A Brief Discussion on 1G to 5G , Edge Computing, and Beyond…

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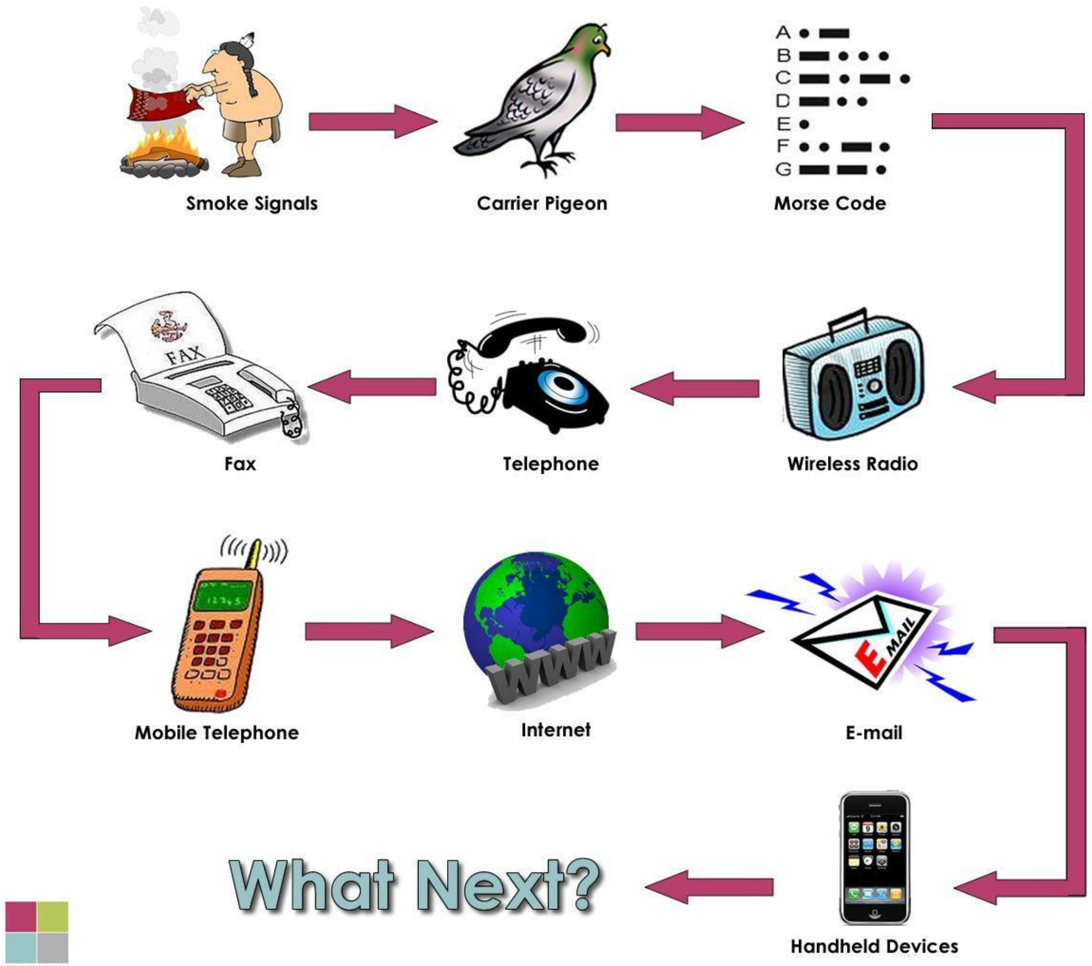
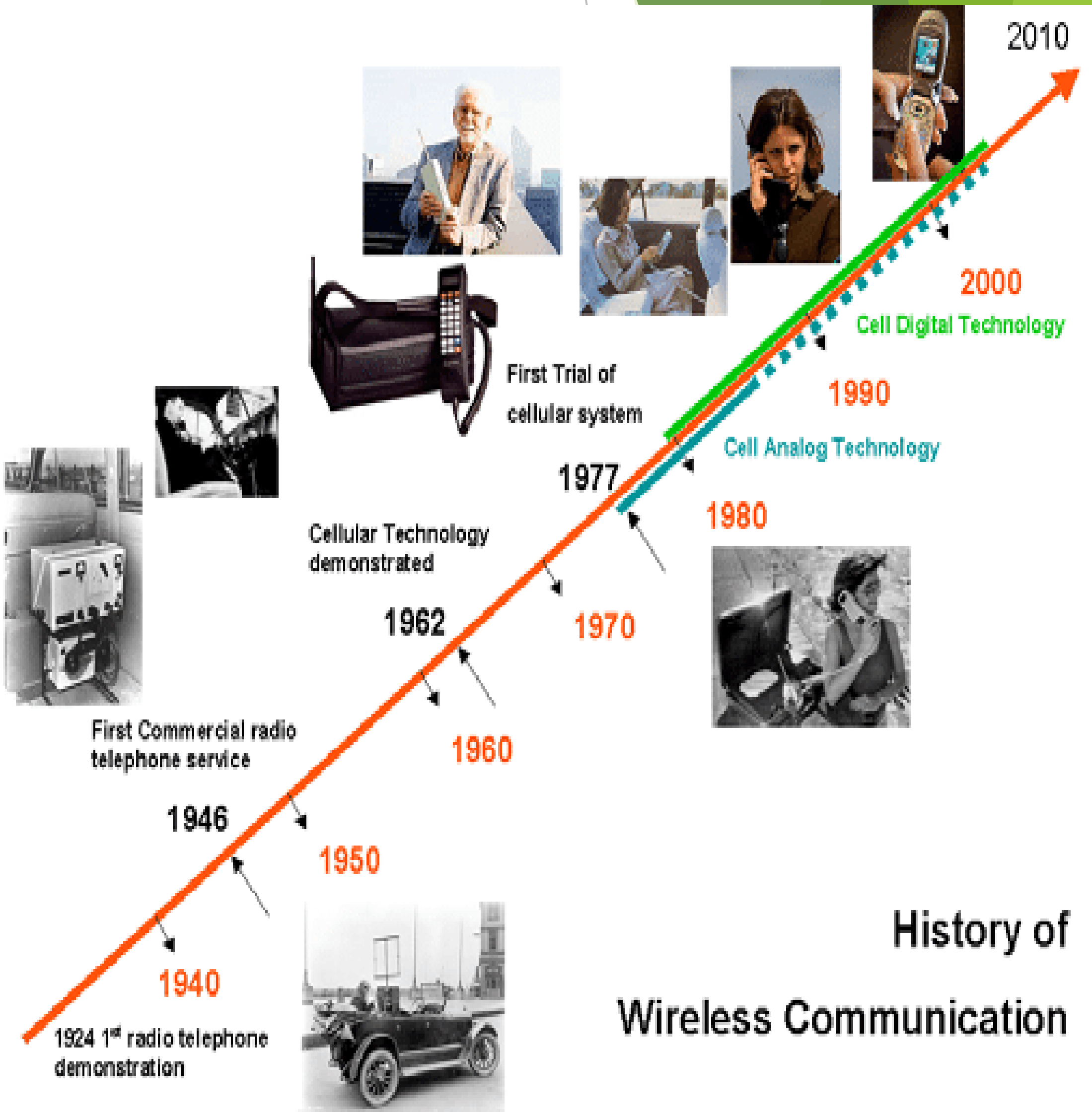
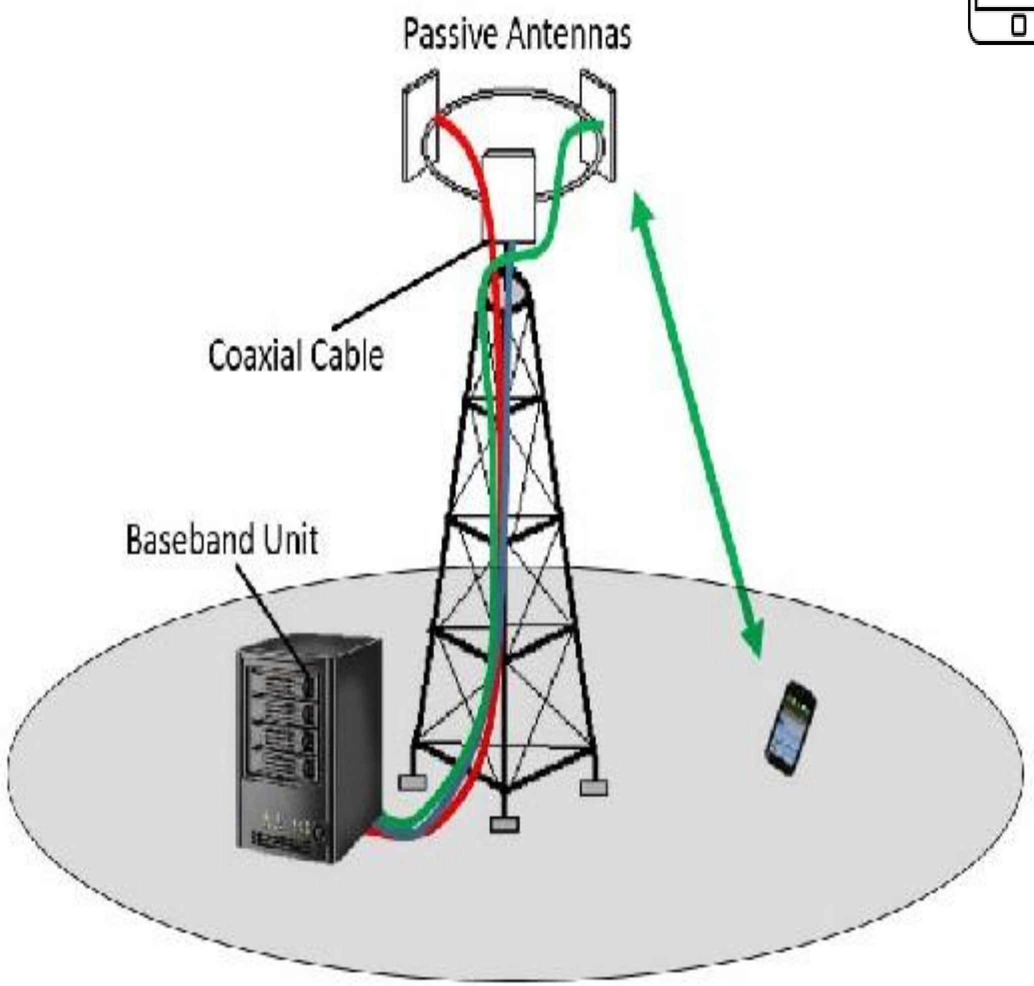
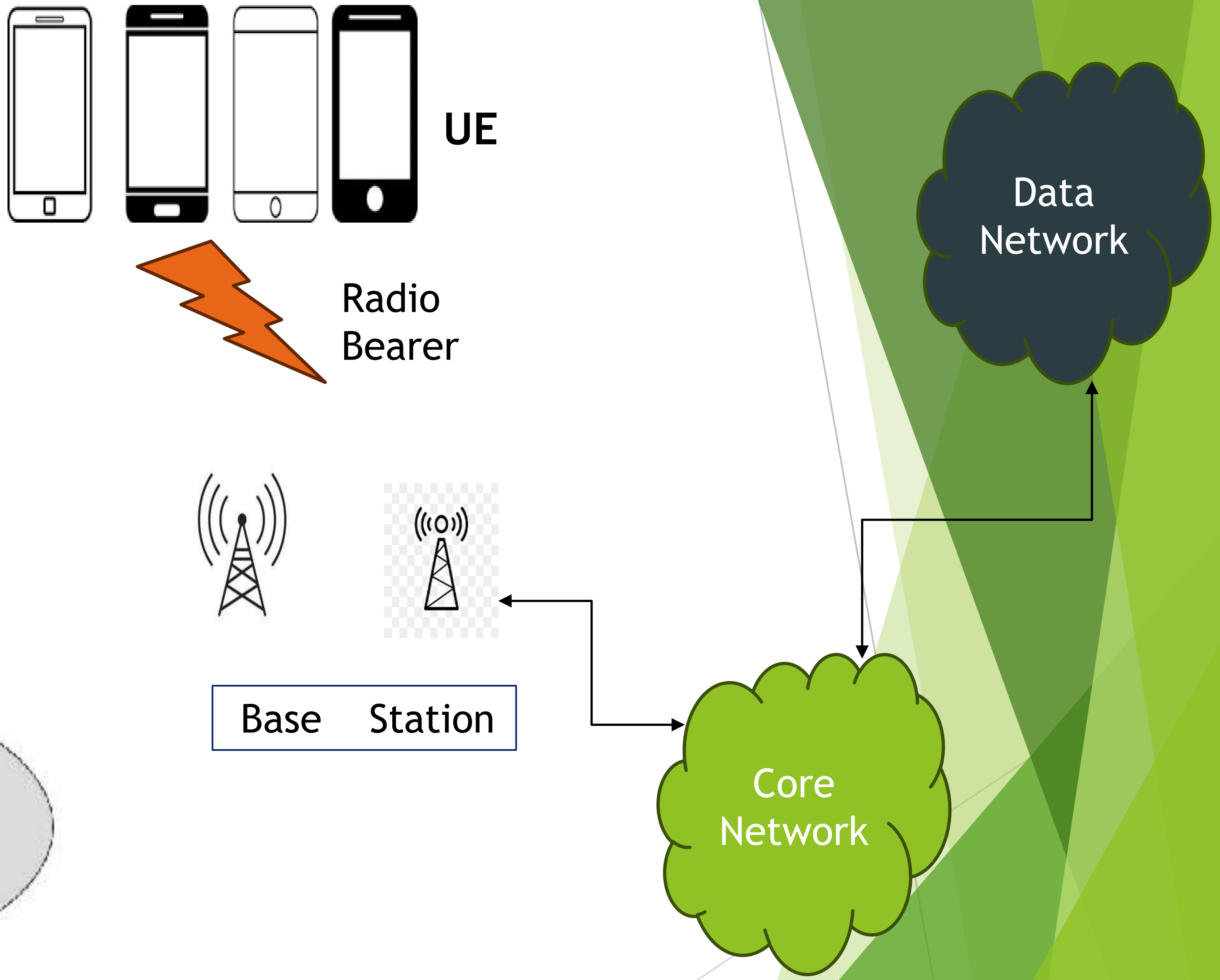
Commincation Timeline





History of Wireless Communication


Passive Antennas
Coaxial Cable
Baseband Unit


UE
Radio
Bearer
Base Station
Core
Network
Data
Network

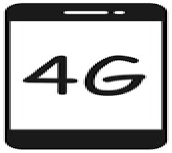
1G

Launched in 1979, the 1G refers to the first generation of wireless cellular technology. It was used for voice communication. The 1G delivered analog voice and thus there was no data transmission.

2G

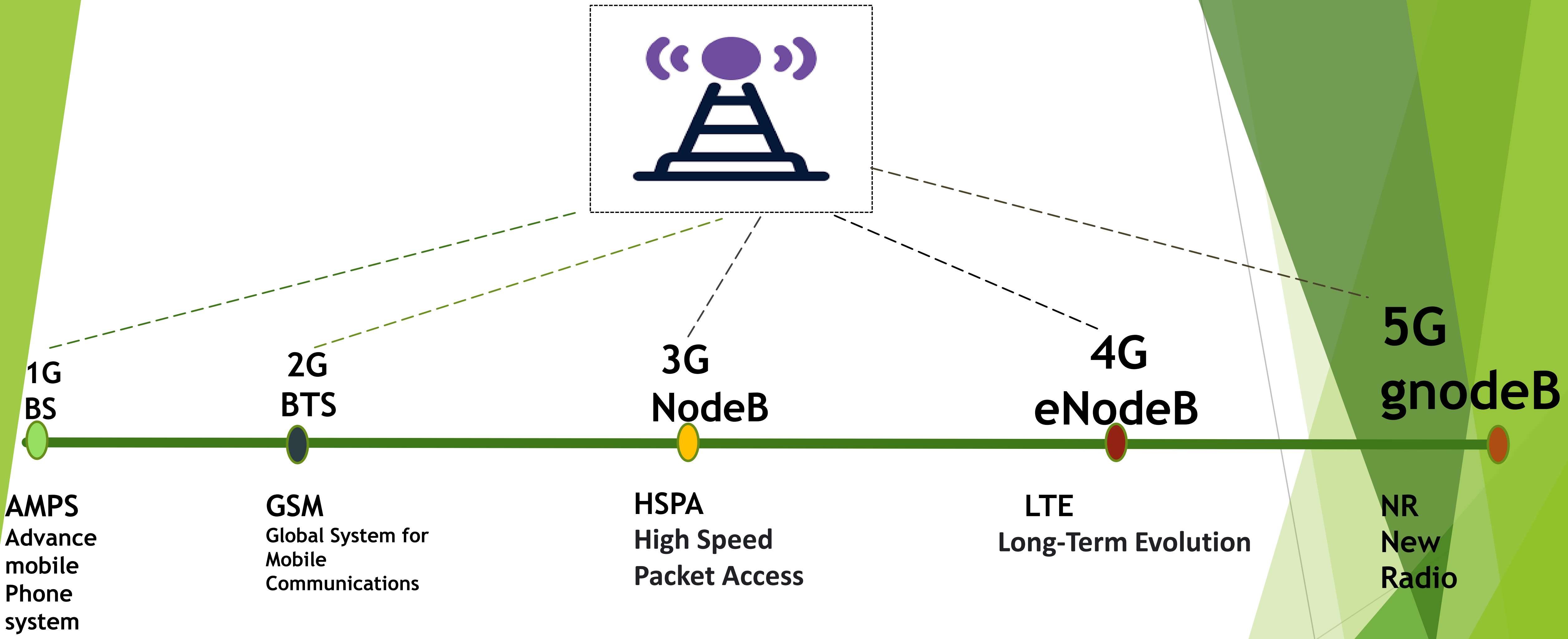
Launched in Finland in 1991, the 2G networks are digital. It provided both voice and data communication services. With General Packet Radio Service (better known as GPRS), 2G offers a theoretical maximum transfer speed of 40 kilobits per second (kbit/s).

11 December 2008, the first 3G mobile and internet services were launched by MTNL in Delhi and Mumbai metropolitan cities.
Later on, the BSNL started deploying the 3G networks all over the country.
Technically, the 3G is the upgrade for 2.5G GPRS and 2.75G EDGE networks for providing faster data transfer.



The 4G system relies on all-Internet Protocol (IP) based communication such as IP telephony instead of the traditional circuit-switched telephony service.
Along with IP telephony, the 4G has got its footprint in HD TV streamed multimedia, video conferencing, 3D television, and gaming services.
Data speeds of LTE-Advanced
•Peak download 1000 Mbit/s
•Peak upload 500 Mbit/s

Speed-wise, the 5G is faster than 4G. It can deliver up to 20 Gigabits-per-second (Gbps) peak data rates and 100+ Megabits-per-second (Mbps) average data rates. As of July 3, 2019, mm Wave had a top speed of 1.8 Gbit/s on AT&T’s 5G network.


1G
BS
2G
BTS
3G
NodeB
4G
eNodeB
5G
gnodeB
AMPS
Advance mobile Phone system
GSM
Global System for Mobile Communications
HSPA
High Speed Packet Access
LTE
Long-Term Evolution
NR
New Radio

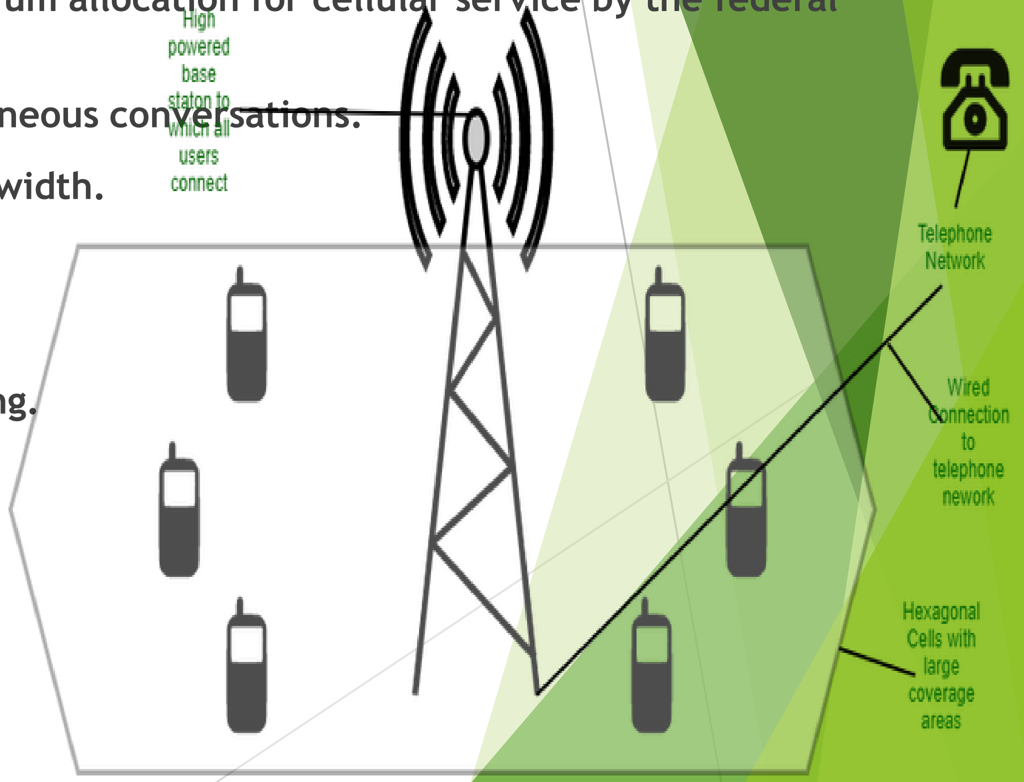
1G to 5G Evolution

1G	2G	3G	4G	5G
Mobile voice communication	Efficient voice to reach billions	Focus shifts to mobile data	Mobile broadband and emerging expansion	A unified future-proof platform
1980s	1990s	2000s	2010s	2020s
Analog voice	Digital voice	Wireless Internet	Mobile broadband	Wireless Edge
AMPS, NMT, TACS	D-AMPS, GSM, IS-95 (CDMA)	CDMA2000/EV-DO WCDMA/HSPA+,	LTE, LTE Advanced, Gigabit LTE	5G New Radio (NR)

AMPS in 1G -

- AMPS (Advanced Mobile Phone System) was invented by Bell Labs and first installed in the United States in 1982. In all mobile phone systems, a geographic region divides up into cells, which is why the devices are sometimes called cell phones. Base station consists of a computer and transmitter/receiver connected to the antenna. In a small system, all the base stations are connected to a single device called MSC (Mobile Switching Center) or MTSO(Mobile Telephone Switching Office).

- It is an analog system and is based upon initial electromagnetic spectrum allocation for cellular service by the federal communication commission.
- It uses FDMA (frequency division multiple) access for multiple simultaneous conversations.
- When the number of conversations is very high, it requires high bandwidth.
- It was the first to use hexagonal cells.
- Cells in AMPS are 10 km to 20 km across.
- Since it was analog technology, it suffers from noise and eavesdropping.



Features of 1G

Frequency
450, 800 and 900 MHz

Modulation
FM

One user
per channel

Access technique
FDMA

Service
Analog Voice

Frequency
Reuse

Channels Bandwidth
30/25KHZ

AMPS (USA),
TACS (UK), NMT
(Nordic), C-Netz
(Germany)

PSTN
network

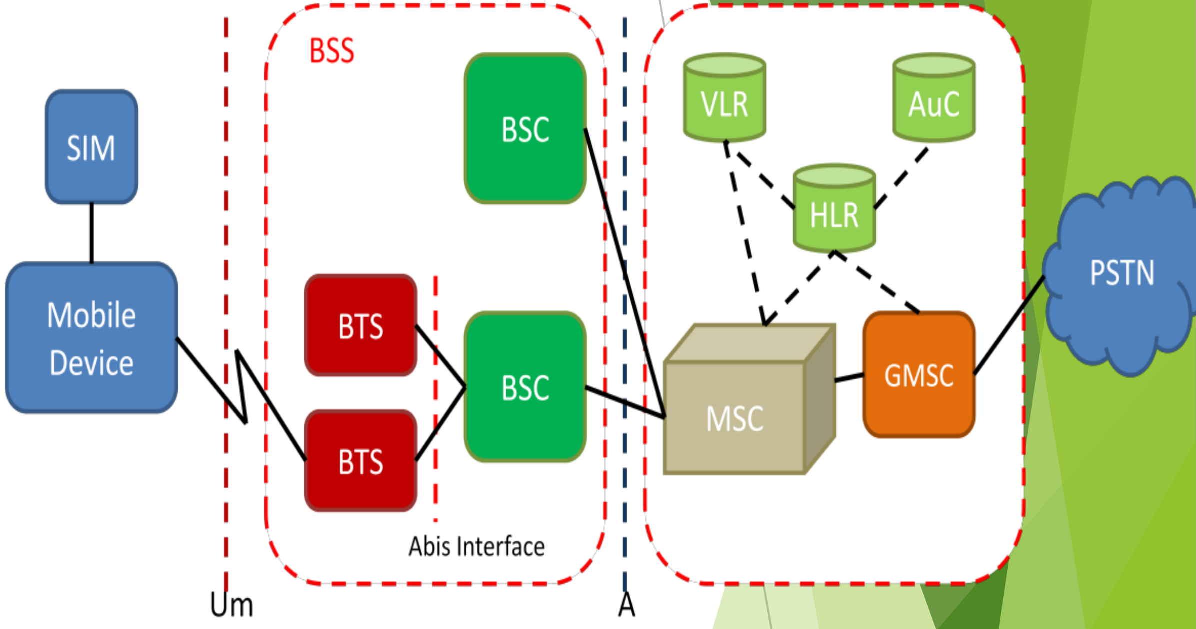
GSM in 2G

GSM (Global System for Mobile Communications) is the most widely used mobile communication system worldwide.

It is a second-generation (2G) mobile communication system that uses digital technology to transmit voice and data.

In a GSM network, calls are routed and transmitted through a combination of various components such as Mobile Station (MS), Base Station System (BSS), and Mobile Switching Center (MSC).

GSM (Global System for Mobile Communications) is a second-generation (2G) digital cellular network standard that revolutionized mobile telephony by enabling digital voice, text messaging, and international roaming.



Component	Function
MSC (Mobile Switching Center)	Core switch that routes voice calls and SMS. Handles mobility, handovers, and call setup.
HLR (Home Location Register)	Central database that stores permanent subscriber info like IMSI, services, and location.
VLR (Visitor Location Register)	Temporary database linked to MSC; stores information about subscribers currently in the MSC area.
AUC (Authentication Center)	Provides authentication and encryption data to ensure secure communication.
EIR (Equipment Identity Register)	Database of valid and blacklisted mobile devices using IMEI numbers.

BTS (Base Transceiver Station)	Handles radio transmission to/from mobile devices. Each BTS covers one cell.
BSC (Base Station Controller)	Manages multiple BTSs; handles radio resources, handovers, power control, and traffic concentration.

Features of 2G

Digital Voice

Mobility

SMS

Access technique FDMA/TDMA

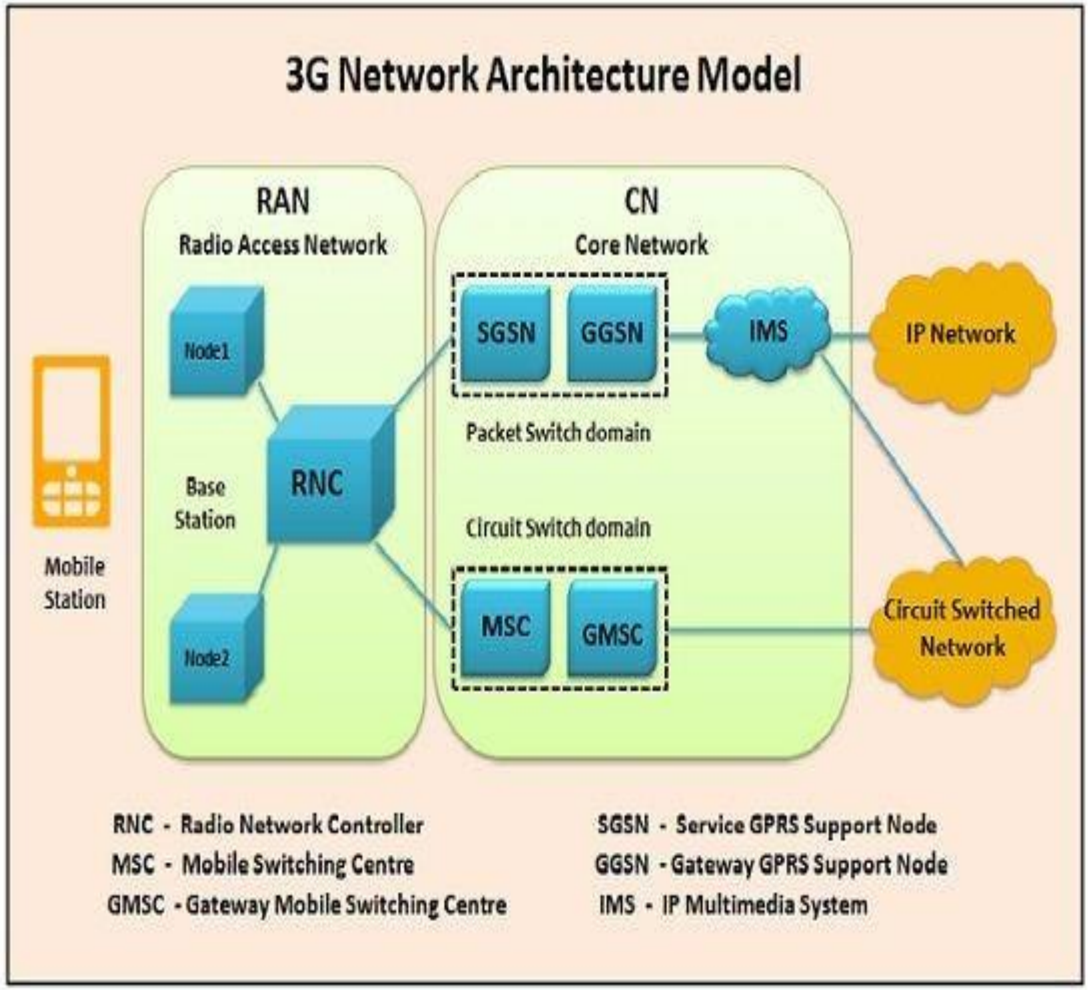
GSM,Data com

Frequency Reuse

Channels Bandwidth
900 MHz and **1800 MHz** (international)
850 MHz and **1900 MHz** (U.S.)

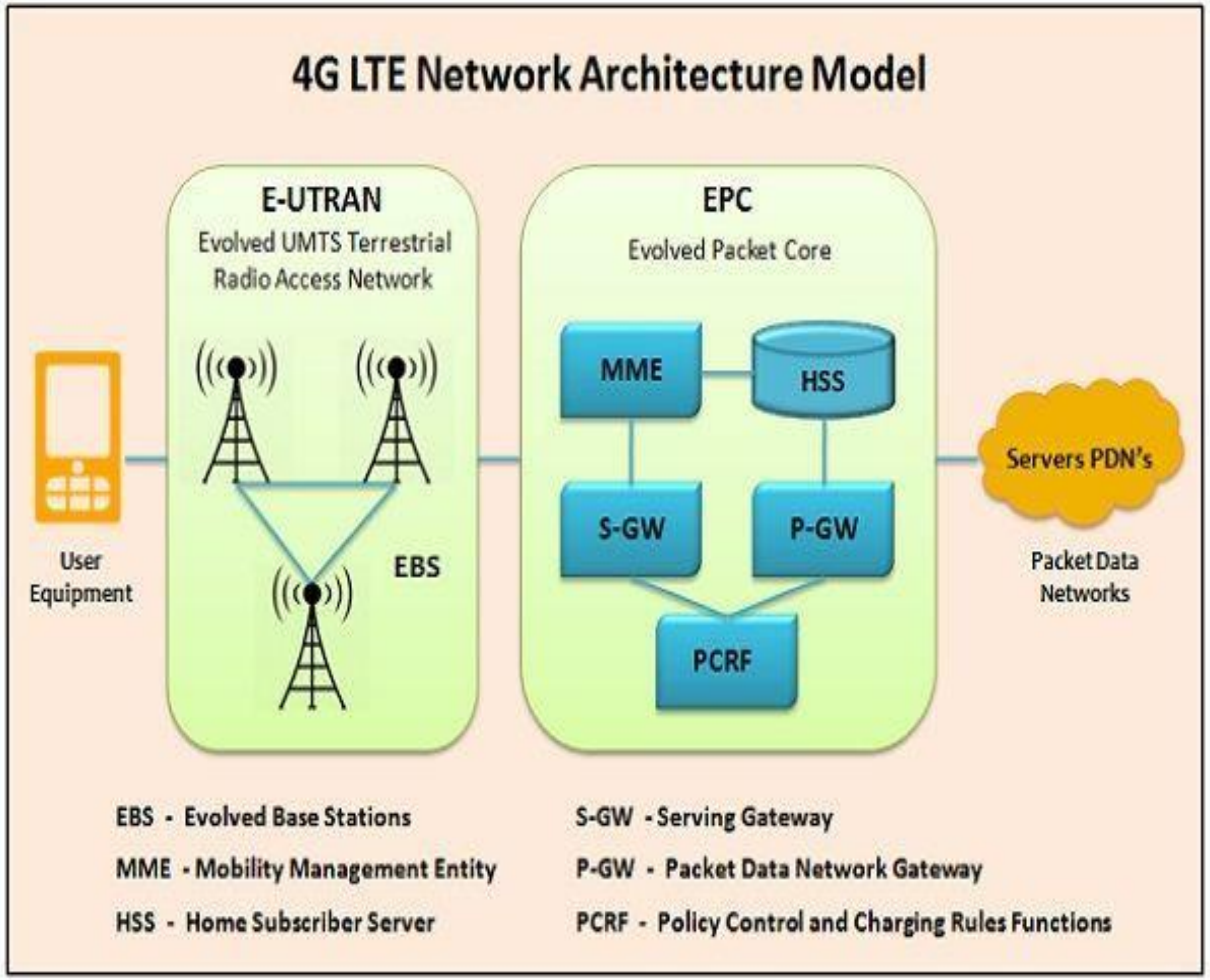
9.6-14.4 kbps (GSM); up to **384 kbps** with **EDGE** (2.75G)

PSTN/Circuit switching network



Subsystem	Main Components	Functions
UE	ME, USIM	User access, identity, authentication
UTRAN	Node B, RNC	Radio access, handover, resource control
CN (CS)	MSC, VLR	Voice switching, mobility, call control
CN (PS)	SGSN, GGSN	Data routing, IP connectivity
Databases	HLR, AUC, EIR	User info, security, equipment management

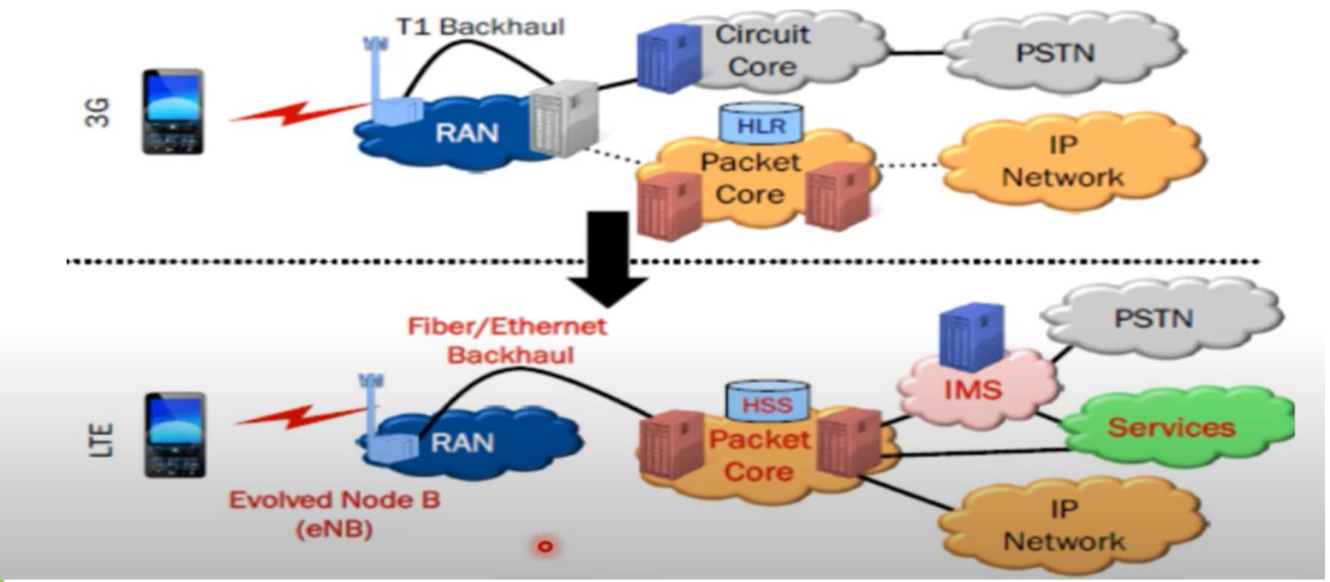
EPC (Evolved Packet Core)



Component	Function
MME (Mobility Management Entity)	Handles signaling, user authentication, tracking, paging, handover control, bearer management.
SGW (Serving Gateway)	Routes and forwards user data packets between eNodeB and PGW; also anchors during handovers.
PGW (Packet Data Network Gateway)	Connects UE to external networks (Internet, IMS); handles IP address allocation, QoS enforcement, filtering.
HSS (Home Subscriber Server)	Central database with subscriber profiles, authentication keys, QoS settings, roaming info.
PCRF (Policy and Charging Rules Function)	Controls QoS and charging policies for each user session.

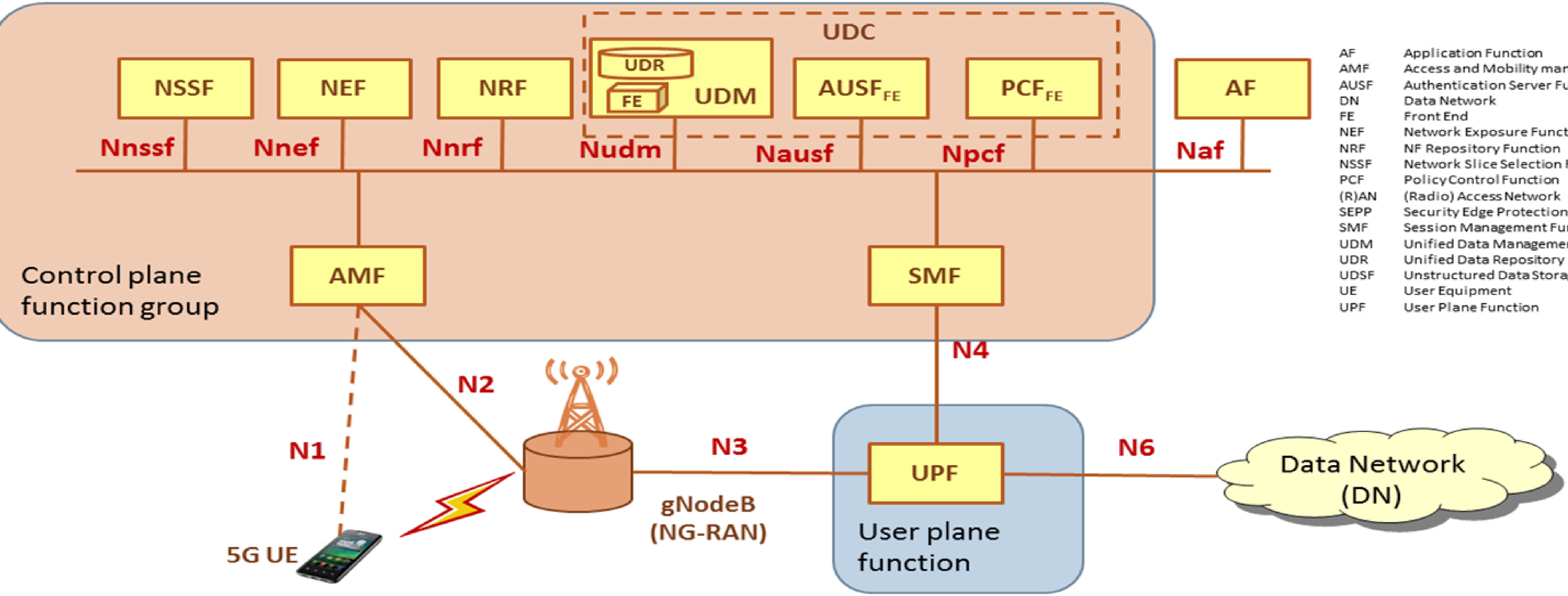
Component	Description
UE (User Equipment)	Mobile device (phone, tablet, etc.) with a USIM for authentication.
eNodeB (Evolved Node B)	Combines base station and controller (Node B + RNC in 3G); handles radio transmission, scheduling, handovers, encryption, QoS, and signaling with core.

3G to 4G transformation-



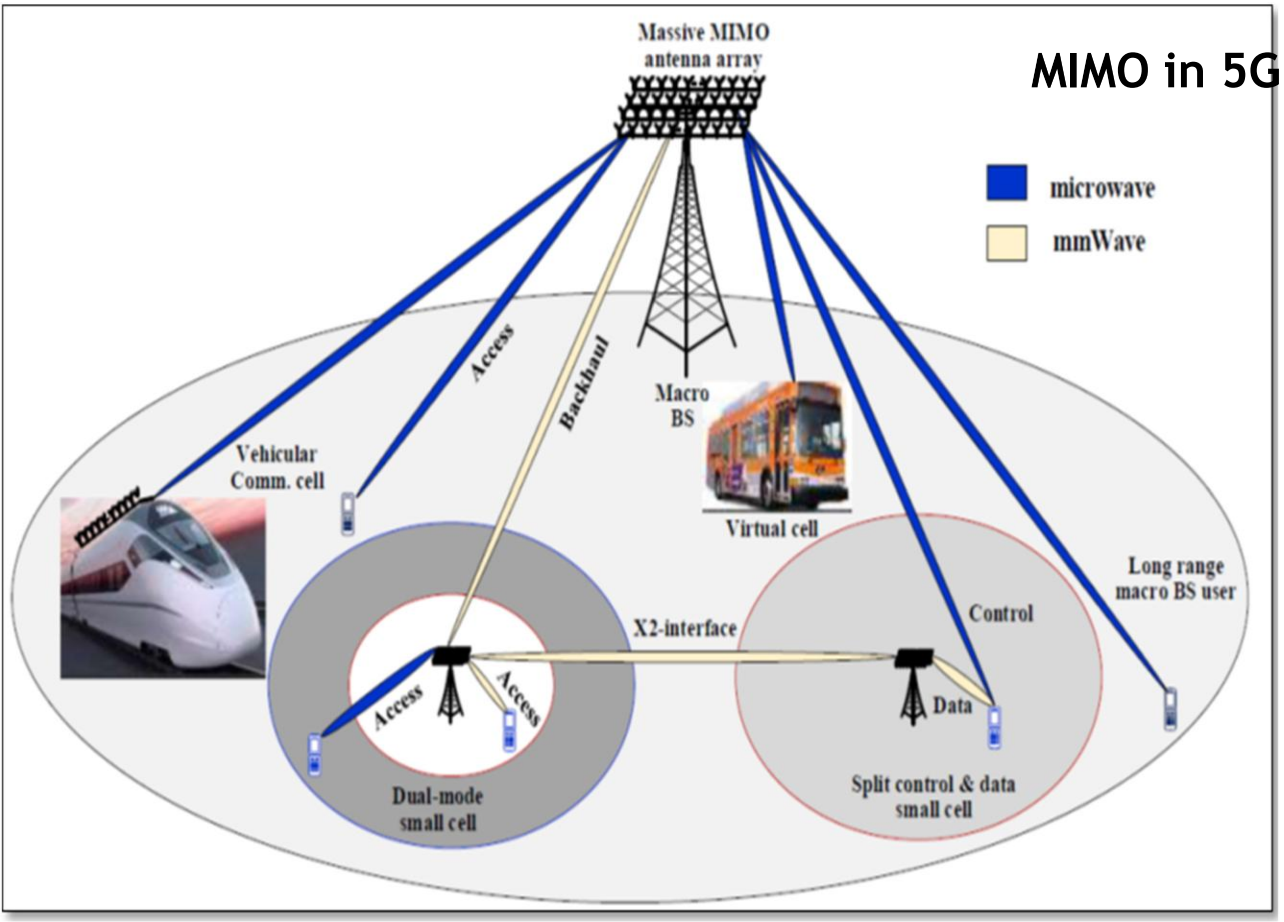
Feature	3G	4G LTE
Core Type	Circuit + Packet	All-IP (Packet-switched)
Speed	~384 kbps	Up to 100 Mbps+ (DL)
Voice	Circuit-switched	VoLTE (IP-based voice)
Latency	~100–300 ms	<10 ms
Architecture	Node B + RNC	eNodeB (no RNC)

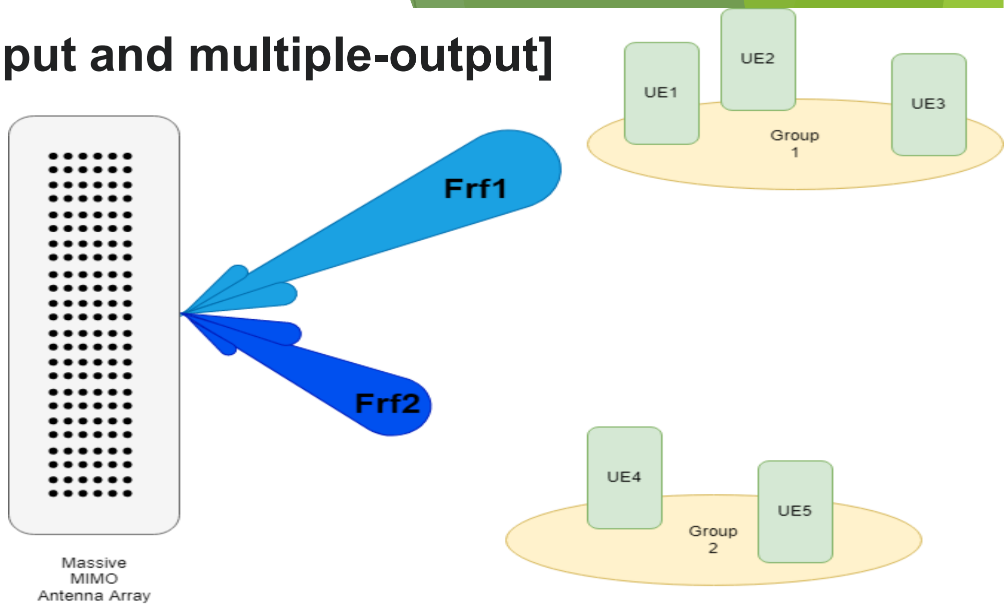
5G core architecture -

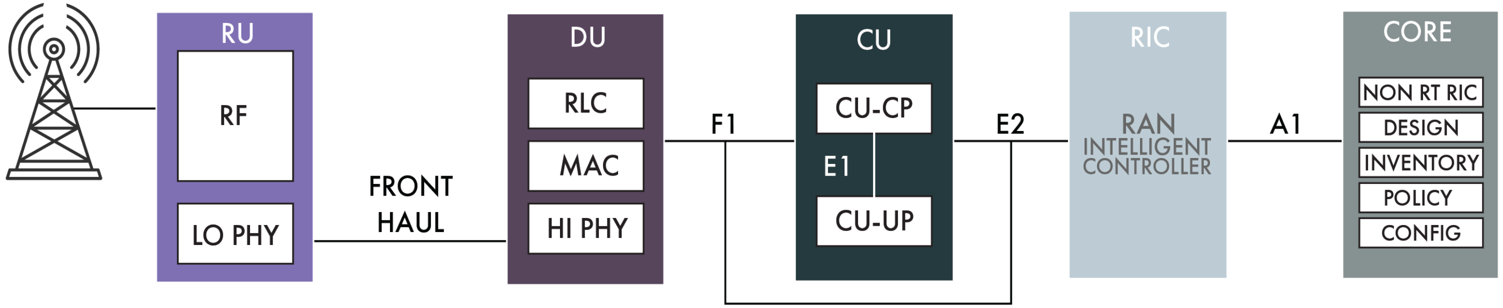


AF	Application Function
AMF	Access and Mobility management Function
AUSF	Authentication Server Function
DN	Data Network
FE	Front End
NEF	Network Exposure Function
NRF	NF Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
(R)AN	(Radio) Access Network
SEPP	Security Edge 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

MIMO in 5G [multiple-input and multiple-output]





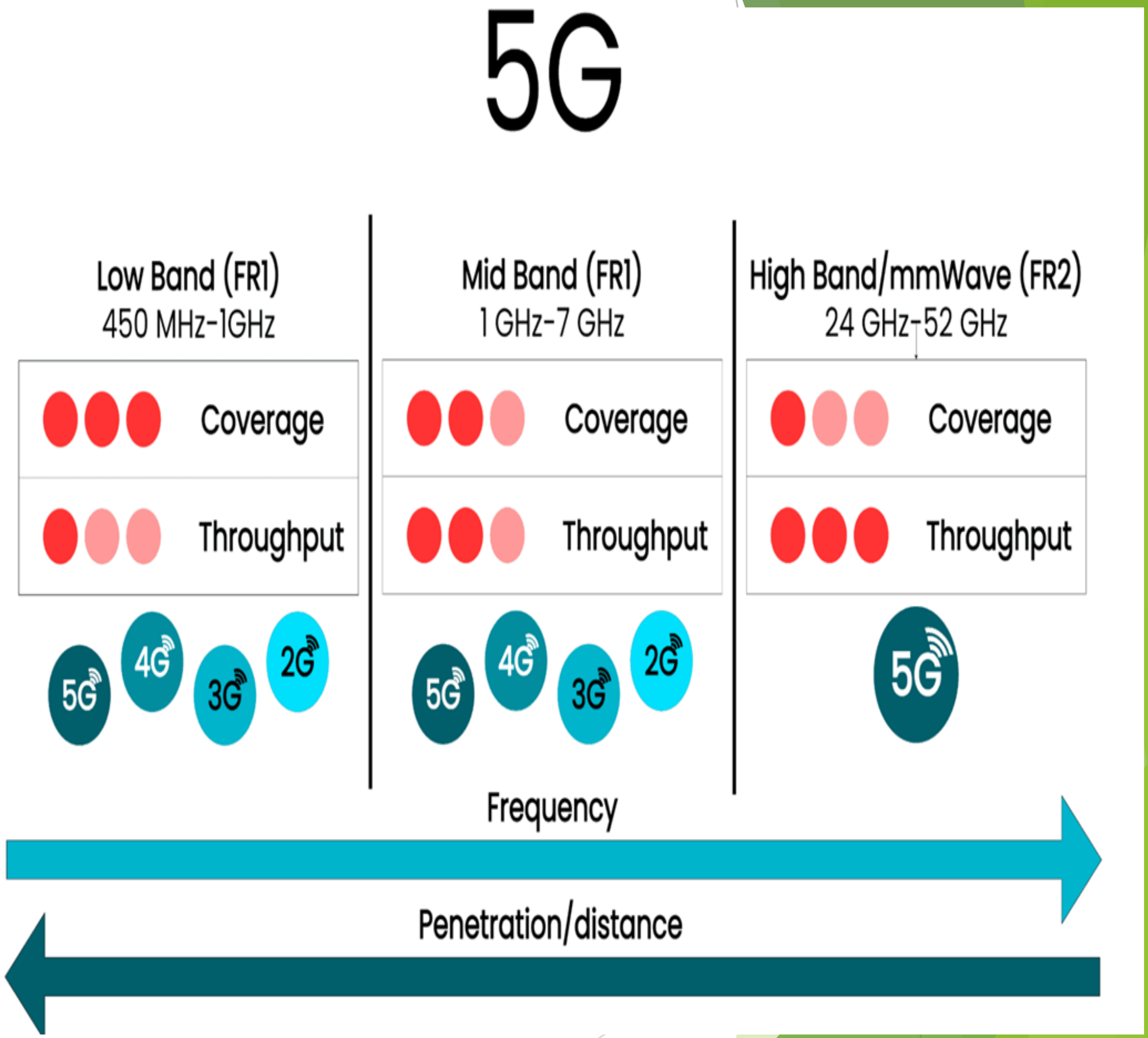


•Airtel supports the following 5G bands in India –

900 MHz (n8)
•1800 MHz (n3)
•2100 MHz (n1)
•3300 MHz (n78)
•26 GHz (n258)

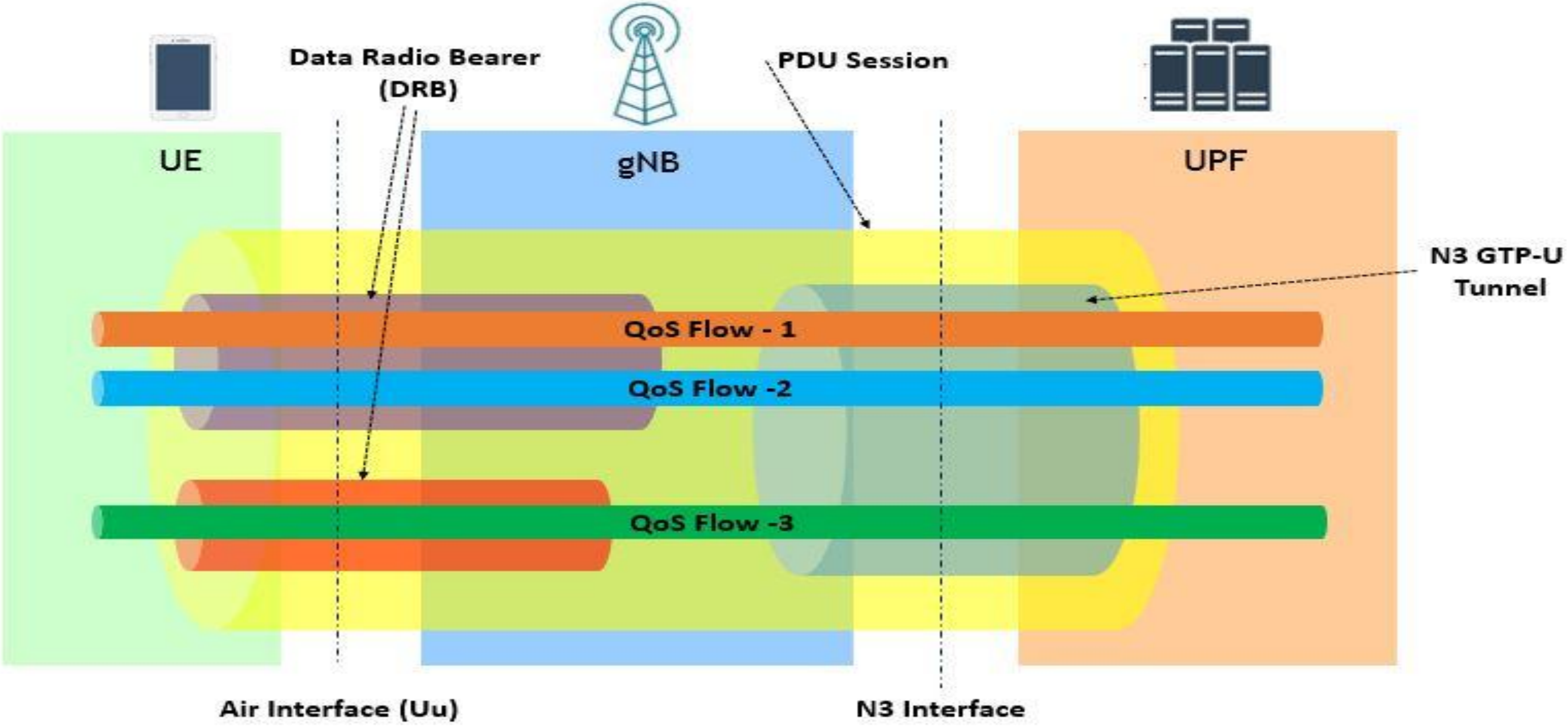
•Reliance Jio supports the following 5G bands in India –

700 MHz (n28)
•3300 MHz (n78)
•26 GHz (n58)



GPRS Tunnelling Protocol (GTP) is a group of IP-based communications protocols used to carry general packet radio service (GPRS) within GSM, UMTS, LTE and 5G NR radio networks.

QoS flow….



PDU (**Protocol Data Unit**)Session Establishment-

- **PDU stands for Packet Data Unit. PDU Session Establishment is the process of establishing a data path between the UE and the 5G core network through UPF.**
- **A PDU session is a logical connection between the UE and a data network, such as the internet or a private network. It is used to carry user data and can support different types of services, such as voice, video, and data.**
- **The UE initiates the PDU Session Establishment process by sending a request to the 5G core network. The request includes information about the type of service that the UE wants to use, and the type of traffic.**
- **Once the PDU session has been established, the UE can use it to send and receive data. The 5G core network manages the resources used by the PDU session to ensure that the network is used efficiently and that the UE receives the appropriate QoS.**
- **PDU Session Establishment is a key component of 5G networks, as it enables the efficient and secure transport of data between the UE and the network.**
- **This is equivalent to PDN Setup process in LTE.**

Evolution of PDU Concept from 1G to 5G

Generation	Technology	PDU Relevance	Remarks
1G	Analog voice	❌ No PDU concept	Circuit-switched, analog communication with no packet-based structure.
2G	GSM (digital)	⚠️ Basic framing (data units)	Early digital framing exists, but PDUs not explicitly defined in packet terms.
3G	UMTS, CDMA2000	✅ PDU introduced (RLC, MAC layers)	Layered packet structure begins, including PDUs at RLC/MAC layers in 3GPP.
4G	LTE	✅✅ Structured PDUs in EPC & NAS	Explicit PDUs used in user and control planes, e.g., NAS-PDU, RRC-PDU.
5G	NR + 5GC	✅✅✅ Advanced PDU Sessions	**"PDU Session"** is a core 5G concept; establishes end-to-end logical connection (e.g., IP, Ethernet, Unstructured PDUs).

Type of PDU Session-

- **IP PDU** –IPv4/IPV6 ,Dual Stack (IPV4 and IPV6),Support full QoS ,SSC mode 1,2,3

- **Ethernet PDU** Session-UE connectivity to layer two Ethernet ,Example 1. Fix wi fi access, Device connectivity in factory unit

- **Unstructured PDU session -** Data Type not define , support IoT protocol.

PDU QoS flow id default =1

PDU parameters-

- PDU session identifier (session id)
- S-NSSAI (slice identifier)
- DNN Name (name of DNN)
- PDU Session types- IPV4/IPv6/Dual stack /ethernet or Unstructured
- SSC mode (Service and session continuity mode)
- User plane security information

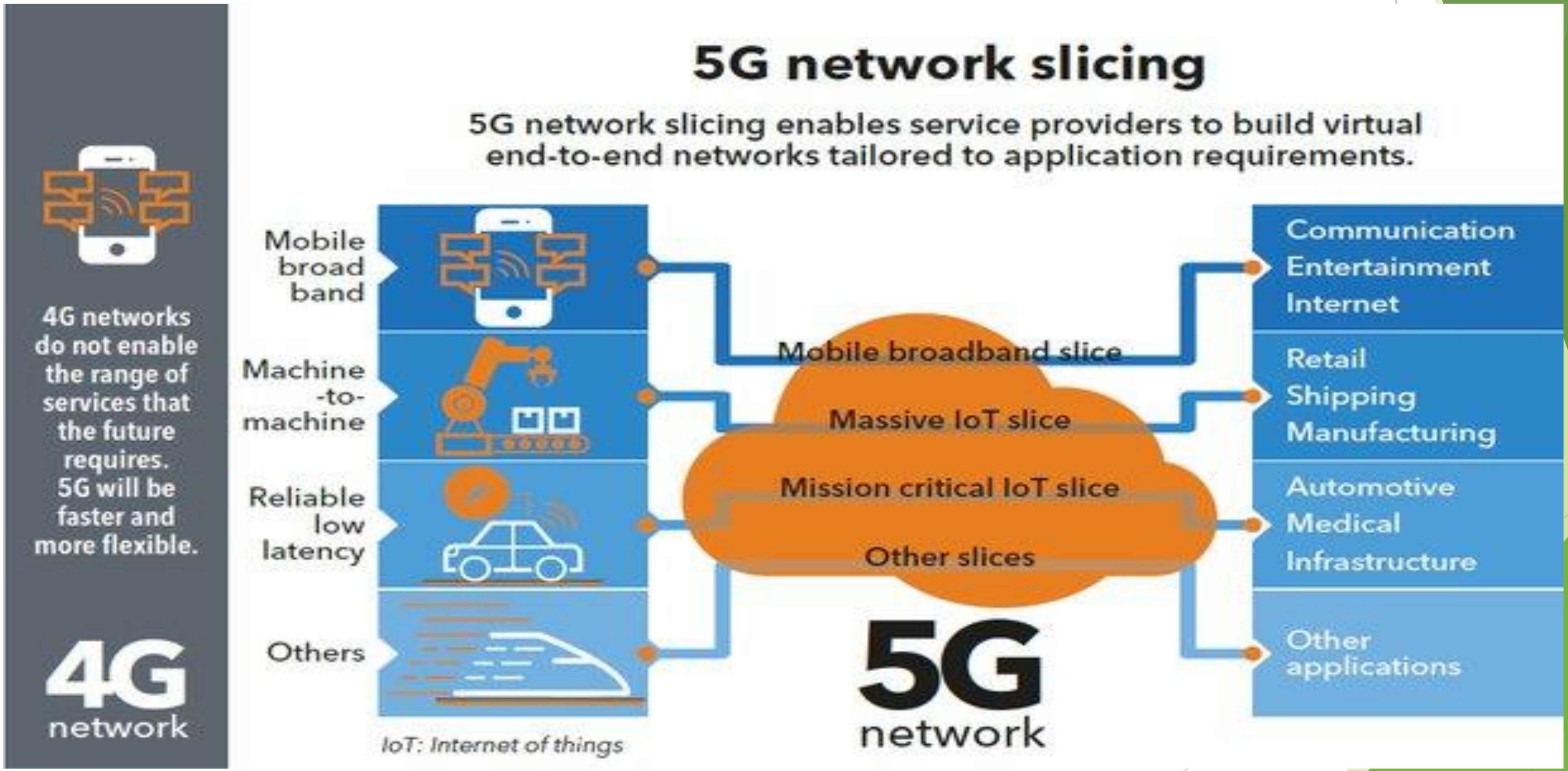
Summary

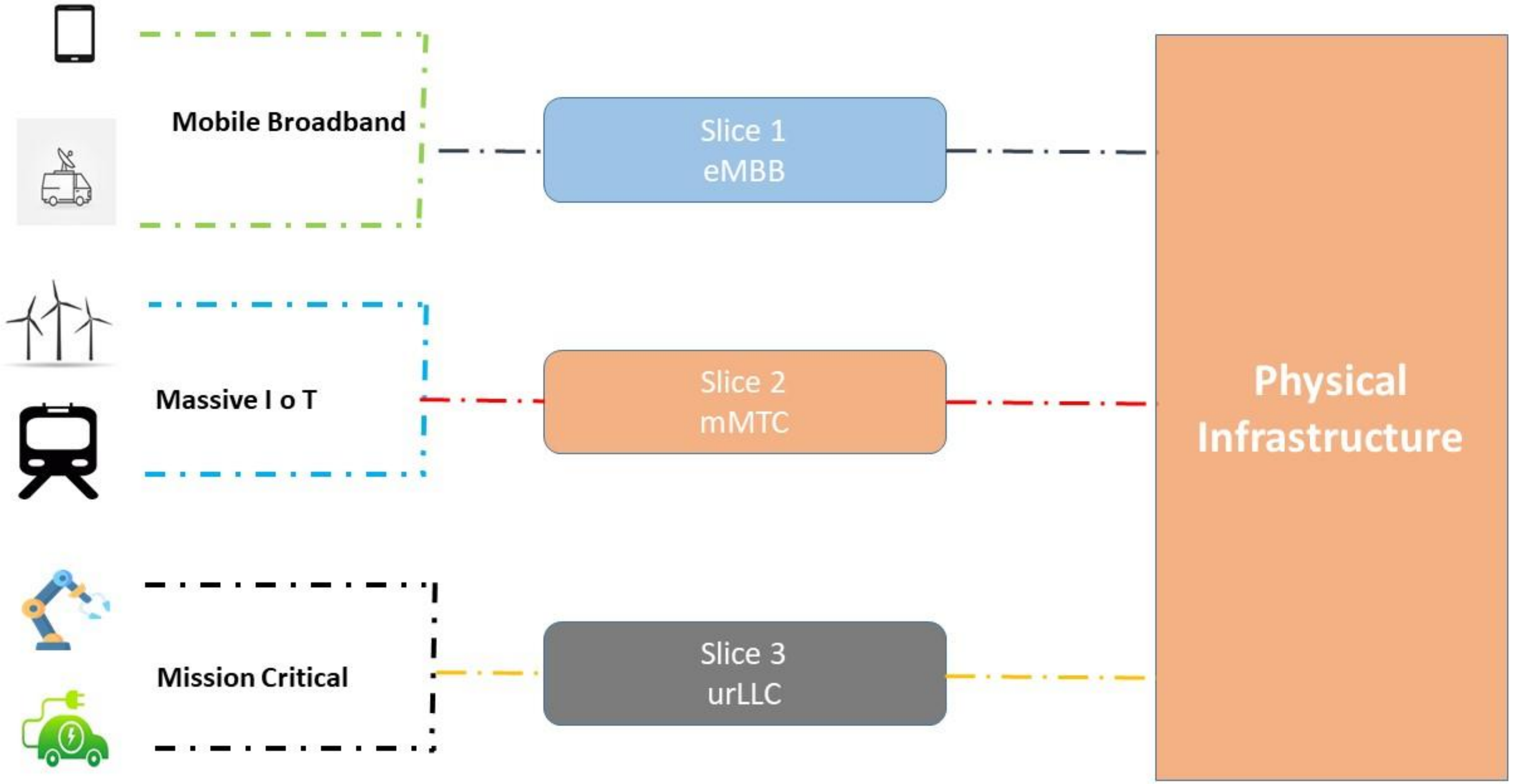
Generation	Frequency Bands Used	Band Type	Typical Range (MHz/GHz)	Notes
1G	Analog (AMPS, NMT)	Low Band	800-900 MHz	Large cell coverage; used for analog voice; low capacity
2G	GSM, CDMA	Low Band	850 MHz, 900 MHz, 1800 MHz, 1900 MHz	Digital voice and basic SMS; frequency reuse and better security
3G	UMTS, WCDMA, CDMA2000	Low/Mid Band	850 MHz, 900 MHz, 1900 MHz, 2100 MHz	Improved data speeds (up to Mbps); simultaneous voice + data
4G	LTE	Low/Mid Band	700 MHz to 2.6 GHz	High-speed mobile broadband; supports VoLTE and HD streaming
5G	NR (New Radio)	Low/Mid/High Band	<1 GHz, 1-6 GHz (sub-6), 24-100 GHz (mmWave)	Gigabit speeds, low latency, supports IoT, URLLC, and mMTC

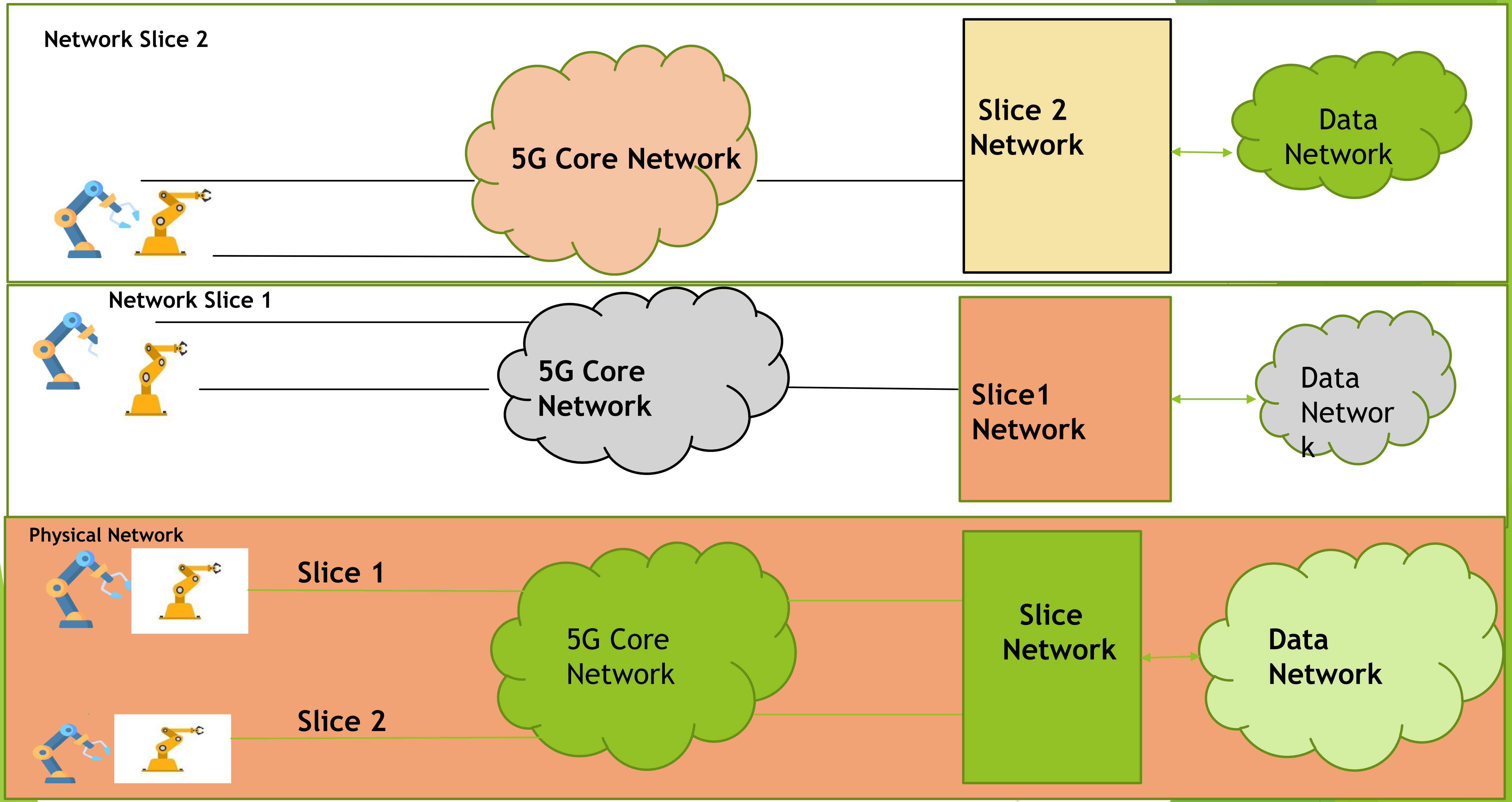
Optimization approach

Generation	Optimization Techniques	Description
1G	Frequency Division Multiple Access (FDMA)	Each user assigned a separate frequency band; simple but inefficient use of spectrum
	Analog modulation	Limited capacity and prone to interference
2G	Time Division Multiple Access (TDMA)	Divides each frequency into time slots to support multiple users
	Code Division Multiple Access (CDMA)	Uses spread-spectrum to allow many users over the same frequency with different codes
	Frequency reuse with cell planning	Spectrum is reused in non-adjacent cells to increase capacity
3G	Wideband CDMA (WCDMA)	Higher bandwidth and efficient spectrum use via spreading codes
	Adaptive power control	Minimizes interference by adjusting transmit power dynamically
	Soft handoff	Users connected to multiple base stations to reduce dropped calls and improve QoS
4G	Orthogonal Frequency Division Multiple Access (OFDMA)	Subdivides spectrum into orthogonal sub-carriers, improving spectral efficiency
	Dynamic spectrum allocation	Allocates spectrum resources based on real-time traffic demand
	Carrier aggregation (CA)	Combines multiple frequency bands to increase data rates and spectrum utilization
	MIMO (Multiple Input Multiple Output)	Uses multiple antennas to increase capacity without extra spectrum
5G	Massive MIMO	Extends MIMO to tens or hundreds of antennas for higher spectral efficiency
	Beamforming	Directs radio signals to specific users, reducing interference and improving throughput
	Dynamic spectrum sharing (DSS)	Allows 4G and 5G to share spectrum dynamically in the same band
	Network slicing	Enables multiple logical networks on shared physical infrastructure, optimizing spectrum use per service type
	Millimeter wave (mmWave) utilization	Opens up large bandwidths in high-frequency ranges for ultra-fast data rates
	AI-based spectrum management	Uses machine learning for predictive allocation and interference mitigation

Network Slicing in 5G

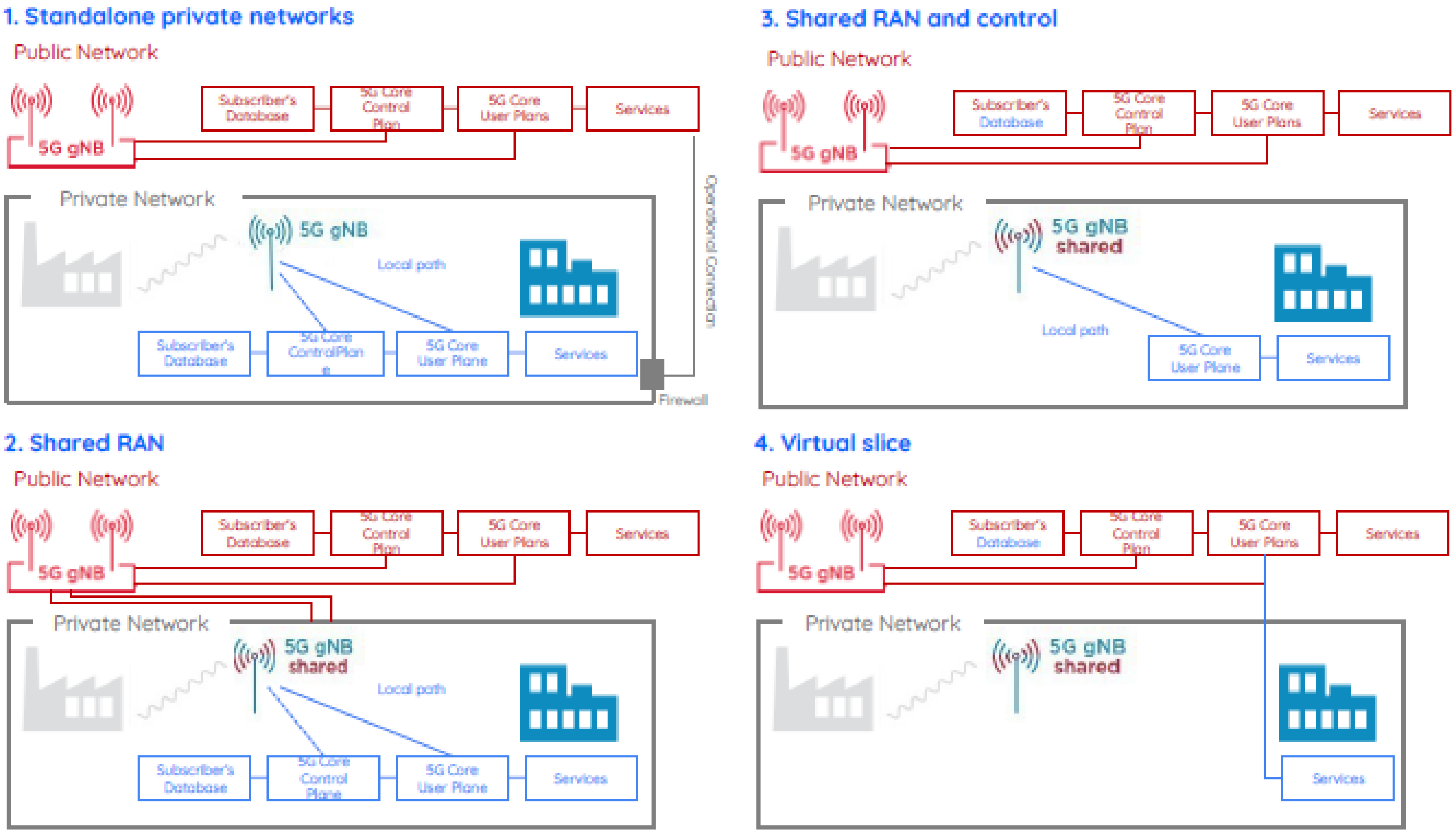



Mobile Broadband
Slice 1
eMBB
Massive I o T
Slice 2
mMTC
Mission Critical
Slice 3
urLLC
Physical Infrastructure



Factory Network with 5G network slicing

Private 5G Network



There are four main types of 5G private networks:

1) Standalone private networks
2) Standalone private networks with MNO providing shared RAN
3) Public network integrated private networks using RAN and control sharing
4) Public network integrated private networks using end-to-end network slicing

Red icons indicate the system is managed by an MNO and blue icons signify the system is managed by the enterprise. Red and blue colours indicate the component is shared (e.g. shared RAN and database).

Umbrella of stand.-