Introduction to 5G Networks

OBJECTIVES

- Introduction to 5G Networks (SA, NSA, 3GPP, Spectrum, etc)
- 5G Architecture and Components (two main subsystems: the Radio Access Network (RAN) and the Mobile Core)
- Interactive Demo: 5G Capabilities (SDN, NFV, Network Slicing, etc)
- Benefits of 5G in IoT
- Homework Assignment

MPSSDEGB
कौशल से रोजगार, समृद्धि अपार

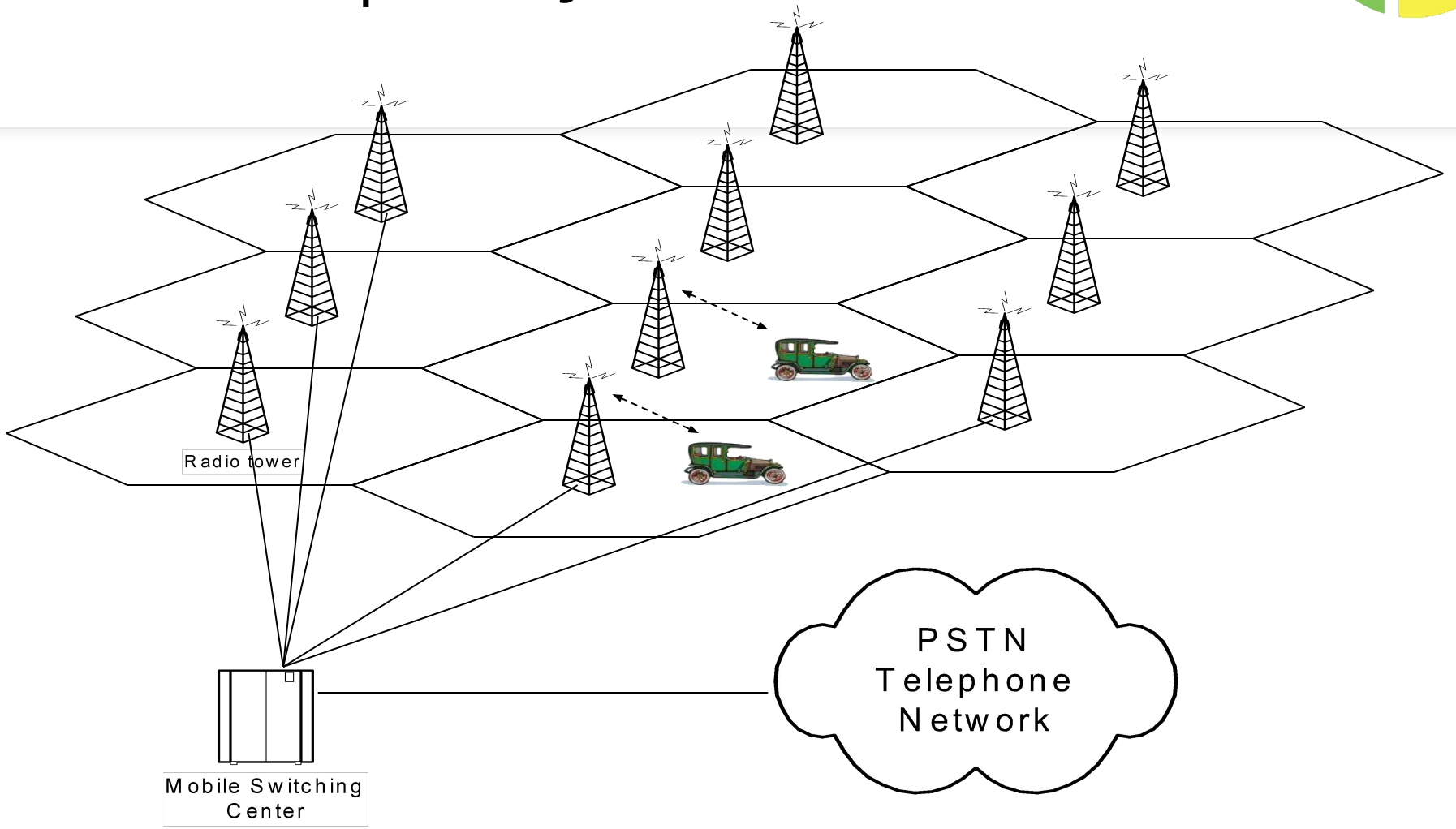
FITT
Foundation For Innovation And Technology Transfer

SANKALP
Ministry of Skill Development & Entrepreneurship

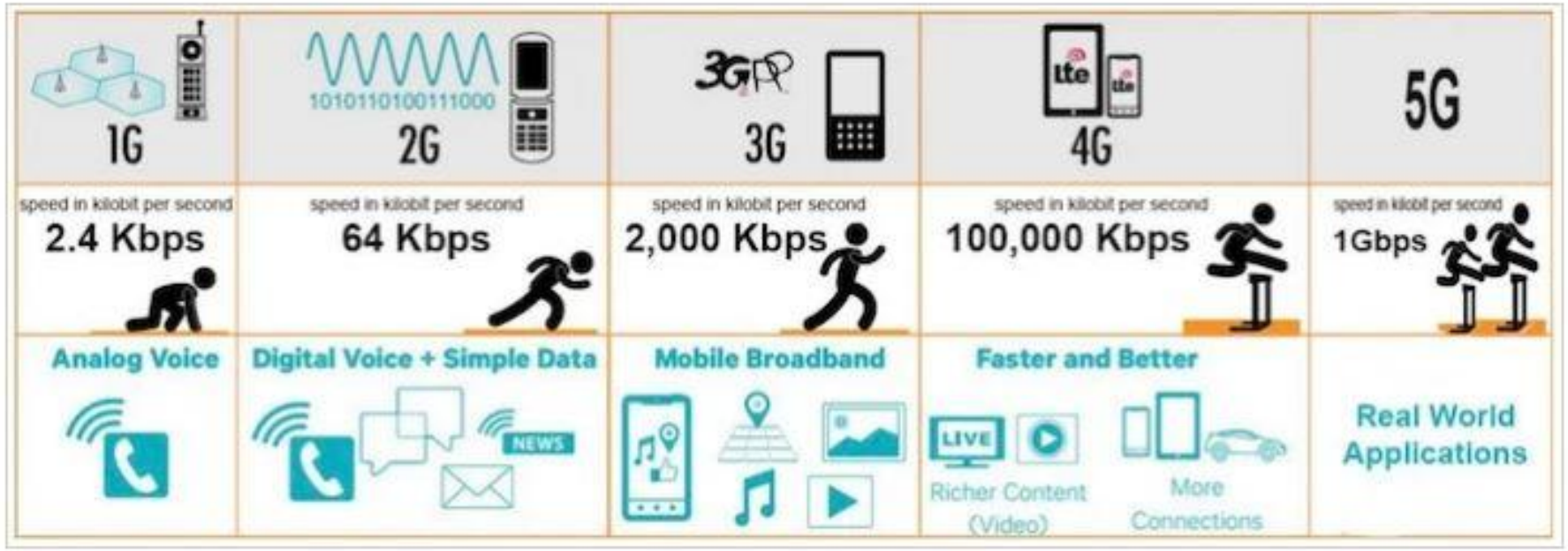
Recommended Book

https://www.amazon.in/Internet-Things-Surya-Durbha/dp/0190121092/ref=cm_cr_arp_d_bdcrb_top?ie=UTF8

Cellular Telephony - Architecture



Evolution of 1G – 5G



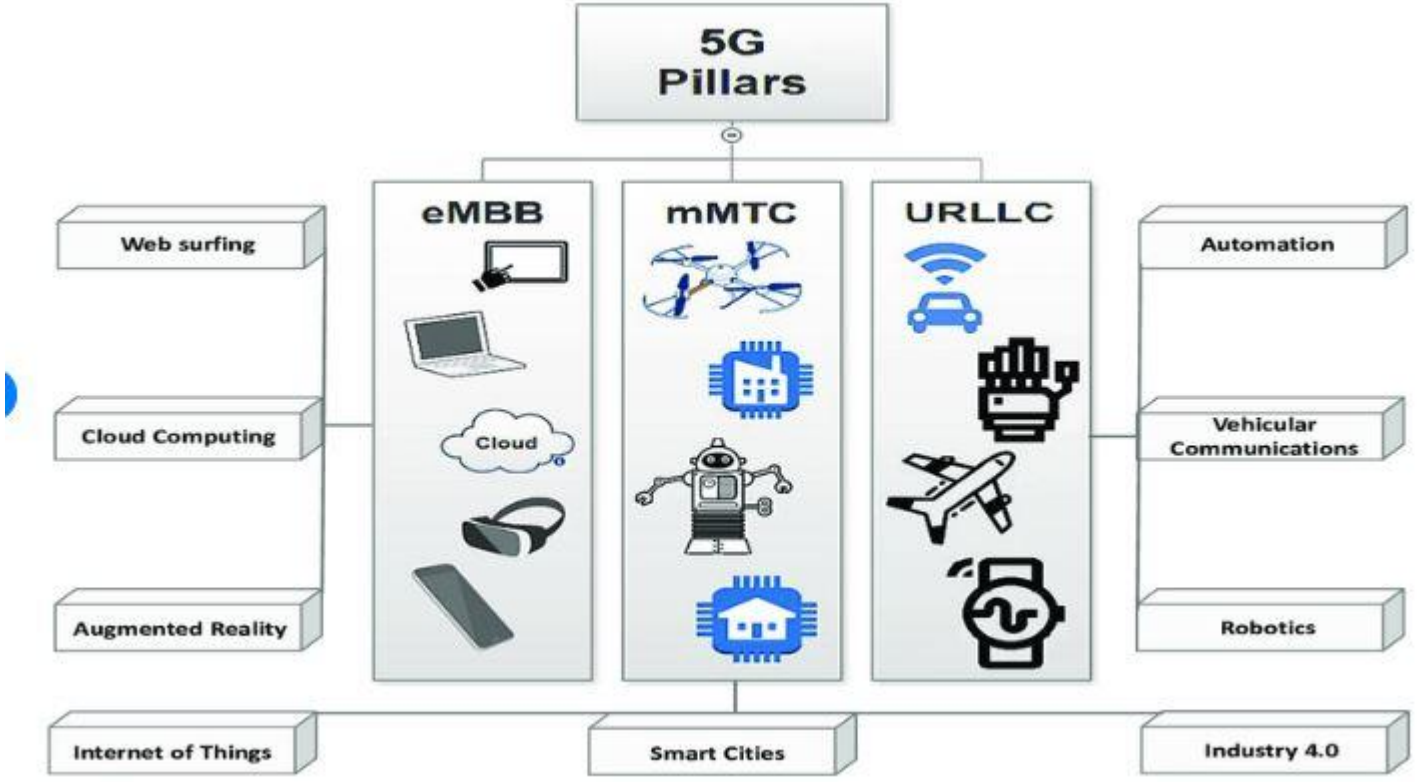
https://www.allaboutcircuits.com/news/from-1g-to-5g-the-evolution-of-telephony-and-wireless-networks/

Overview of Cellular technology

Technologies / Features	*1G*	*2G/2.5G*	*3G*	*4G*	*5G*
Evolution	1970	1980	1990	2000	2010
Deployment	1984	1999	2002	2010	2015
Data Rate	2 kbps	14.4-64 kbps	2 Mbps	200 Mbps to 1 Gbps for low mobility	10 Gbps to 100 Gbps
Famous Standards	AMPS	2G: GSM,C]DMA 2.5G: GPRS, EDGE, 1xRTT	WCDMA, CDMA-2000	LTA, WiMAX	Not yet defined
Technology behind	Analog cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Undefined IP and seamless combination of broadband. LAN/WAN/PAN/ WLAN	Undefined IP and seamless combination of broadband. LAN/WAN/ PAN/WLAN
Service	Voice	2G: Digital Voice, SMS 2.5G: Voice+Data	Integrated high quality audio, video and data	Dynamic information access, wearable devices	Dynamic information access, wearable devices with AI capabilities
Multiplexing	FDMA	TDMA,CDMA	CDMA	CDMA	CDMA
Type of Switching	Circuit	2G: Circuit 2.5G: Circuit and packet	Packet	Packet	Packet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical
Core Network	PSTN	PSTN	Packet network	Internet	Internet

Source: https://www.researchgate.net/figure/Difference-between-1G-2G-3G-4G-5G-11_tbl1_311795558

5G Pillars



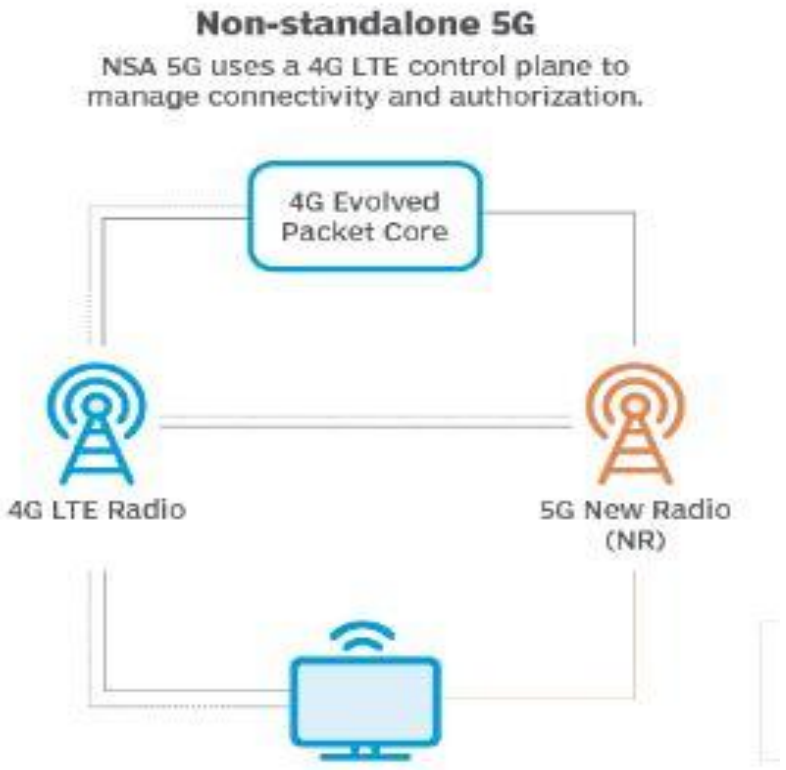
https://www.researchgate.net/figure/The-fifth-generation-networks-pillars-with-examples-of-each-of-them_fig2_359928664

SA, NSA, 3GPP, Spectrum

- Standalone 5G
- Non-standalone 5G
- The 3rd Generation Partnership Project
- 5G spectrum

Non Standalone 5G

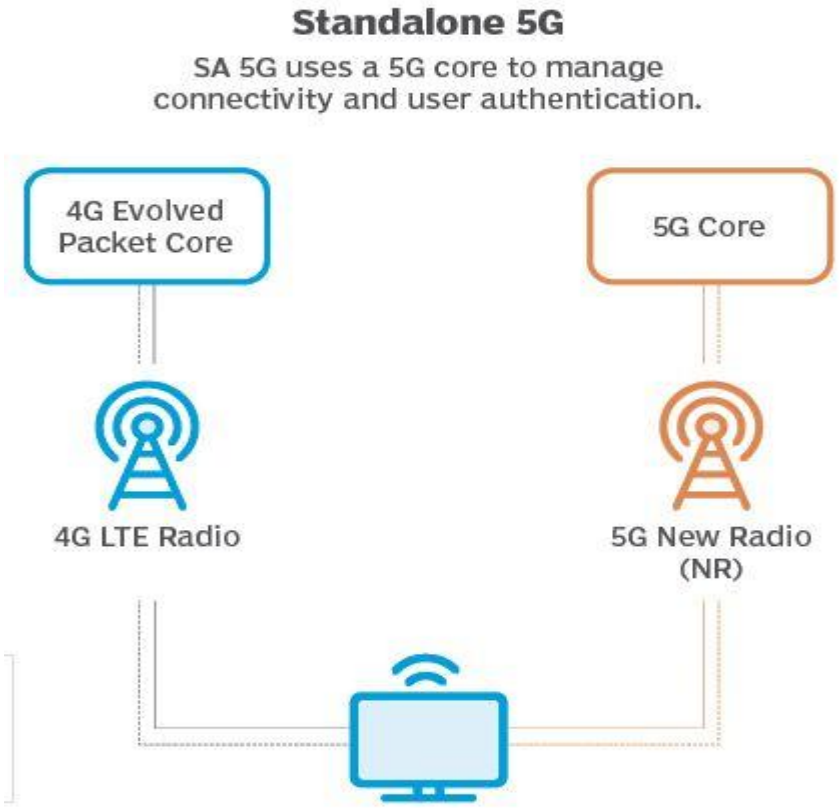
- NSA 5G, 5G that lacks independent infrastructure support.
- The NSA, or Non-Standalone, is a 5G radio access network that acts alongside a 4G LTE core called the Evolved Packet Core (EPC) and is responsible for managing control plane operations.
- The NSA (Non-Standalone) system comprises a base station that supports both 4G and 5G networks, with the 4G base station being given priority.



Source:
https://www.techtarget.com/searchnetworking/feature/5G-NSA-vs-SA-How-does-each-deployment-mode-differ

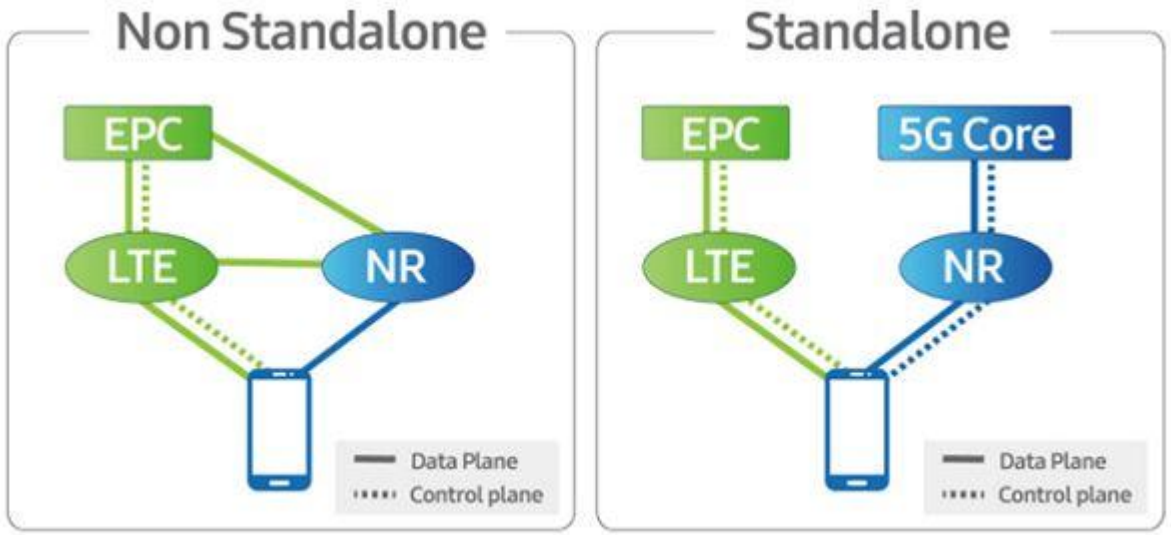
Standalone 5G (SA 5G)

- SA 5G networks comprise a 5G Radio Access Network (RAN)
- SA networks, which possess 5G cores, are capable of executing crucial 5G operations and provide benefits such as decreased latency, enhanced network performance, and the capacity to administer network management activities through a central controller.



Source:
https://www.techtarget.com/searchnetworking/feature/5G-NSA-vs-SA-How-does-each-deployment-mode-differ

Standalone 5G Vs Non Standalone 5G



Source:
https://www.everythingrf.com/community/non-standalone-5g-nr-vs-standalone-5g-nr

3rd Generation Partnership Project

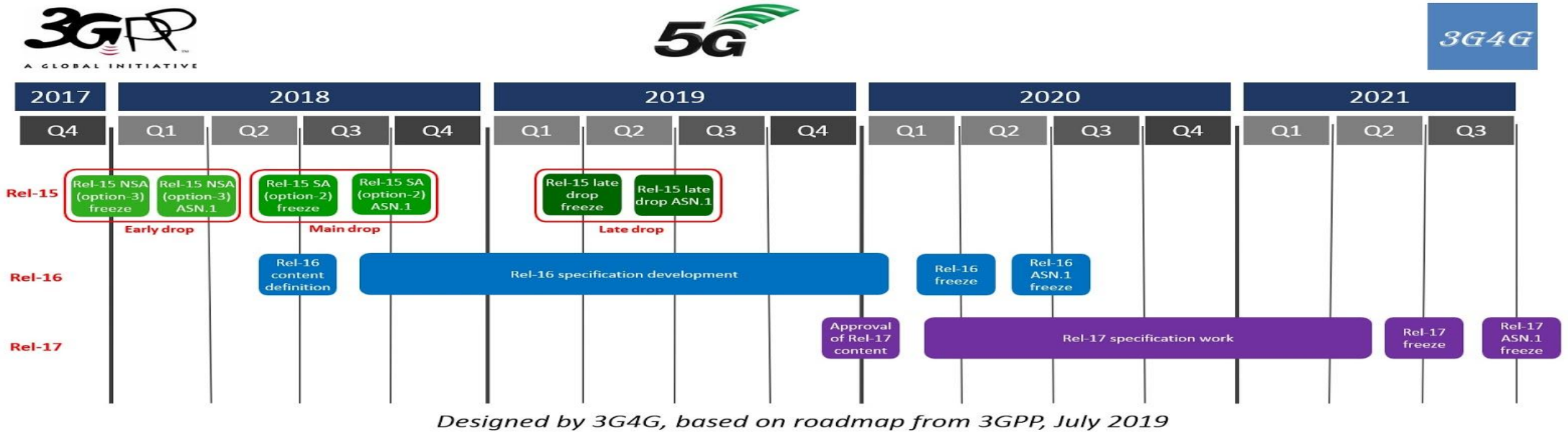
- Global standards organization for mobile communication
- 760+ Companies from all over the world actively participating
- A new Release every 15 to 24 months
- A new Generation every 10 years – 3G/UMTS, 4G/LTE, 5G
- Standards for all sectors of mobile communication – VoLTE, NB-IoT
- ~20 Working Groups & TSGs, each meeting 4 to 8 times a year
- Contribution driven
- Consensus based

Source: 3GPP

Source: https://blog.3g4g.co.uk/2023/08/tutorial-quick-introduction-to-3gpp.html

The 3rd Generation Partnership Project

- The 3rd Generation Partnership Project (3GPP) brings together seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), referred to as "Organizational Partners," to create Reports and Specifications that establish the standards for 3GPP technologies in a stable environment.

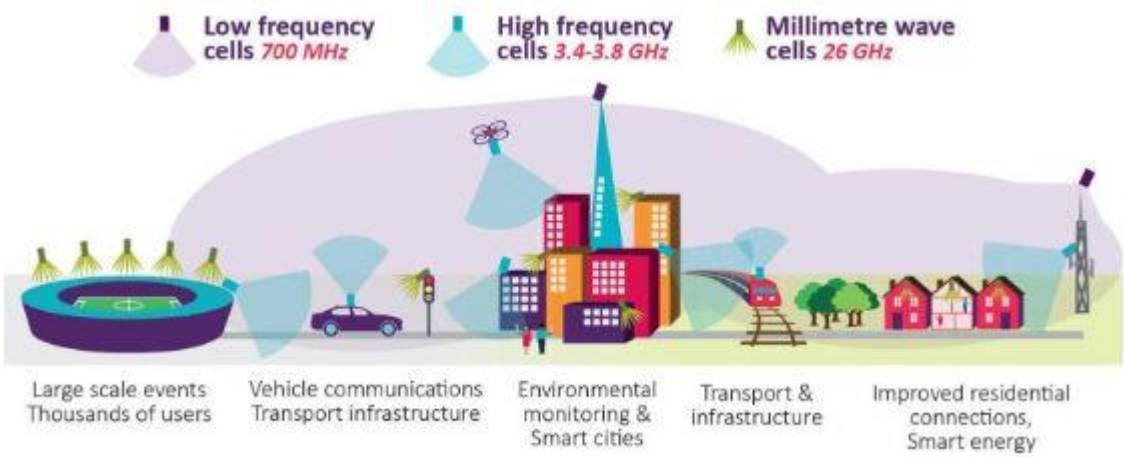


Designed by 3G4G, based on roadmap from 3GPP, July 2019

Source : https://blog.3g4g.co.uk/2019/07/3gpp-5g-standardization-update-post.html

5G Spectrum

- The 5G spectrum is categorized into three distinct frequency bands: low, mid, and high.
- Every band possesses distinct capabilities
- The frequency band between 24.25 to 29.5 GHz has been widely authorized and implemented as the primary spectrum for 5G millimeter wave technology globally.
- In India the accessible bands include: 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2500 MHz, 3300 MHz, and 26 GHz.



Expected 5G Frequency Band Usage: Reproduced courtesy OFCOM

Source : https://www.cablefree.net/wirelesstechnology/4glte/5g-frequency-bands-lte/

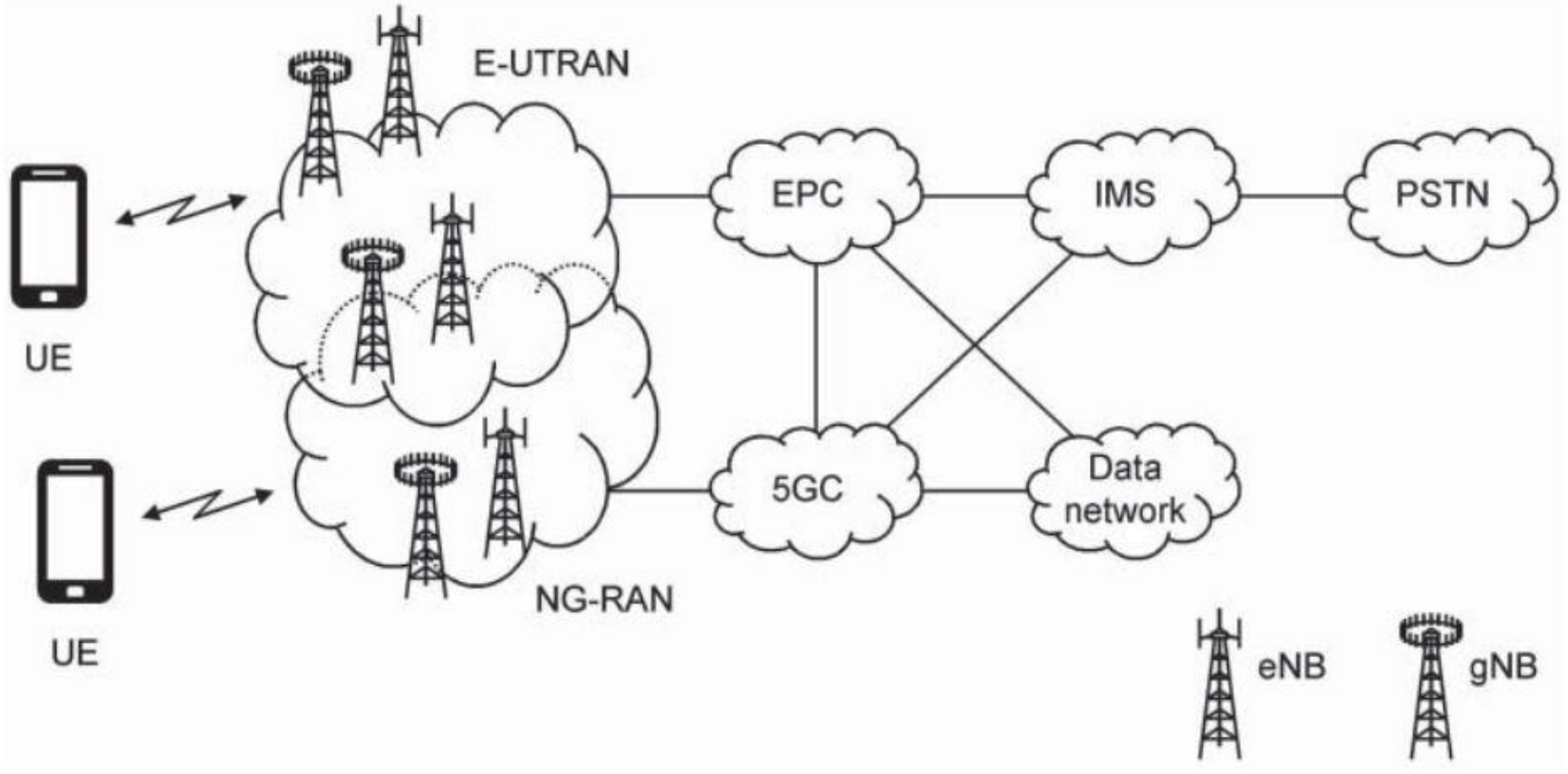
India specific spectrum allocation

- In India 600 MHz, 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz, 2500 MHz, 3300 MHz, 26 GHz bands are currently in use for mobile services.

Source : https://telecomtalk.info/india-spectrum-holding-timeline/

Architecture of 5G

High-level Architecture



Source : An Introduction to 5G The New Radio, 5G Network and Beyond Christopher Cox

Architecture of 5G Contd.,

- **The 5G core network (5GC)** contains new network functions that support NFV, SDN and network slicing.
- The 5G base station is known as a **next-generation Node B (gNB).**
- The gNB communicates with the mobile over an air interface known as the New Radio (NR), which supports millimeter-wave and multiple antenna communications.
- An individual eNB or gNB is known as a node.

Architecture of 5G Contd.,

- Individual node can lie in either the E-UTRAN, the NG-RAN or both.
- In Release 15, the 5G core network handles voice calls using VoIP
- Release 16 introduces support for SRVCC, in which the network can convert an IMS voice call to a circuit-switched call, and can hand the mobile over to a 3G cell.

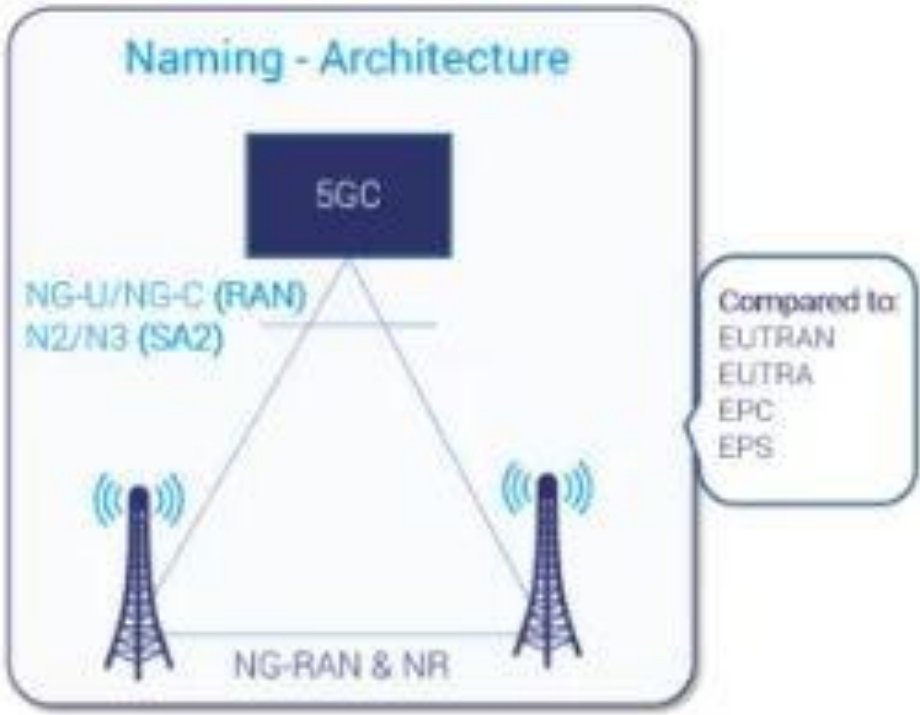
5G Architecture and Components

- Pre requisite for 5G Architecture
- LTE and 5G Differences
  - ✔ Naming in the 5GS architecture
  - ✔ Base station naming

Source : https://www.grandmetric.com/blog/2018/07/14/lte-and-5g-differences-system-complexity/

Naming in the 5GS architecture

- LTE was meant to be "a Long Term Evolution" of UMTS.
- In 5G world. On the air interface, NR (new radio), whereas the new RAN is NG-RAN (next-generation RAN).
- No New Core or even a Next Generation Core, but rather a 5GC (5G Core Network).
- The entire system is known as the 5GS (5G System).

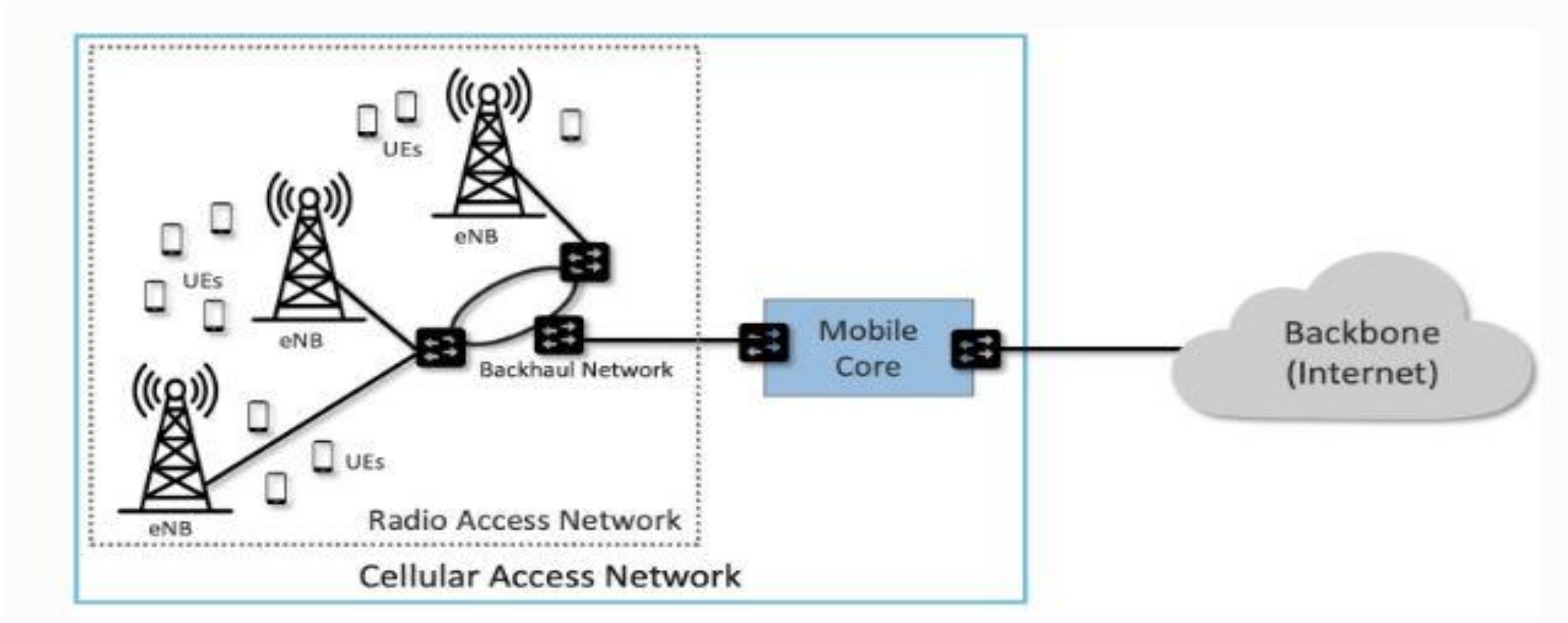


Source : https://www.grandmetric.com/blog/2018/07/14/lte-and-5g-differences-system-complexity/

Base station naming

1G	2G	3G	4G	5G
• Base Station	• Base Transceiver Station	• NB (NodeB)	• eNB (evolved NodeB)	• gNB

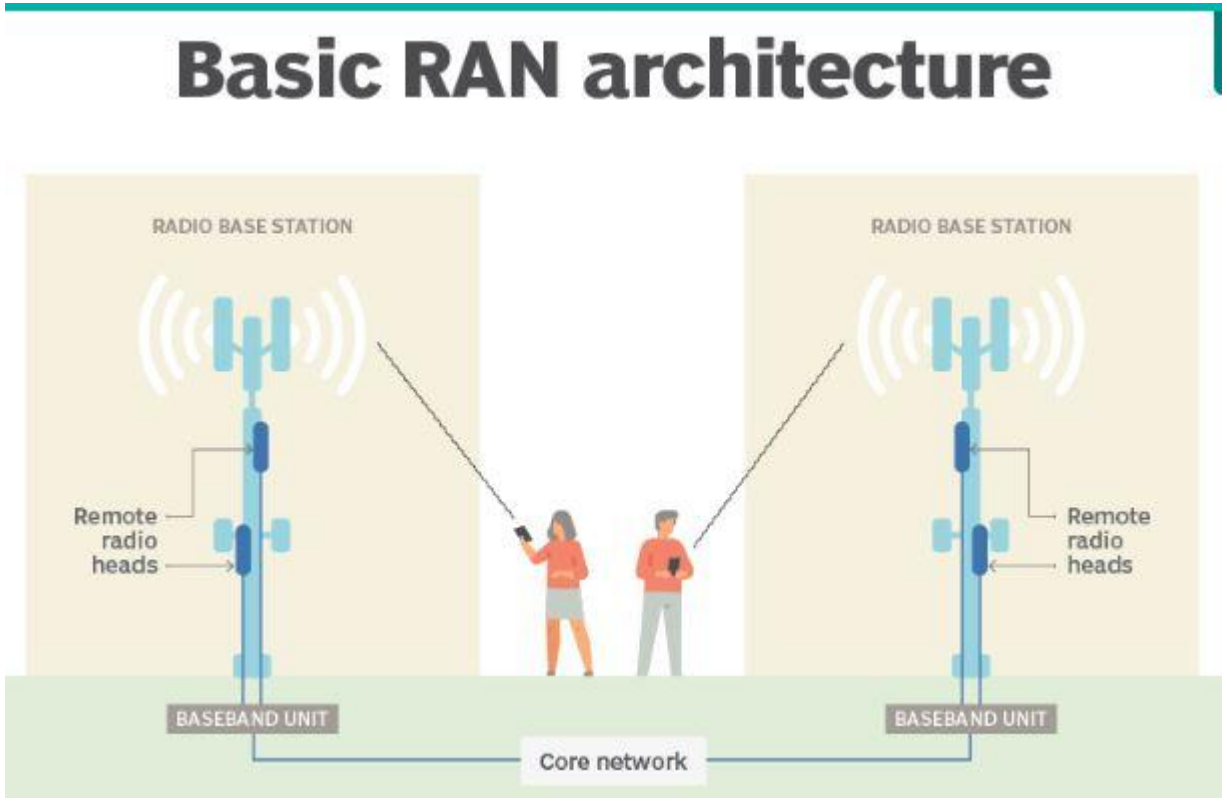
Radio Access Network



Source: https://github.com/SystemsApproach/private5g

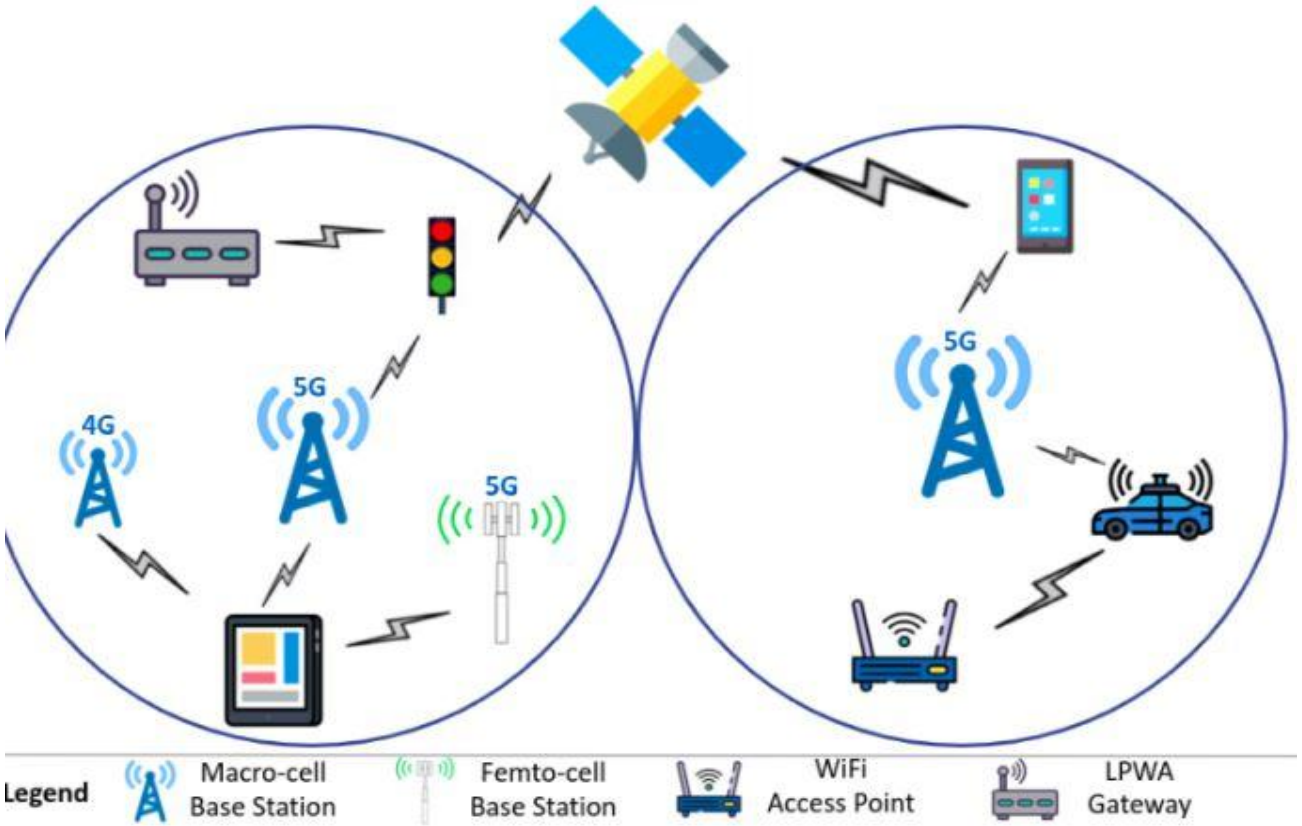
Components of RAN

- RAN components
- Base stations
- Antennas
- Radios



Source: https://www.techtarget.com/searchnetworking/definition/radio-access-network-RAN

Components of Multi Connectivity (MC)



- multi-connectivity, a mobile user equipment (UE) communicates with multiple base stations simultaneously, where each base station provides a cell group as radio resources to the UE

Source : https://www.mdpi.com/1424-8220/22/19/7591

Functions of Mobile Network

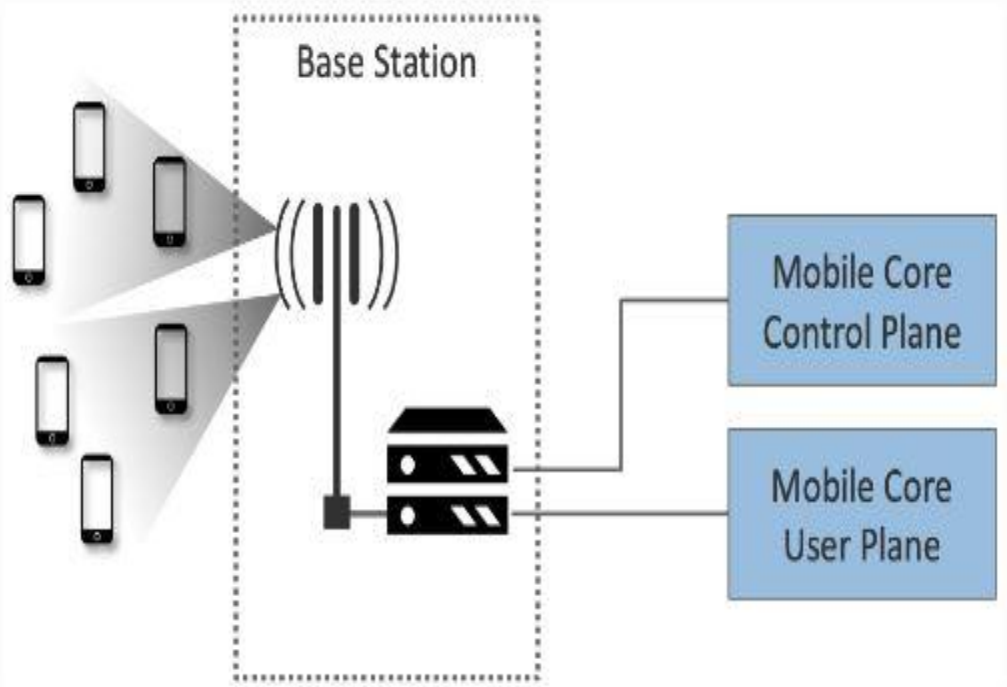
- Verifies the identity of devices before connecting them to the network
- Offers Internet Protocol (IP) access for both data and voice services.
- Ensures that this link meets the specified Quality of Service (QoS) requirements
- Monitors user movement to guarantee continuous provision of service.
- Monitors subscriber usage for the purpose of billing and charging.

Mobile Core

- In 4G Mobile Network was called the *Evolved Packet Core (EPC)*
- In 5G Mobile Network is called the *5G Core (5GC)*.
- the Mobile Core runs near the edge of the network, effectively providing a bridge between the RAN in some geographic area and the greater IP-based Internet
- The 3GPP standard gives a options for where the Mobile Core can be placed, from small areas to hundreds of kilometers across.

Mobile Core

- 3GPP defines the elements responsible for implementing the RAN and Mobile Core, which includes sub-layers
- Network operators used to purchase proprietary implementations of each subsystem from a single vendor.



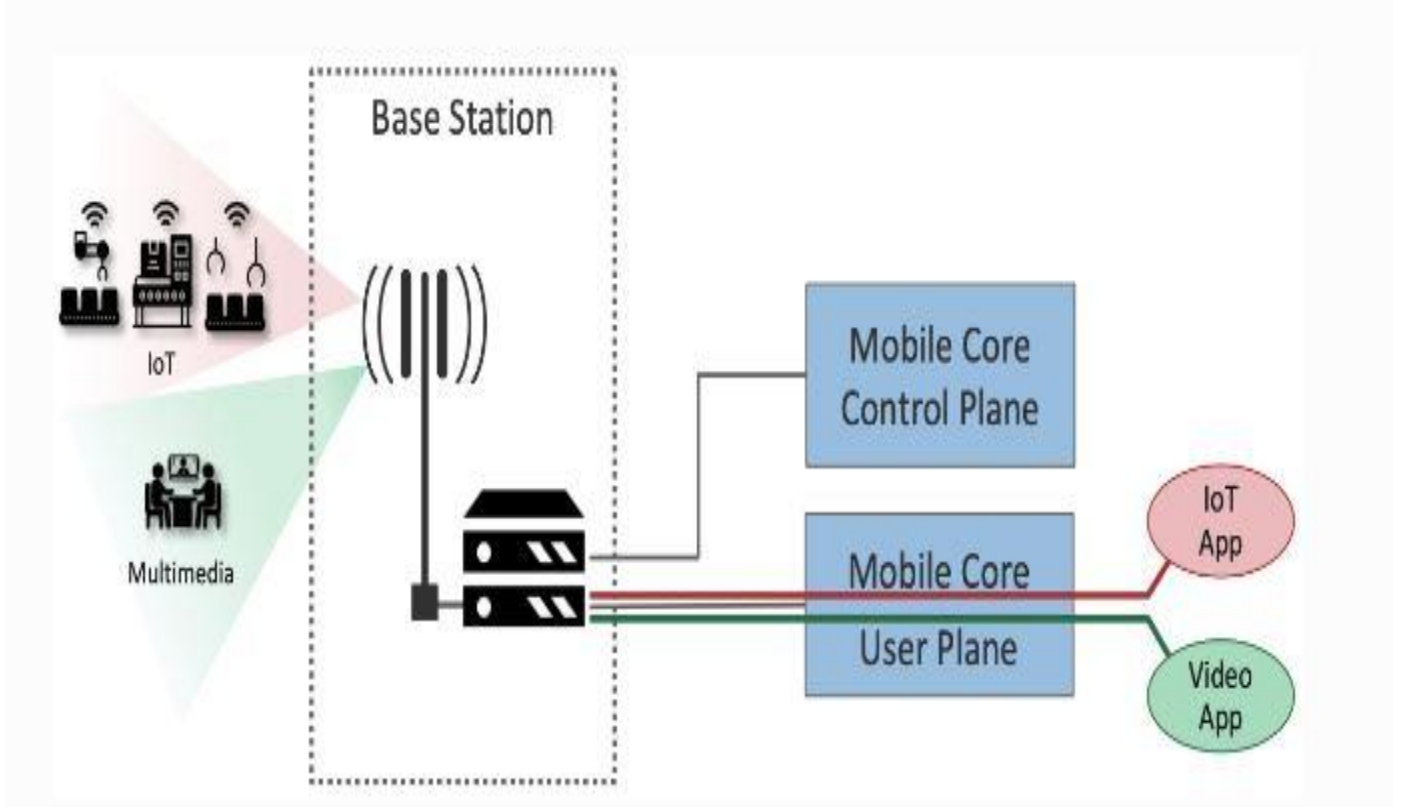
Mobile Core divided into a Control Plane and a User Plane, an architectural feature known as CUPS: Control and User Plane Separation

Source: https://github.com/SystemsApproach/private5g

Mobile Core

- key aspirational goals of 5G is the ability to segregate traffic for different usage domains into isolated network slices

Different usage domains (e.g., IoT and Video Streaming) instantiate distinct network slices to connect a set of devices with one or more applications.

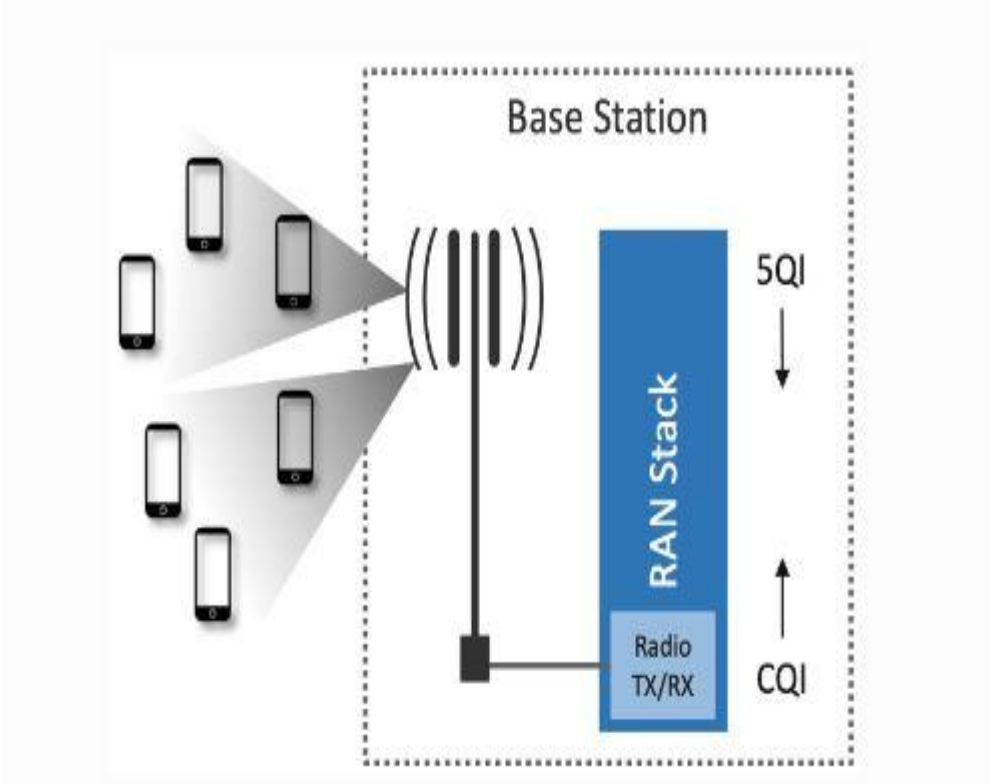


Source: https://github.com/SystemsApproach/private5g

Mobile Core

- The base stations of the Radio Access Network (RAN) establish communication with User Equipment (UE) using electromagnetic radio waves.
- The Radio Access Network (RAN) has the responsibility with managing the allocation of the radio spectrum among several User Equipment (UE) devices that are connected to multiple base stations within a specific geographical area.
- RAN is capable of handling that spectrum without the need to concern itself with the complexity of waveforms, modulation, or coding techniques.

Mobile Core



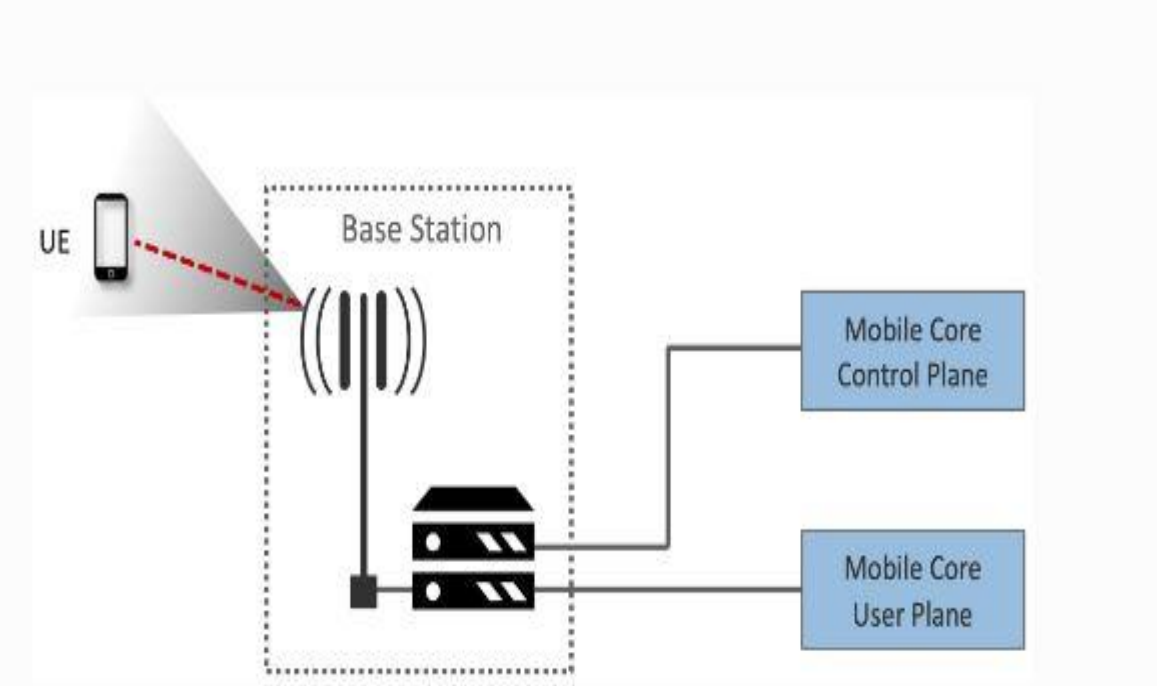
- Channel Quality Indicator (CQI)
- 5G QoS Identifier (5QI)

measures of signal quality (CQI) and declarations of intended data delivery quality (5QI)

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Radio Access Network

- each base station establishes the wireless channel for a subscriber's UE upon power-up or upon handover when the UE is active
- This channel is released when the UE remains idle for a predetermined period of time

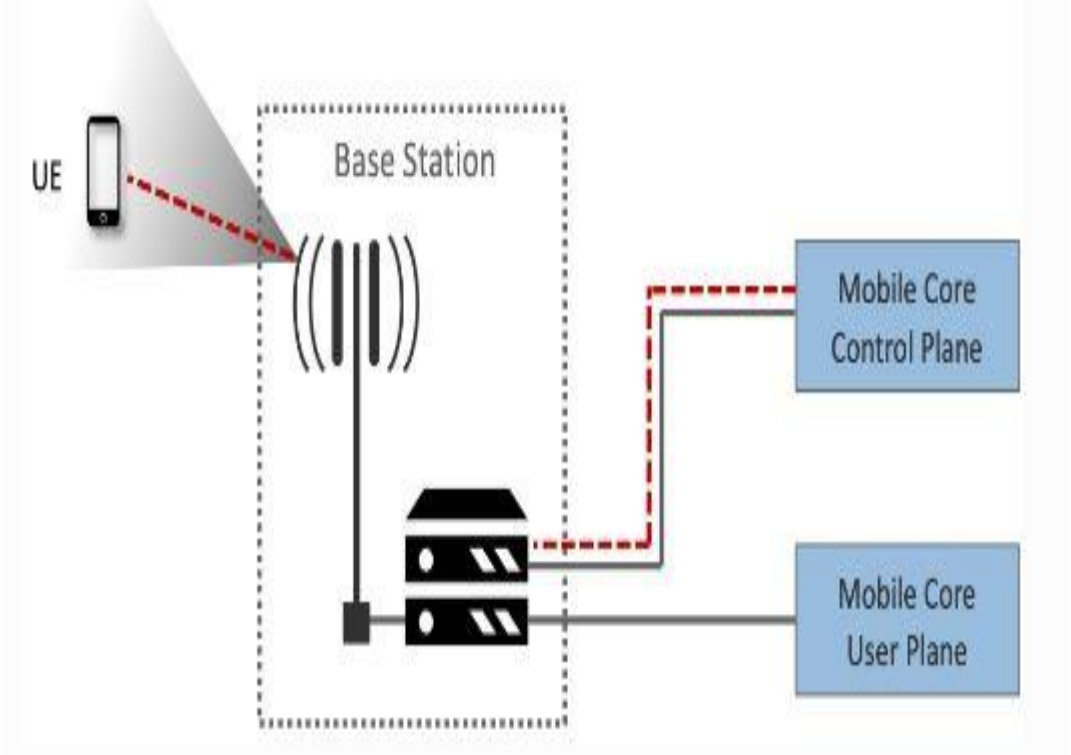


UE detects (and connects to) base station

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Radio Access Network

- each base station establishes "3GPP Control Plane" connectivity between the UE and the corresponding Mobile Core Control Plane component, and forwards signaling traffic between the two
- traffic enables UE authentication, registration, and mobility tracking

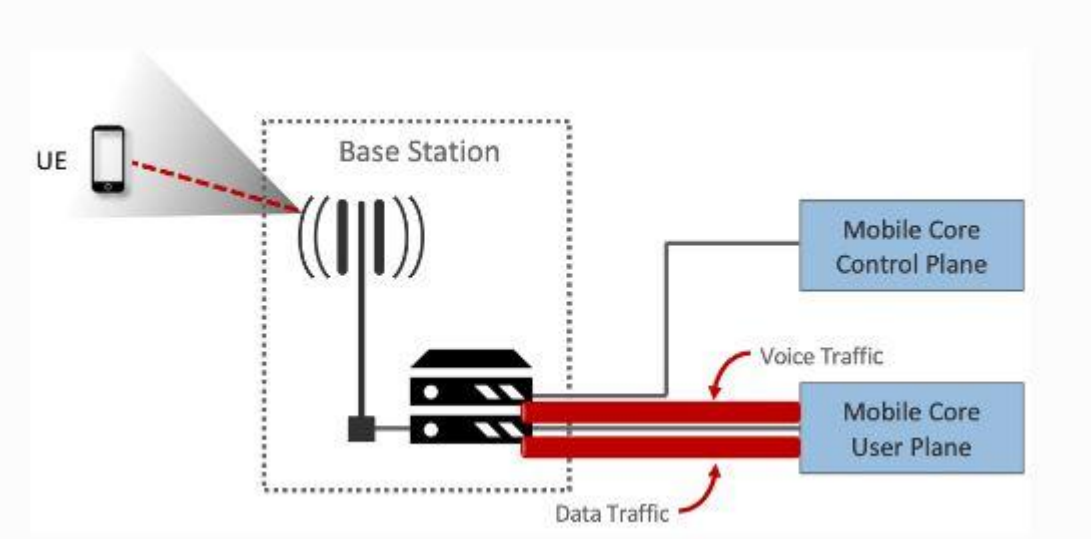


Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Base Station establishes control plane connectivity between each UE and the Mobile Core

Radio Access Network

- for each active UE, the base station establishes one or more tunnels to the corresponding Mobile Core User Plane component
- Figure shows just two (one for voice and one for data), and while in practice 4G was limited to just two, 5G aspires to support many such tunnels as part of a generalized network slicing mechanism.

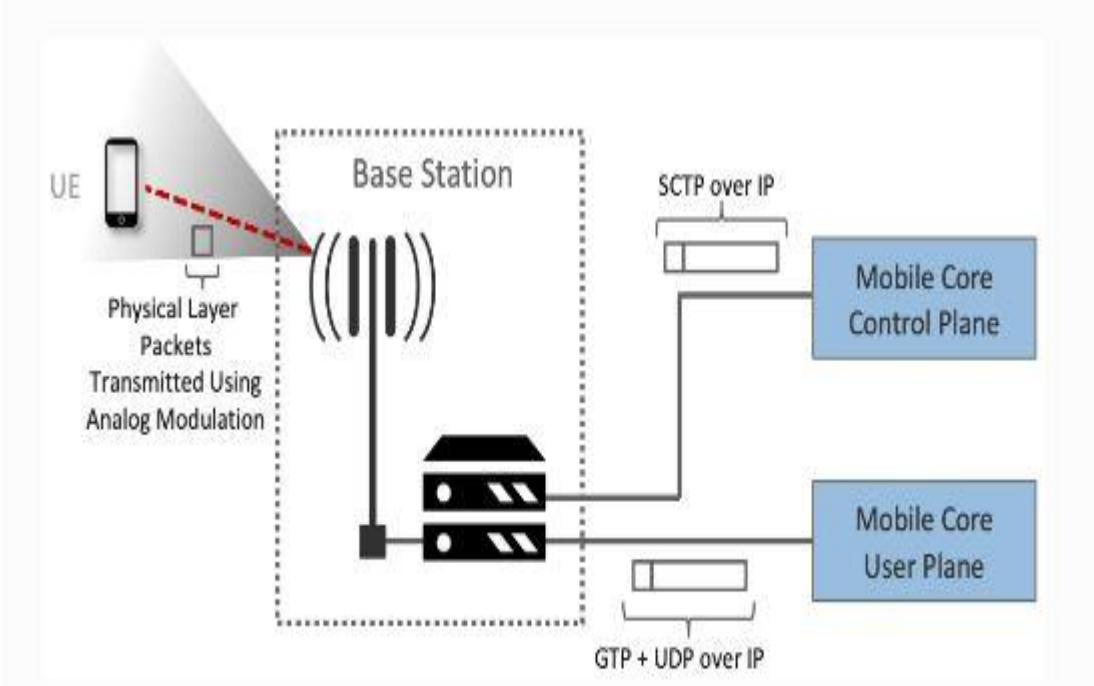


Base station establishes one or more tunnels between each UE and the Mobile Core's User Plane (known in 3GPP terms as PDU session)

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Radio Access Network

- the base station forwards both control and user plane packets between the Mobile Core and the UE. These packets are tunneled over SCTP/IP and GTP/UDP/IP, respectively. SCTP (Stream Control Transport Protocol) is an alternative reliable transport to TCP, tailored to carry signaling (control) information for telephony services.
- GTP (a nested acronym corresponding to (General Packet Radio Service) Tunneling Protocol) is a 3GPP-specific tunneling protocol designed to run over UDP.



Base Station to Mobile Core (and Base Station to Base Station) control plane tunneled over SCTP/IP and user plane tunneled over GTP/UDP/IP.

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Radio Access Network

- each base station coordinates UE handovers with neighboring base stations, using direct station-to-station links
- Exactly like the station-to-core connectivity shown in the previous figure, these links are used to transfer both control plane (SCTP over IP) and user plane (GTP over UDP/IP) packets.

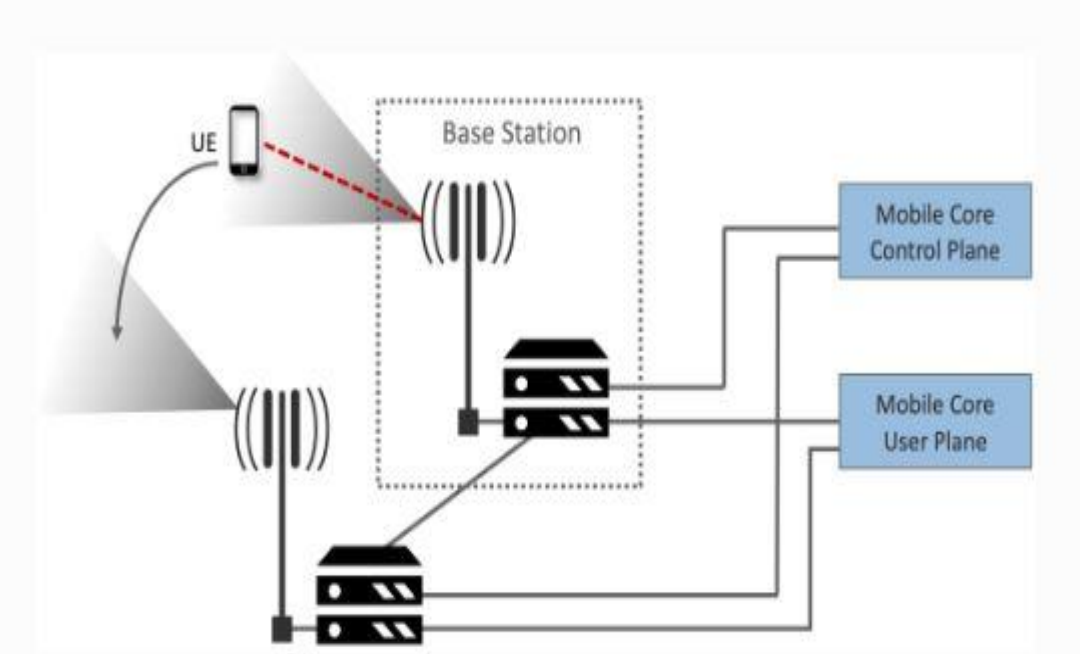
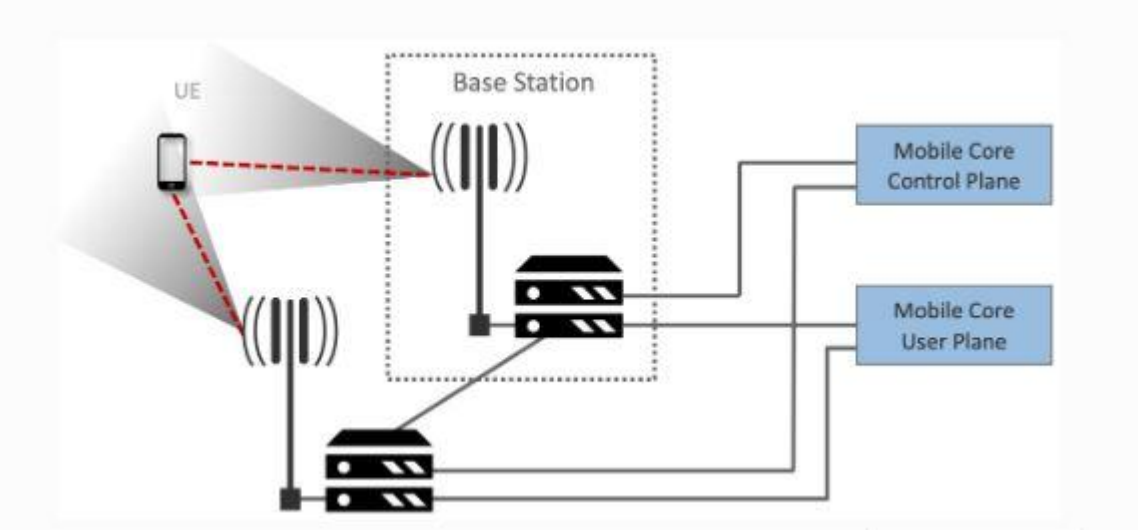


Figure 11. Base Stations cooperate to implement UE hand over.

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Radio Access Network

- the base stations coordinate wireless multi-point transmission to a UE from multiple base stations, which may or may not be part of a UE handover from one base station to another.



Base Stations cooperate to implement multipath transmission (link aggregation) to UEs.

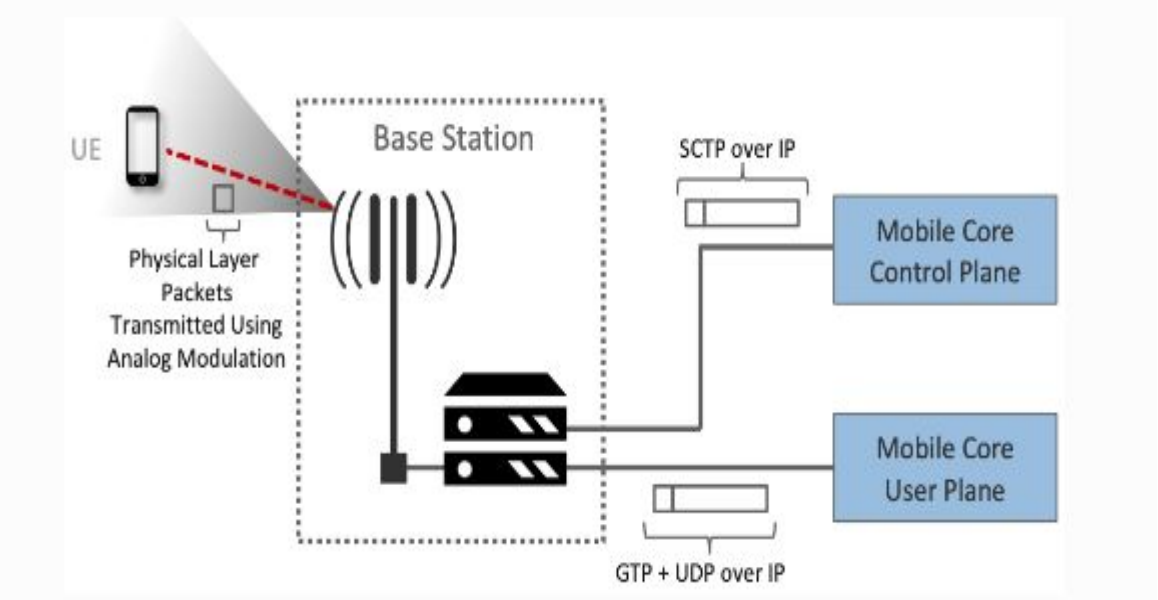
Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Mobile Core

- It is the responsibility of the Mobile Core to connect mobile users to the packet data network.
- The Mobile Core makes sure that users are real people and tries to give them the service they signed up for.
- The Mobile Core needs to keep track of where customers are at the level of the base station that serves them because users may move between base station coverage areas.

Mobile Core Security

- Initially, every base station has trust in its connection to the Mobile Core over a secure private network.
- over this network, the base station builds the tunnels, as seen in the figure.



Base Station to Mobile Core (and Base Station to Base Station) control plane tunneled over SCTP/IP and user plane tunneled over GTP/UDP/IP.

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Mobile Core Security

- An IMSI (International Mobile Subscriber Identity) is a distinct identity burnt into each SIM card, serving as a worldwide unique identifier for every device connected to the global mobile network.

- An IMSI is a 64-bit identification that contains a Format field used as a mask to extract additional pertinent information.

MCC: Mobile Country Code (3-digit decimal number).

MNC: Mobile Network Code (2 or 3-digit decimal number).

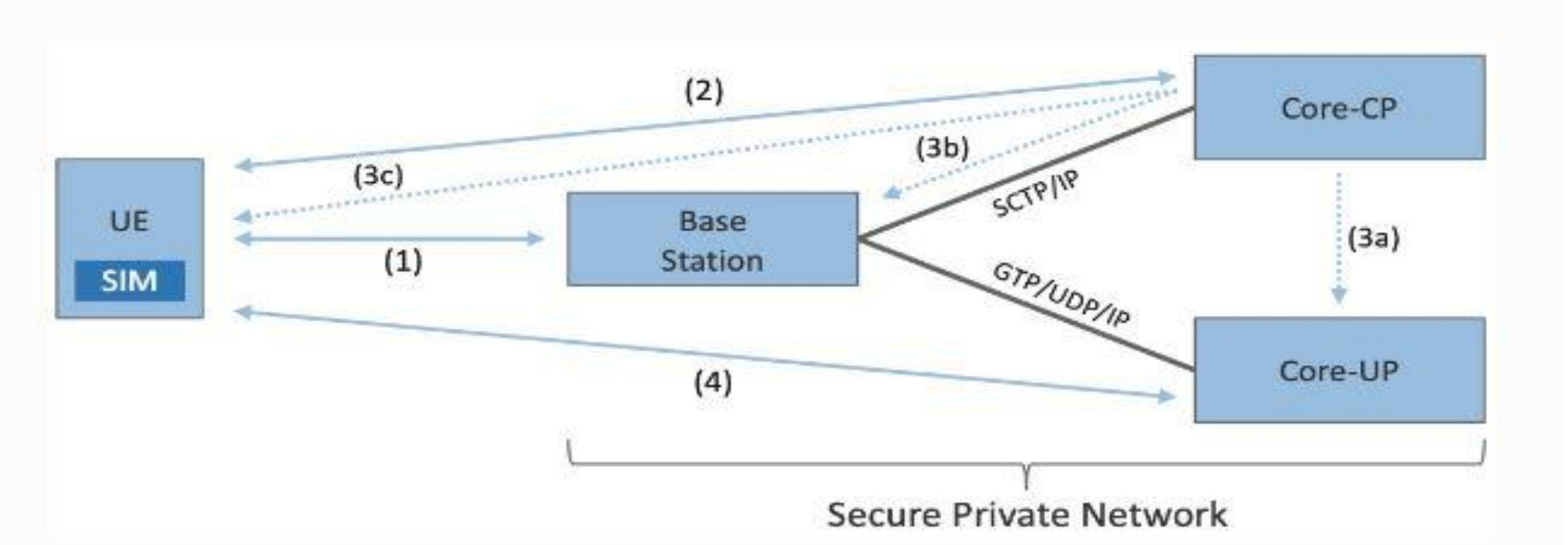
ENT: Enterprise Code (3-digit decimal number).

SUB: Subscriber (6-digit decimal number).

Mobile Core Security

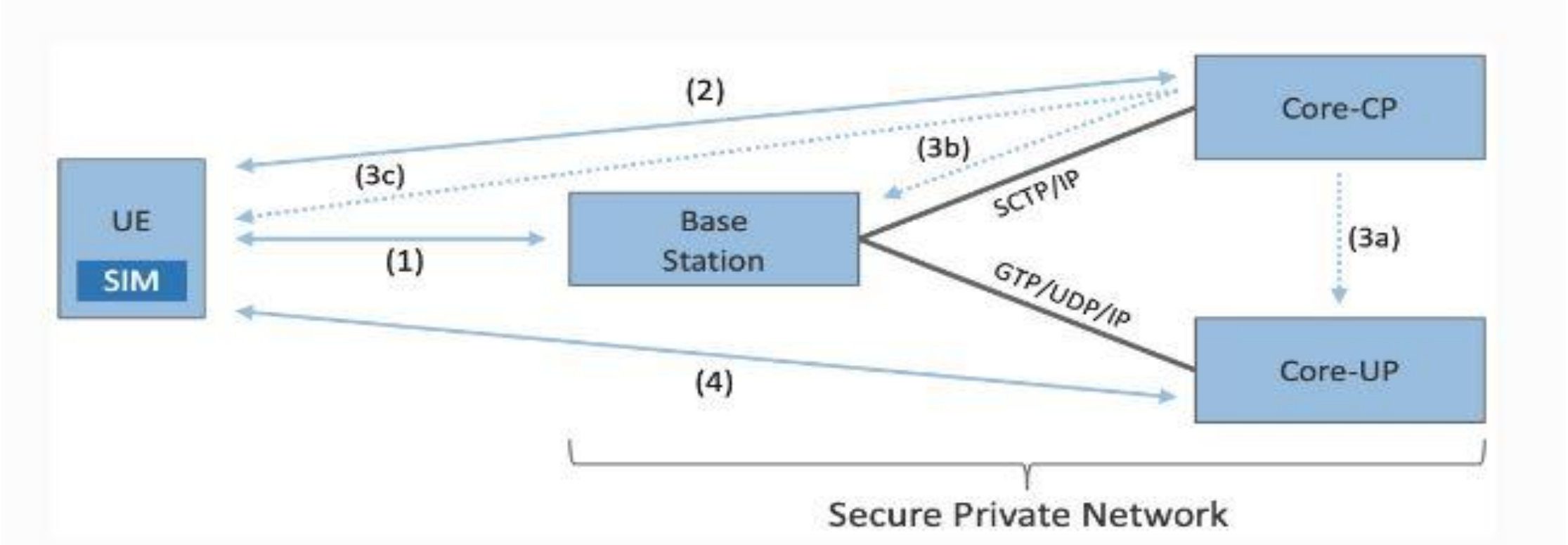
- The MCC/MNC pair, also known as the Public Land Mobile Network (PLMN) identifier, is crucial in the process of roaming. When a User Equipment (UE) attempts to connect to a "foreign network," these fields are utilized to locate the "home network."
- The remaining International Mobile Subscriber Identity (IMSI) is then used to access a subscriber profile, which determines whether or not roaming is enabled for the device.

Mobile Core Security



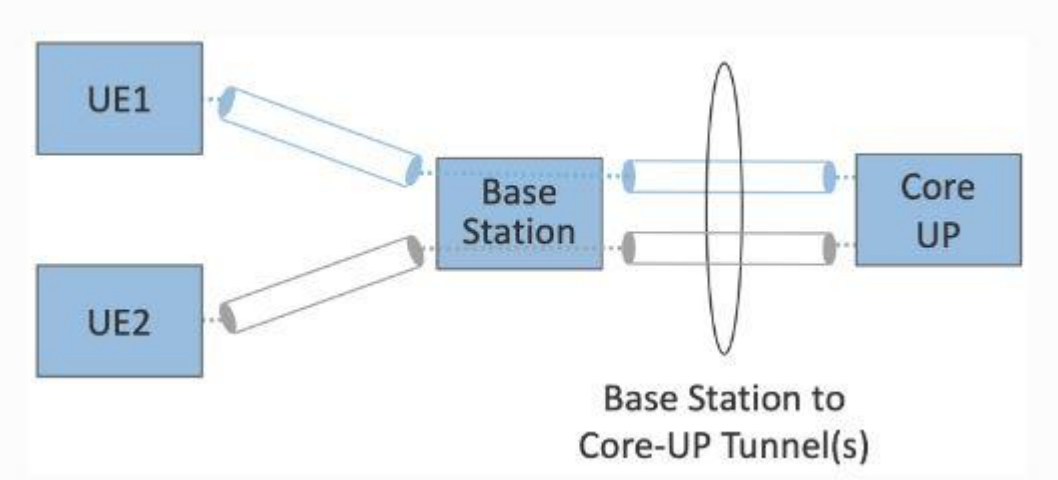
Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Mobile Core Security Contd.,



Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Mobile Core Security Contd.,



Sequence of per-hop tunnels involved in an end-to-end User Plane channel.

Source : https://5g.systemsapproach.org/arch.html#radio-access-network

Mobile core - Summary

- 3GPP specifies an interface via which one Mobile Core (on behalf of one MNO) requests another Mobile Core (on behalf of another MNO) to map the IMSI, phone number, and subscriber profile.

5G Capabilities (SDN, NFV, Network Slicing, etc)

- Network slicing: 5G networks offer network slicing through the use of Software-Defined Networking (SDN) and Network Functions Virtualization (NFV).(Example)
- SDN: Separates the data and control planes, allowing administrators to administer features from a single place. SDN also handles traffic flow via the central control plane's application program interfaces (APIs).
- NFV: Virtualizes network infrastructure by decoupling tasks that are normally performed in hardware and implementing them as software.Network slicing is made possible by NFV.

Software-defined Networking

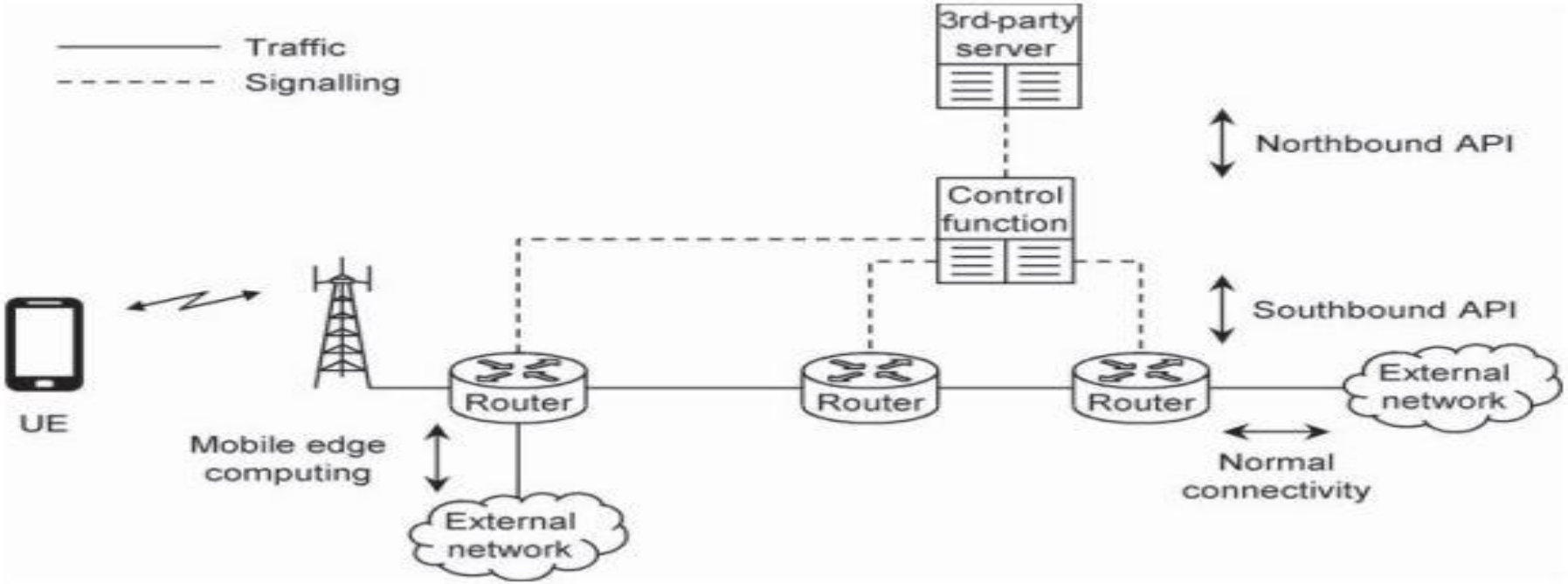
- main tasks

The user plane (UP) functions transmit communications from one network element to another. Decision-making processes are dispersed across the whole network.

- Limitations

Decision-making processes are dispersed throughout the network.

Architecture of a software-defined mobile telecommunication network



Source : An Introduction to 5G The New Radio, 5G Network and Beyond Christopher Cox

Network Slicing

- Easily changed to adapt to changes in NFV and SDN
- Network slices, which are made possible by NFV and SDN, are virtual logical sub-networks that run on shared physical hardware.
- One person in charge of the network can set up, change the settings for, and remove individual slices as needed.
- Each network slice works best with the kind of traffic it carries.

Network Slicing

- Each operator's network slices are separate from each other, which is very important for data transport and security in LTE networks.
- Slicing: IMS calls and internet data are often kept separate to reduce overload issues.
- 5G network slice goes through the core network, the radio access network, and even the air interface.

Network Function Virtualization

- Virtualized network functions (VNFs) are the tools that make up the network parts.
- Benefits

the software and hardware can be uncoupled from one another, with the two procured from different vendors; and it is easier for new vendors to enter the market

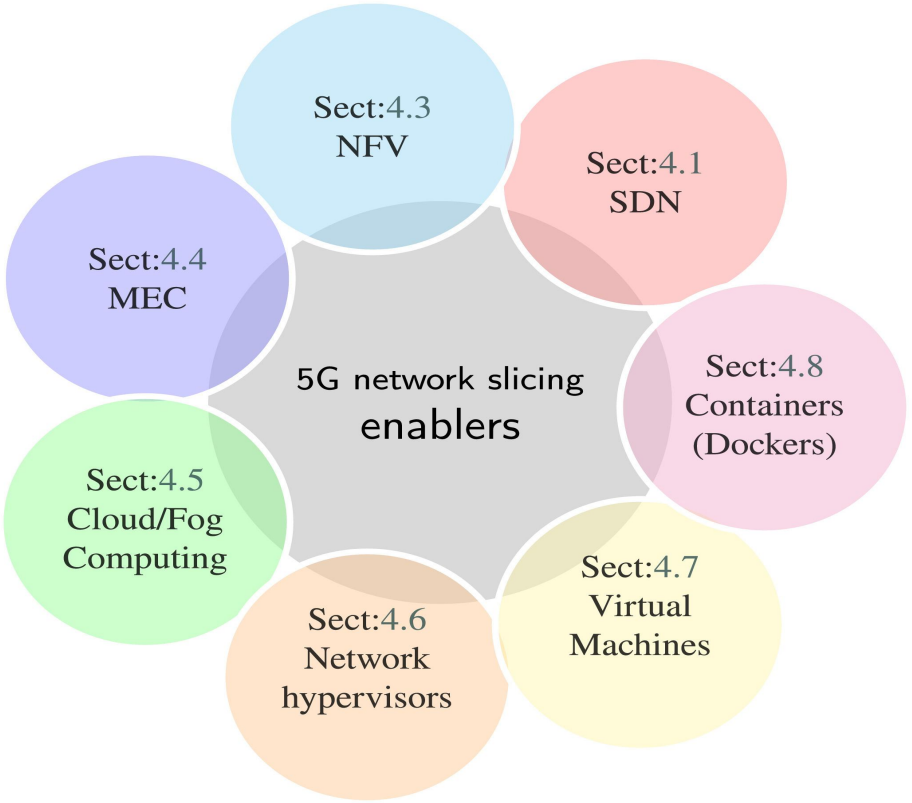
Benefits of NFV

- A centralized RAN refers to a network architecture where the base station's higher-level activities are carried out at a central hub located at a significant distance from the local cell site.
- RAN centralization offers improved security and a smaller footprint at the cell site, and allows the higher-level functions of nearby cells to communicate more effectively.
- If those functions are then implemented using software, the result is a virtualized RAN or cloud RAN (C-RAN)

Benefits of 5G for IoT

- Increased Capacity
- Lower Latency
- Faster Speeds
- Improved Reliability
- Network Slicing
- Edge Computing

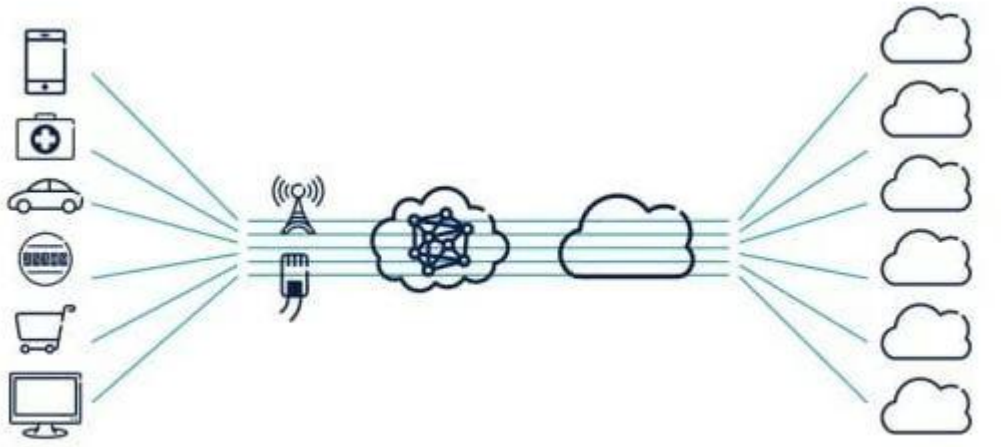
Functionality of 5g SDN, NFV



- Software defined networking (SDN)

Source : https://www.sciencedirect.com/science/article/pii/S1389128619304773

Functionality of 5G NFV

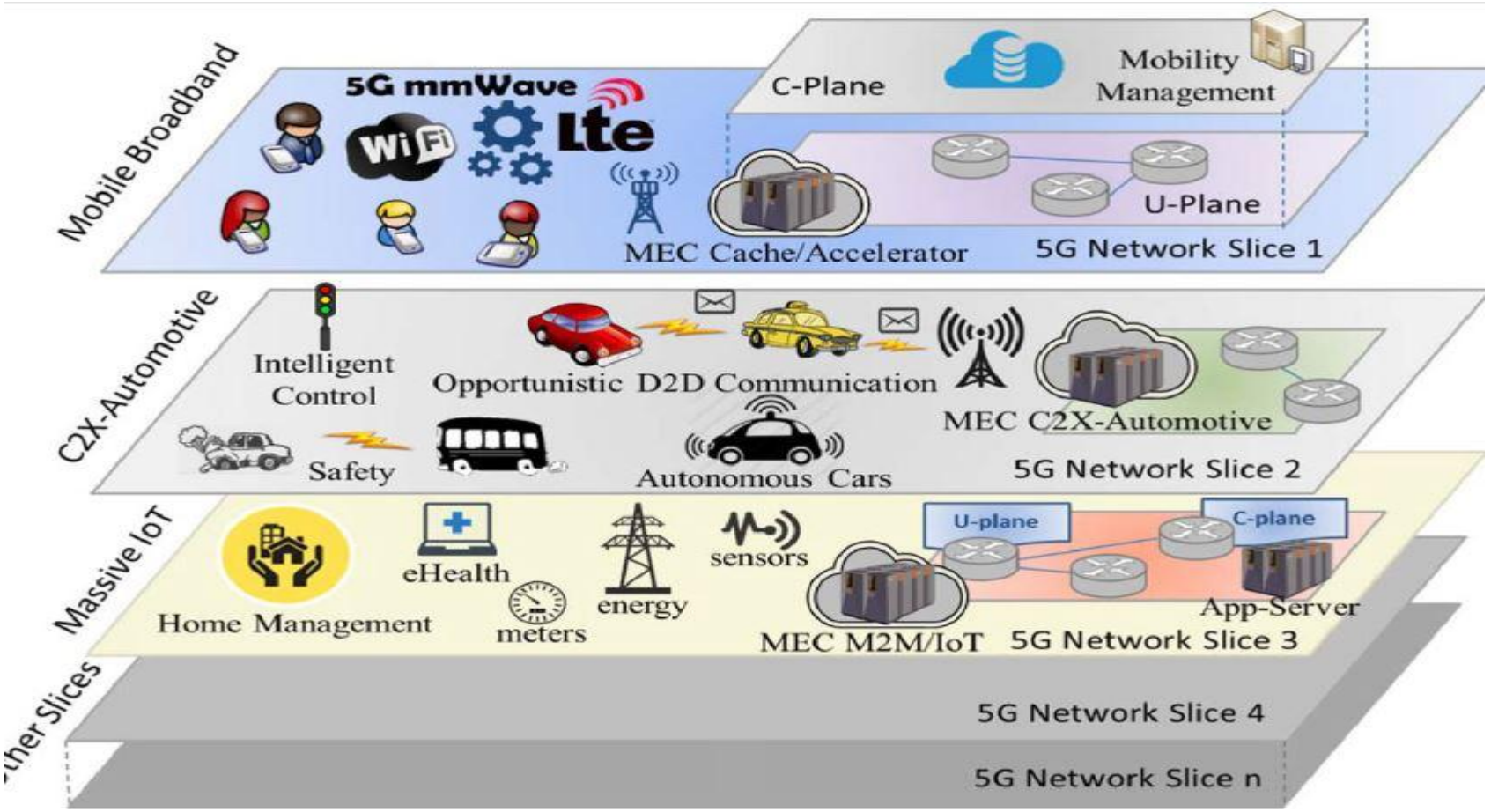


Source: Inside5G

Source : https://www.sdxcentral.com/5g/definitions/top-5g-business-case/5g-nfv/

- One of the main applications of network slicing will be to enhance mobile broadband performance by reducing latency.

Functionality of 5g network slicing with IoT application



Source : https://www.sciencedirect.com/science/article/pii/S1389128619304773

Benefits of 5G for IoT

https://iot.telenor.com/technologies/connectivity/5g/

Benefits of 5G for IoT

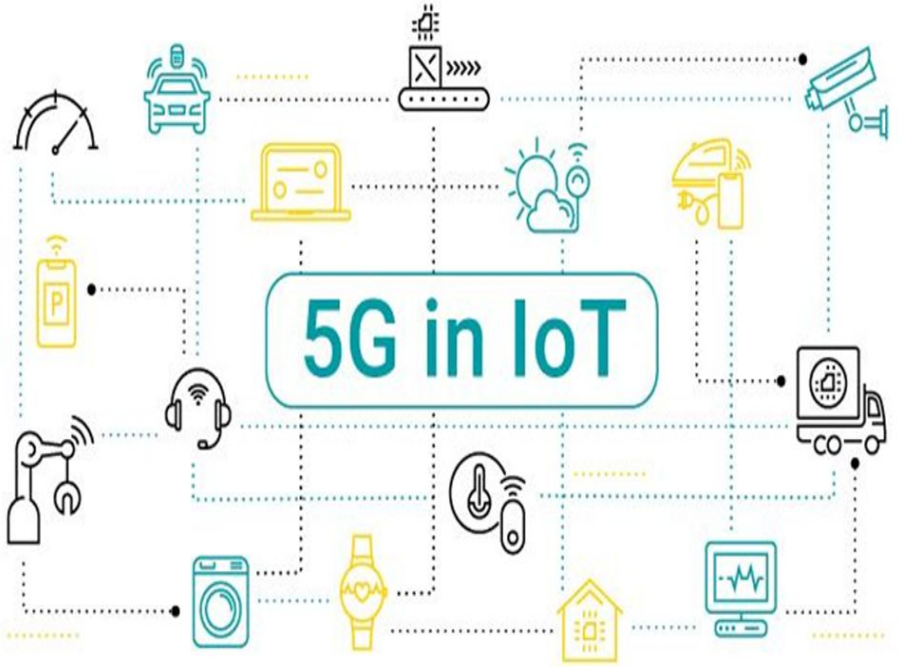
- assisted driving
- delivery robots
- automated guided vehicles (AGVs)
- connected drones and public safety applications.

5G Use Cases in IoT

- Massive mobile IoT
- Enhanced Mobile Broadband
- Critical communication

5G Use Cases in IoT

- 5G IoT for Smart Cities
- 5G IoT for Industrial Automation
- 5G IoT for Autonomous Vehicles
- 5G IoT for Healthcare
- 5G IoT for Agriculture



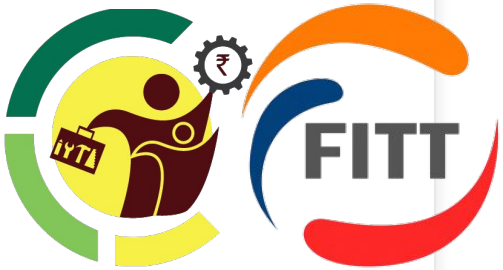
Use case animations

- https://www.youtube.com/watch?v=qj6KqiC_Tyk
- https://www.youtube.com/watch?v=12BiFNIVs6I
- https://www.youtube.com/watch?v=tw-79FiRYKA
- https://www.youtube.com/watch?v=pY_9TxAg95M
- https://www.youtube.com/watch?v=Lpggxti_yw0

5G Opens Up New Opportunities in IoT

- Continuous high-speed connection
- Quick data analysis and decision making
- LTE-M and NB-IoT network functionality improves application coverage or battery life Over time, service levels, data processing, etc. may be controlled more.

Python



Homework

- What is the function of 5G network?
- What is difference between 4G and 5G?
- How will 5G improve our lives?
- Is 5G faster than WIFI?
- What are the components of a 5G base station?
- What is the difference between a base station and a repeater?