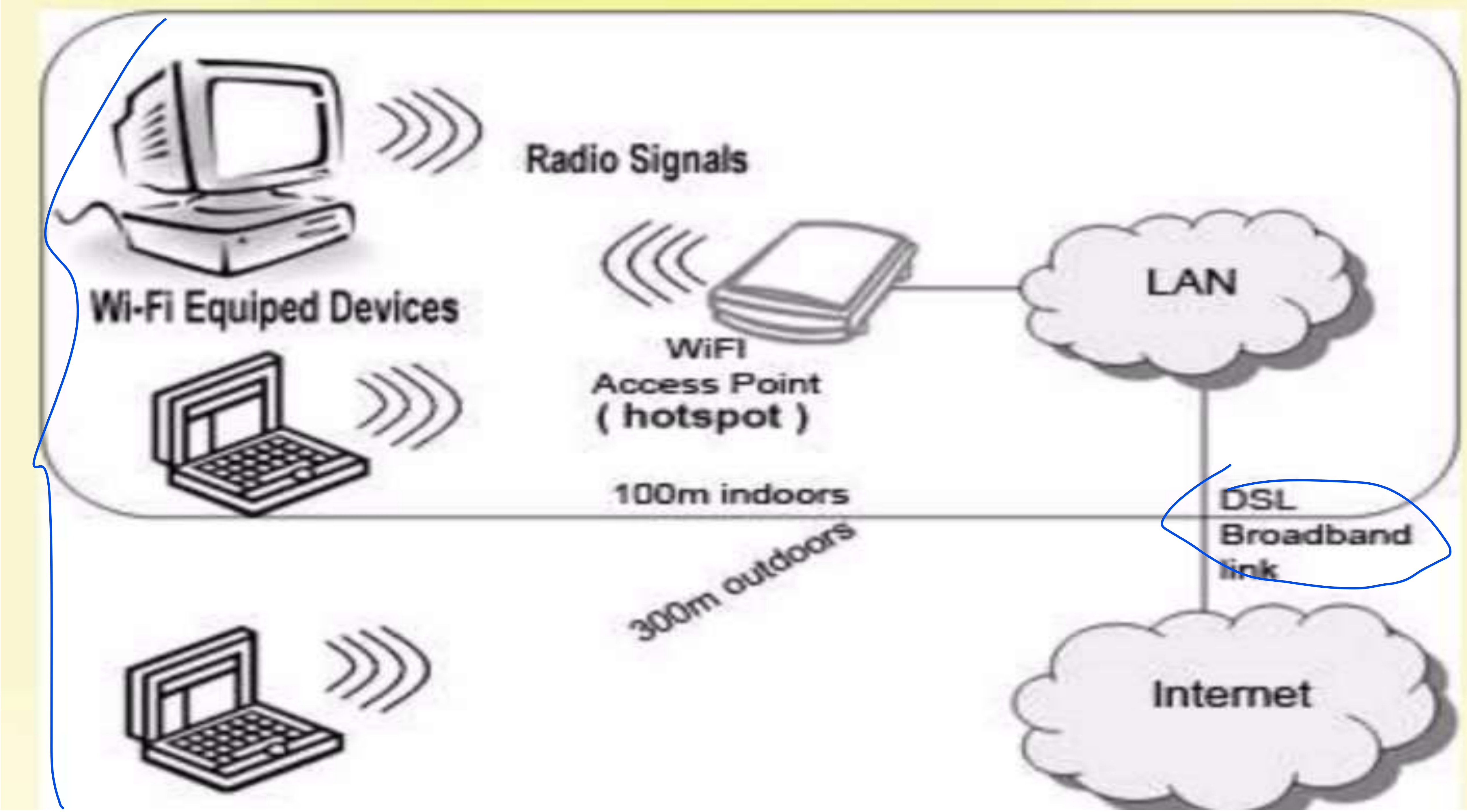
1. **Station (STA)** → Any Wi-Fi-enabled device (laptop, phone).
2. **Access Point (AP)** → Connects wireless STAs to a wired LAN or the internet.
3. **Distribution System (DS)** → Backbone network connecting multiple APs.

Elements of a Wi-Fi Network

- **Access Point (AP)** – The AP is a wireless LAN transceiver or "base station" that can connect one or many wireless devices in the same time to the Internet.
- **Safeguards** – Firewalls and anti-virus software protect networks from uninvited users and keep information secure.
- **Wi-Fi cards (Adapters)** – They accept the wireless signal and relay information. They can be internal and external.

How a Wi-Fi Network Works

- A Wi-Fi hotspot is created by installing an access point to an internet connection.
- An access point acts as a base station.
- When Wi-Fi enabled device encounters a hotspot the device can then connect to that network wirelessly.
- A single access point can support up to 30 users and can function within a range of 100 – 150 feet indoors and up to 300 feet outdoors.
- Many access points can be connected to each other via Ethernet cables to create a single large network.


Radio Signals
Wi-Fi Equiped Devices
WiFi
Access Point
(hotspot)
LAN
100m indoors
300m outdoors
DSL
Broadband
link
Internet

WI-FI APPLICATIONS

- Home
- Small Businesses
- Large Corporations & Campuses
- Health Care
- Wireless ISP (WISP)
- Travellers
- Wi-Fi Camera

Limitations of Wi-Fi

- **Limited range**
- **Interference from other devices** : such as telephones, microwave ovens.
- **High power consumption** :making battery life and heat a concern .
- **Data security risks** :a huge challenge for **Wi-Fi** networks

7. Advantages

- High data rate (up to multi-Gbps)
- Easy deployment (no cables)
- Supports mobility within coverage area
- Interoperable with multiple devices

Mobile IP (Mobile Internet Protocol)

- **Mobile IP** allows a **mobile device (node)** to move between different networks **without changing its IP address.**
- Defined by **IETF RFC 2002**, it ensures **continuous internet connectivity** during mobility.

📱 Example:

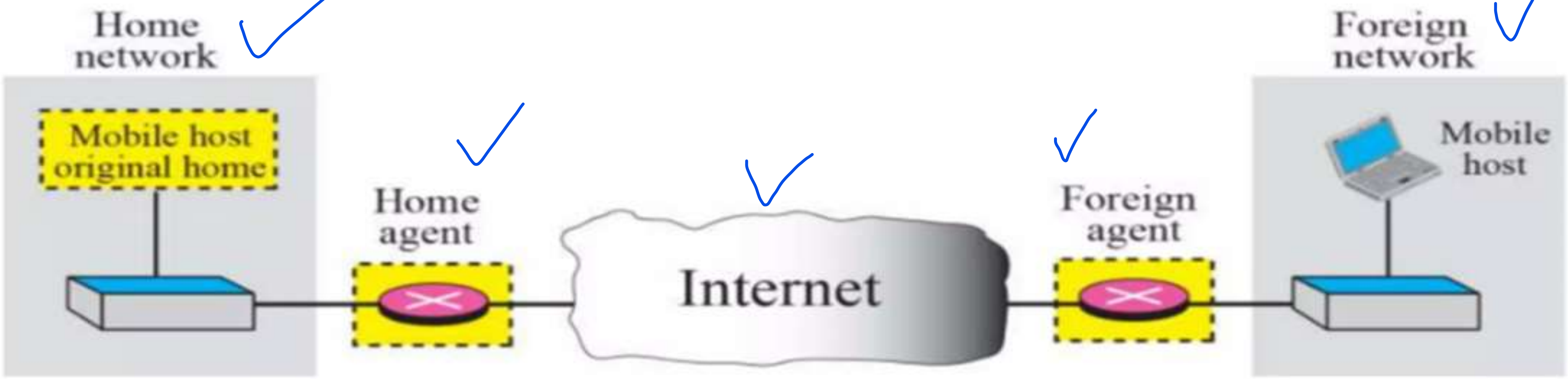
A smartphone moving from home Wi-Fi to mobile data keeps the same IP address so that ongoing sessions (like video calls or downloads) are not interrupted.

🔹 Need for Mobile IP

- In standard IP, a node's IP address identifies **both** its identity and location.
- When the device changes network, the IP address must change → connection breaks.
- **Mobile IP solves this** by separating **node identity** and **location**.

🔹 Entities in Mobile IP

Entity	Function
Mobile Node (MN)	The device that moves across networks.
Home Agent (HA)	Located in the home network; keeps track of MN's current location.
Foreign Agent (FA)	Present in the visited network; provides routing for MN.
Correspondent Node (CN)	The node communicating with the MN.



- **Working Principle**

Step 1: Agent Discovery

- MN learns about FA and HA using *Agent Advertisement* messages.

Step 2: Registration

- MN registers its **Care-of Address (CoA)** (temporary address in foreign network) with the HA through FA.

Step 3: Tunneling

- HA creates a **tunnel** to the MN's CoA.
- Packets destined for the MN are encapsulated and forwarded through the tunnel.

Step 4: Decapsulation

- FA (or MN) decapsulates packets and delivers them to MN.

Advantages

- Seamless mobility across networks
- Maintains continuous sessions
- Compatible with IPv4 and IPv6

Limitations

- Triangular routing (HA → FA → MN) increases delay
- Higher overhead due to encapsulation
- Security and authentication complexity

🔸 Comparison: Mobile IP vs GPRS

Feature	Mobile IP	GPRS
Purpose	Mobility across IP networks	Data service over GSM
Type	Network layer protocol	Cellular network service
Mobility Handling	Uses Home Agent and Foreign Agent	Uses SGSN and GGSN
Connection Type	IP-based	GSM-based
Data Transfer	IP tunneling	Packet switching
Example Use	Roaming between networks	Internet access on 2G/2.5G phones

LTE (4G) Architecture Overview

- **LTE (Long Term Evolution)** is a **4th-generation (4G)** mobile communication standard developed by **3GPP (Release 8 onwards)**.
- It offers **high-speed packet-switched data**, **low latency**, and supports **IP-based voice (VoLTE)** and multimedia services.

📈 Goals of LTE:

- Peak downlink speed up to **100 Mbps**
- Uplink up to **50 Mbps**
- Latency < 10 ms
- All-IP network architecture

LTE Architecture Overview

LTE is divided into **three main components:**

🧩 1. User Equipment (UE)

- The subscriber's device (smartphone, dongle, IoT module).
- Connects wirelessly to the **E-UTRAN** (radio access network).
- Contains **USIM** for user authentication and mobility.

User Equipment(UE):

It Consists of the following important modules

1. Mobile Termination(MT)
2. Terminal Equipment(TE)
3. SIM
    - User Ph. No.
    - Home Network Identity
    - Security Keys

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

- The **radio access part** of LTE.
- Composed of **eNodeBs (evolved Node Bs)** — the LTE base stations.

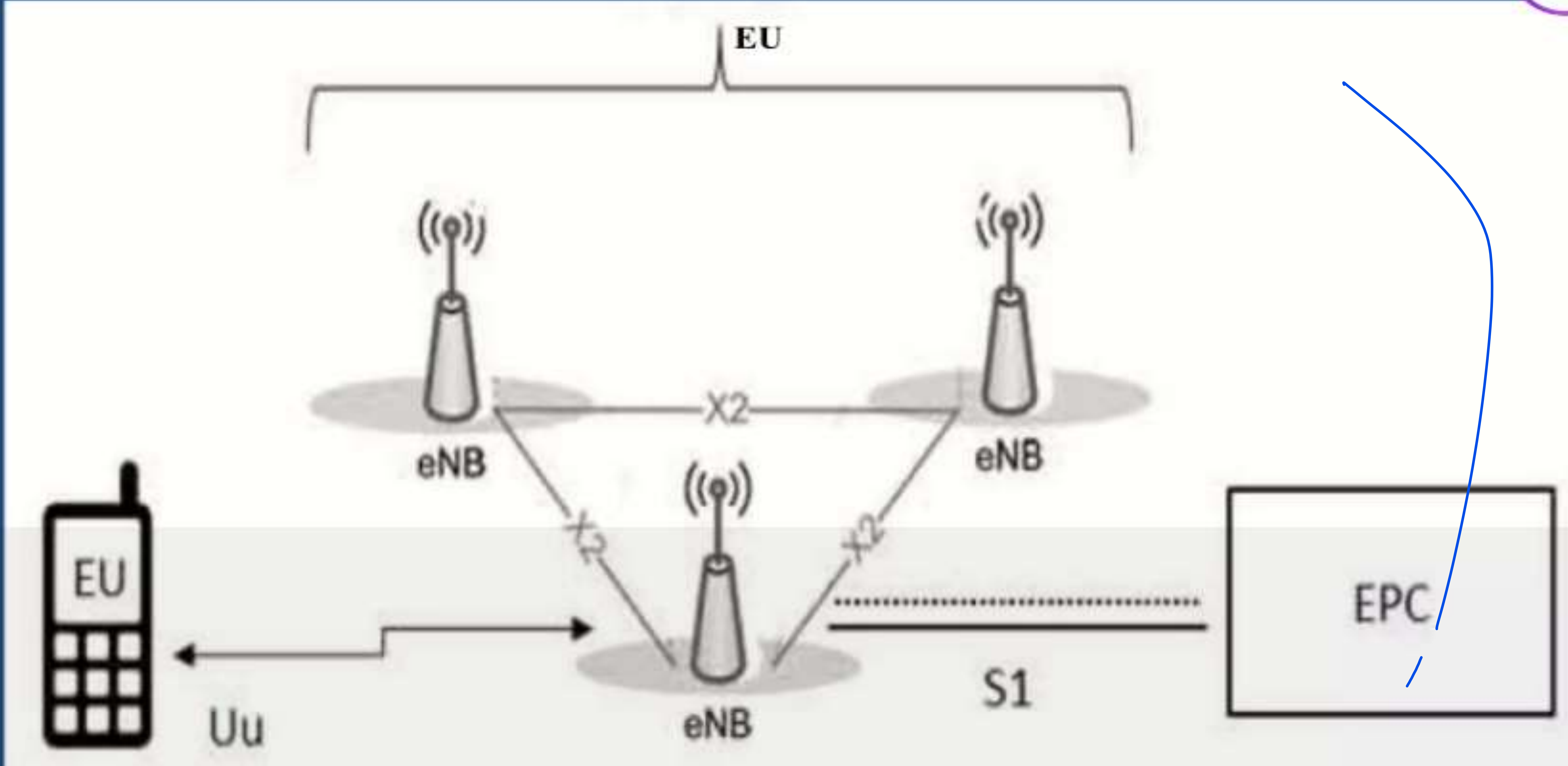
Functions of eNodeB:

- Radio resource management
- Scheduling and QoS control
- Handover decisions
- Encryption and decryption of user data

Each eNodeB connects directly to:

- **User Equipment (UE)** via air interface (**Uu**)
- **EPC (Evolved Packet Core)** via **S1 interface**
- Other eNodeBs via **X2 interface** (for handover)

E-UTRAN(EU):

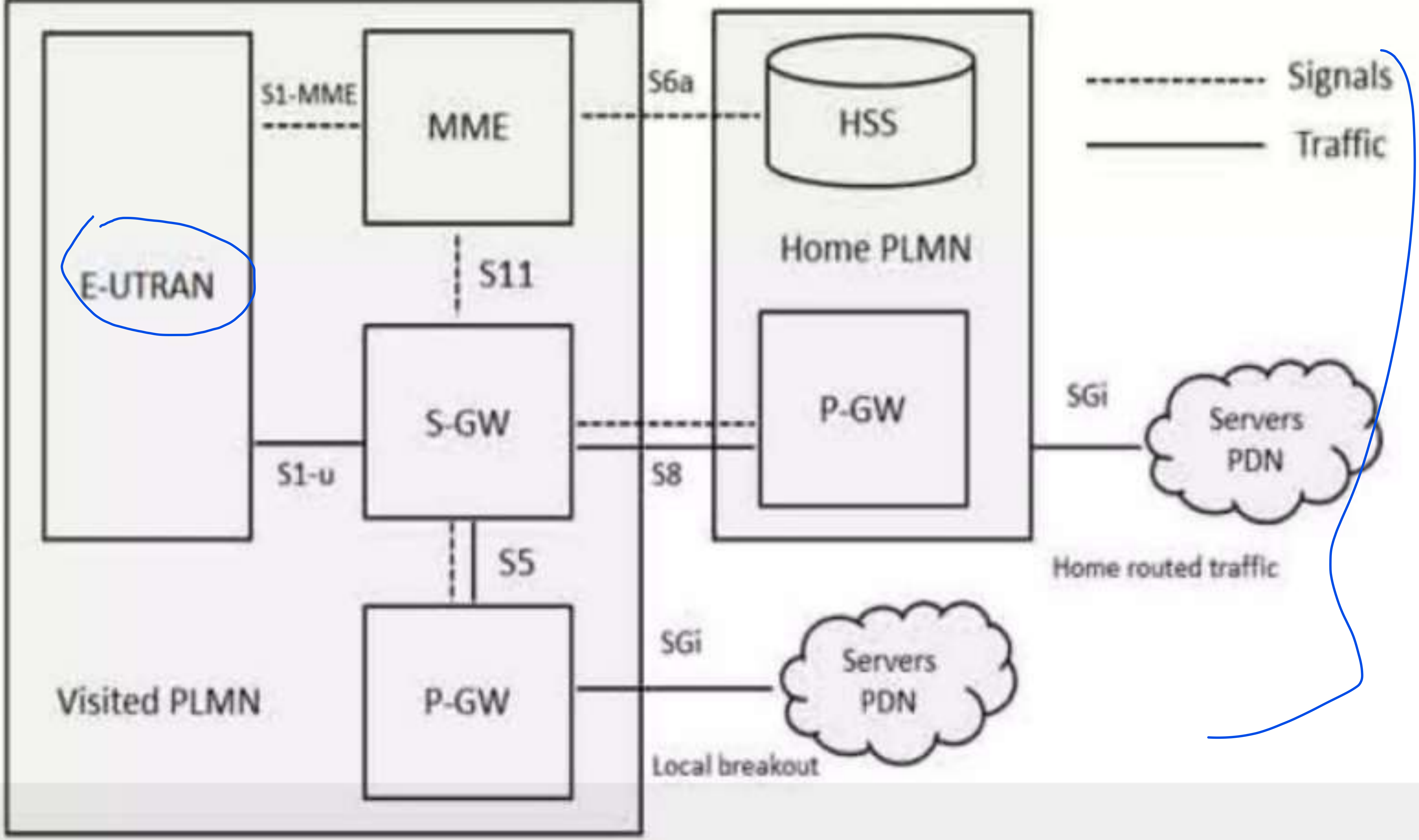


3. EPC (Evolved Packet Core)

The **core network** that handles IP routing, mobility, and session management.

eNodeB(eNB):

- Scheduling and Dynamic allocation of resources to UE (After every 1ms)
- State transition from IDLE mode to Connected mode and vice versa
- Controlling the mobility of the UE in connected mode
- Buffering of data at handover
- Admission and Congestion control


E-UTRAN
S1-MME
MME
S6a
HSS
Signals
Traffic
S11
Home PLMN
S-GW
P-GW
SGi
Servers
PDN
S1-u
S8
S5
Home routed traffic
Visited PLMN
P-GW
SGi
Servers
PDN
Local breakout

Component	Full Form	Function
MME	Mobility Management Entity	Control plane functions: user authentication, attach/detach, bearer setup, handovers
SGW	Serving Gateway	Routes and forwards user data between eNodeB and PDN-GW
PGW	Packet Data Network Gateway	Connects LTE network to external IP networks (Internet, IMS)
HSS	Home Subscriber Server	Stores subscriber data, authentication, QoS, roaming information
PCRF	Policy and Charging Rules Function	Manages QoS policies and billing control

🔷 4. LTE Network Planes

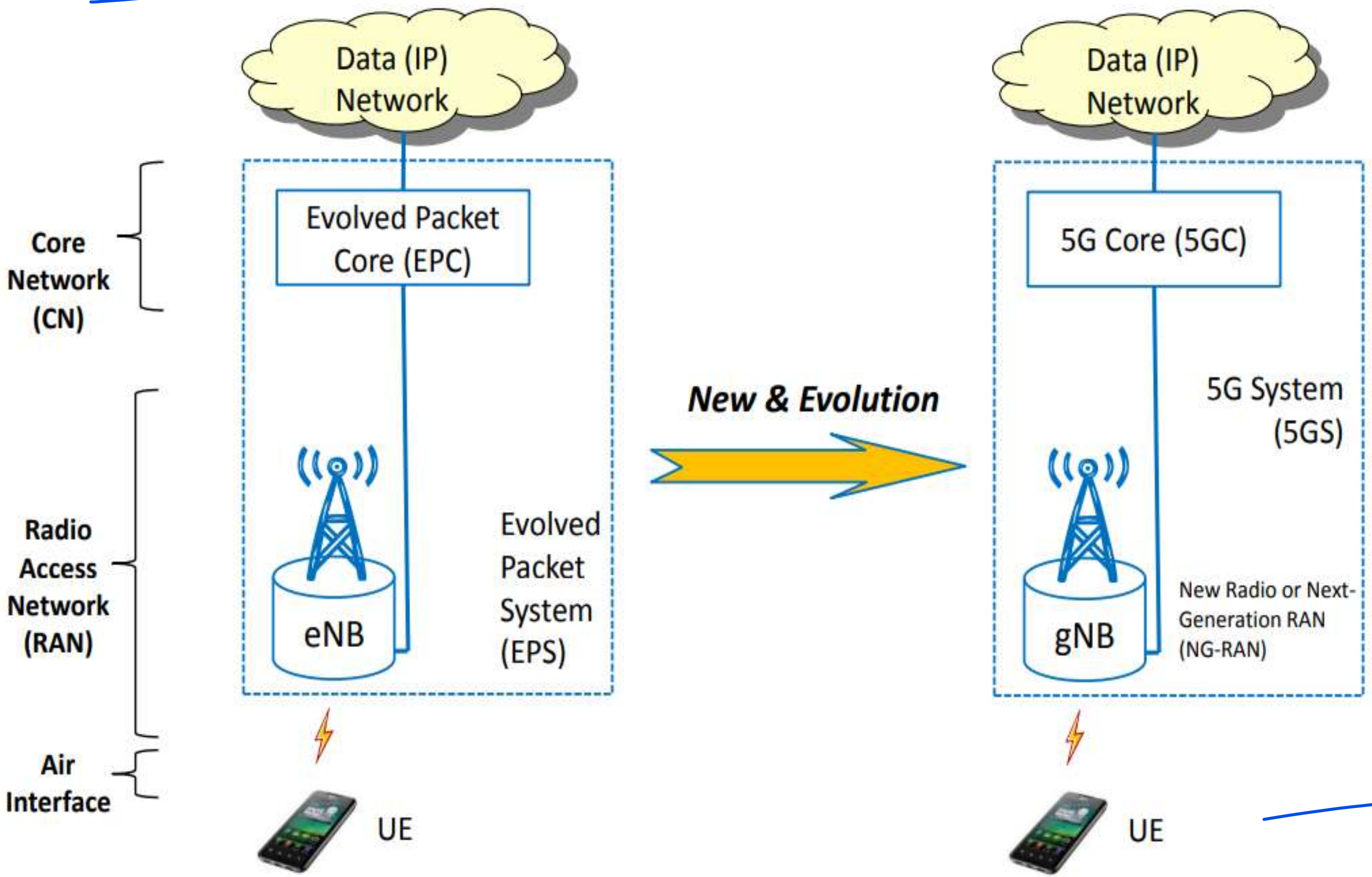
- **Control Plane:** Handles signaling (session setup, mobility, authentication).
  Components → MME, HSS
- **User Plane:** Carries user data (voice/video/IP traffic).
  Components → SGW, PGW, eNodeB

LTE provides a high-speed, all-IP, low-latency network architecture consisting of UE, eNodeB, and EPC.
It represents the transition from circuit-switched 3G systems to fully packet-switched broadband 4G networks.

8. Advantages of LTE (4G)

- Higher data rates and spectrum efficiency
- Lower latency and fast connectivity setup
- IP-based simplified architecture
- Support for multimedia, HD video, and VoLTE
- Easy upgrade path to 5G (NR)

5G Mobile Network Architecture



5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

3GPP TS 23.501: System Architecture for the 5G System; Stage 2

3GPP TS 23.502: Procedures for the 5G System; Stage 2

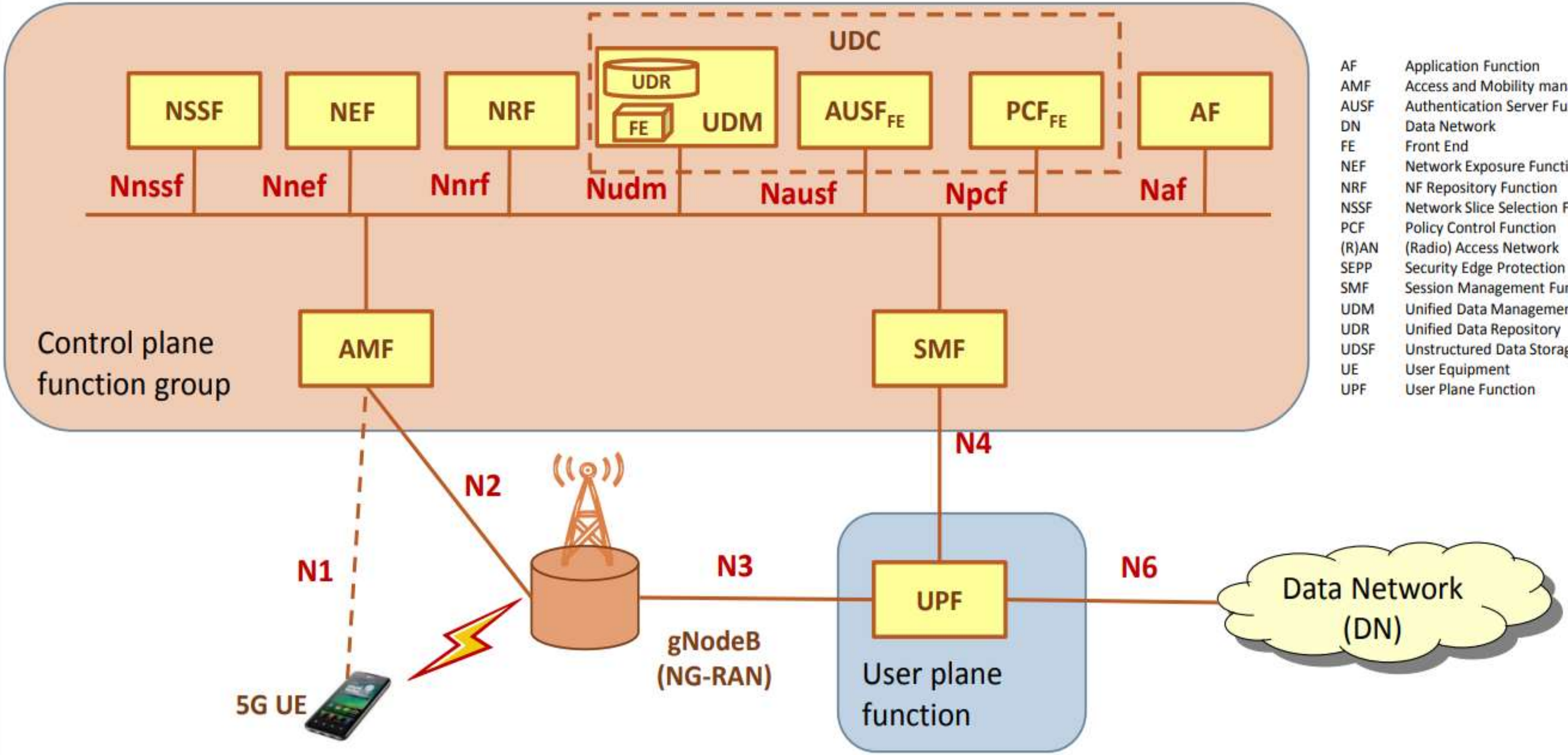
- **5G (Fifth Generation)** mobile technology is the **successor to 4G LTE**, designed to provide **ultra-high-speed**, **low-latency**, and **massive connectivity** for modern and future communication needs.
- Developed under **3GPP Release 15 onwards.**
- It supports not only smartphones but also **IoT, autonomous vehicles, AR/VR, remote surgery, and smart cities.**

🔷 2. Key Objectives of 5G

- **Enhanced Mobile Broadband (eMBB)** → very high data rates.
- **Ultra-Reliable Low Latency Communication (URLLC)** → real-time, mission-critical applications.
- **Massive Machine Type Communication (mMTC)** → connect billions of IoT devices.

Parameter	4G LTE	5G
Peak Data Rate	Up to 1 Gbps	Up to 20 Gbps
Latency	30–50 ms	< 1 ms
Connection Density	~100,000 devices/km^2	~1 million devices/km^2
Spectrum Efficiency	1x	3x–5x
Mobility Support	Up to 350 km/h	Up to 500 km/h
Reliability	99.9%	99.999%

5G System (5GS) – Actual



AF	Application Function
AMF	Access and Mobility management Functio
AUSF	Authentication Server Function
DN	Data Network
FE	Front End
NEF	Network Exposure Function
NRF	NF Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
(R)AN	(Radio) Access Network
SEPP	Security Edge Protection Proxy
SMF	Session Management Function
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UE	User Equipment
UPF	User Plane Function

🔷 4. 5G Architecture Overview

5G architecture is based on **Service-Based Architecture (SBA)**, divided into **two main parts:**

🧩 1. 5G Access Network (NG-RAN)

- Connects **User Equipment (UE)** to the 5G Core Network.
- Consists of:
  - **gNB (Next Generation NodeB)** → 5G base station handling both control and user data.
  - **ng-eNB** → LTE base station upgraded to connect to the 5G Core.

🌐 2. 5G Core Network (5GC)

A cloud-native, all-IP core designed for flexibility, scalability, and service customization.

Key Components of 5GC:

Component	Full Form	Function
AMF	Access and Mobility Management Function	Authentication, registration, handover, and mobility.
SMF	Session Management Function	Manages IP sessions, QoS, and data paths.
UPF	User Plane Function	Handles user data forwarding (like SGW/PGW in LTE).
UDM	Unified Data Management	Stores subscriber profiles.
PCF	Policy Control Function	Defines QoS and policy rules.
NSSF	Network Slice Selection Function	Allocates network slices for different services.
NRF	Network Repository Function	Maintains function registration and discovery.

5. Network Slicing

- A **unique feature of 5G**, allowing the network to be divided into **multiple virtual "slices"**, each optimized for a specific service type.
- Example:
  - One slice for **IoT devices (low power)**
  - Another for **autonomous vehicles (ultra-reliable)**
  - Another for **mobile broadband (high speed)**

6. 5G Protocol Stack

Control Plane:

- **NAS (Non-Access Stratum)**: Between UE and AMF (registration, session control).
- **RRC (Radio Resource Control)**: Between UE and gNB.

User Plane:

- **PDCP, RLC, MAC, PHY layers** similar to LTE but enhanced for 5G NR (New Radio).

🔷 9. Modes of Deployment

Mode	Description
NSA (Non-Standalone)	Uses existing LTE core (EPC) + 5G radio (NR)
SA (Standalone)	Uses full 5G Core (5GC) + 5G radio
Dual Connectivity	UE connected to LTE eNB and 5G gNB simultaneously

🔷 11. Advantages of 5G

- Extremely high data rates (20 Gbps)
- Ultra-low latency (<1 ms)
- Massive IoT connectivity
- Support for new applications (AR/VR, autonomous driving, telesurgery)
- Efficient use of spectrum and energy

📡 Mobile Communication Protocols

🔹 Introduction

Mobile communication protocols define the **rules and procedures** that enable mobile devices and network elements to communicate efficiently and reliably.
They ensure **data transfer**, **call setup**, **handover**, **security**, and **mobility management** across wireless networks.

🔹 Classification of Protocols

Mobile communication uses a **protocol stack** divided into multiple layers similar to the OSI model:

🧱 1. Physical Layer Protocols

- Responsible for transmission of data over radio waves.
- Defines modulation, coding, and multiple access techniques.

🌐 2. Data Link Layer Protocols

- Provides **error detection**, **frame synchronization**, and **link control**.
- Divided into:
  - **MAC (Medium Access Control)** – manages access to the shared radio channel.
  - **RLC (Radio Link Control)** – segmentation/reassembly and retransmission.
  - **PDCP (Packet Data Convergence Protocol)** – header compression and security.

🚦 3. Network Layer Protocols

- Handles **mobility management**, **routing**, and **handover**.
- Important protocols:
  - **GPRS Tunneling Protocol (GTP)** – for user data transfer between GPRS/LTE networks.
  - **Mobile IP** – ensures a mobile node keeps the same IP address when moving across networks.
  - **ICMP, IP, ARP** – used for addressing and error control.

ICMP (Internet Control Message Protocol) ARP (Address Resolution Protocol)

🧩 4. Transport Layer Protocols

- Ensures **end-to-end communication** between applications.
- **TCP (Transmission Control Protocol)** – reliable communication.
- **UDP (User Datagram Protocol)** – faster, connectionless communication (e.g., for VoIP, streaming).

💬 5. Application Layer Protocols

- Supports **end-user services** such as voice, messaging, and internet applications.
- Common protocols:
  - **HTTP/HTTPS** – web access.
  - **SMTP/POP3/IMAP** – email.
  - **FTP** – file transfer.
  - **SIP (Session Initiation Protocol)** – call setup in VoIP.
  - **DNS** – domain name resolution.

Functions of Mobile Communication Protocols

1. Call setup and release
2. Handover management
3. Authentication and encryption
4. Mobility and session continuity
5. ~~Error control and flow management~~
6. Quality of Service (QoS) maintenance