INTRODUCTION TO 5G

ECE 525E – WIRELESS & MOBILE COMMUNICATION

Tuesday, April 15, 2025

WHAT IS 5G CELLULAR MOBILE COMMUNICATION? /01

5G is designed to of faster speeds, reduced latency, and increased capacity compared to previous generations like 4G.

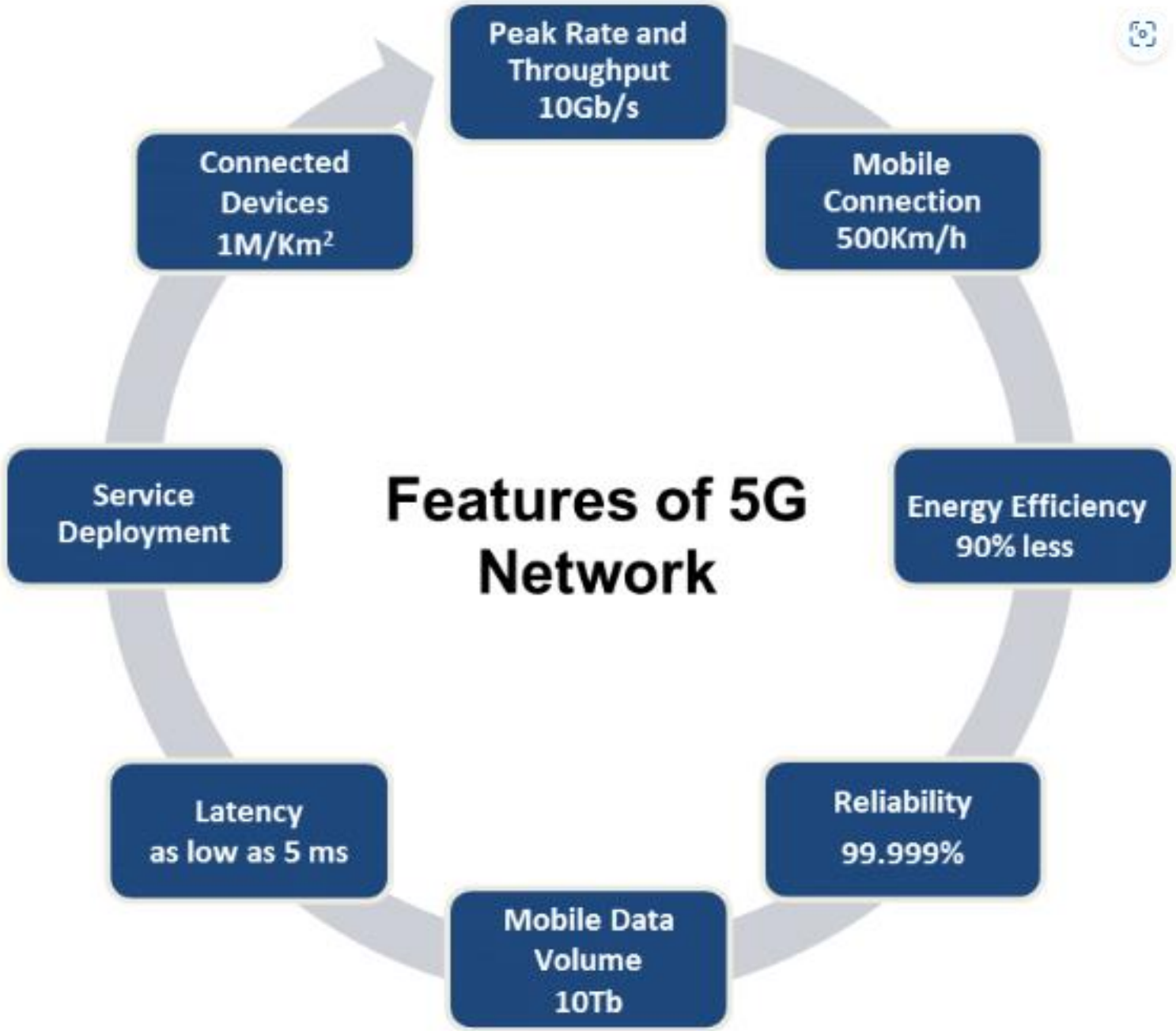
1. **Faster Speeds:** 5G aims to deliver significantly higher download and upload speeds, potentially over 100 times faster than 4G.
2. **Lower Latency:** 5G reduces the delay between sending a request and receiving a response (latency).
3. **Increased Capacity:** 5G can handle more data traffic simultaneously, allowing for more users and devices to connect without congestion.
4. **Improved Efficiency:** 5G is more energy efficient and uses the radio spectrum more effectively.

WHAT IS 5G CELLULAR MOBILE COMMUNICATION? /02

1. **5G is designed to connect virtually everyone and everything together including machines, objects, and devices.**
2. 5G wireless technology is meant to:
   a) deliver higher multi-Gbps peak data speeds,
   b) Offer ultra low latency,
   c) Give more reliability,
   d) Have massive network capacity,
   e) Offer increased availability,
   f) Give more uniform user experience to more users.

NEW FEATURES OF 5G

1. **New Spectrum Frequencies:** 5G utilizes new higher radio frequency bands.
2. **Advanced Radio Technology:** 5G employs new technologies like **massive MIMO (multiple input multiple output)** to enhance network efficiency and capacity.
3. **Software-Driven Core Network:** 5G is built on a virtualized and software-driven architecture.


Features of 5G Network
Peak Rate and Throughput 10Gb/s
Mobile Connection 500Km/h
Energy Efficiency 90% less
Reliability 99.999%
Mobile Data Volume 10Tb
Latency as low as 5 ms
Service Deployment
Connected Devices 1M/Km²

WHO INVENTED 5G?

1. No one company or person owns 5G.
2. Several companies within the mobile ecosystem contribute to bringing 5G to life under **3rd Generation Partnership Project (3GPP).**
3. **3GPP** is the industry organization that defines the global specifications for 3G UMTS (including HSPA), 4G LTE, and 5G technologies.
4. **3GPP** is driving many essential inventions across all aspects of 5G design, from the air interface to the service layer.
5. **3GPP 5G members** include:
   a) Infrastructure vendors
   b) Component/device manufacturers
   c) Mobile network operators
   d) Vertical service providers.

WHAT IS THE TECHNOLOGIES IN 5G?

1. **5G is based on OFDM (Orthogonal frequency-division multiplexing),** a method of modulating a digital signal across several different channels to reduce interference.

2. **5G uses 5G NR (New Radio) air interface alongside OFDM principles**.

3. **5G also uses other wider bandwidth technologies in the sub-6 GHz and mmWave.**

5G SERVICES /01

5G is used across three main types of connected services, i.e

1. **Enhanced Mobile Broadband (eMMB):** making our smartphones
   a) Faster,
   b) More uniform data rates,
   c) Lower latency
   d) Lower cost-per-bit.
2. **Ultra-reliable low latency communications (uRLLC) services for Mission-critical communications:** transform industries with
   1. ultra-reliable
   2. Available
   3. low-latency links like remote control of critical infrastructure, vehicles
   4. medical procedures.
3. **Massive machine-type communications (mMTC) services:** Use massive IoT to connect a massive number of embedded sensors (typically >100)

5G SERVICES /02

USE CASE	KEY PERFORMANCE INDICATOR	SPECIFICATION
Enhanced Mobile Data Rate Broadband (eMBB)	• Data rate • Mobility Speed • Use Scenario • Network Efficiency	• 10 – 20 Gb/s peak • 500 km/h • Macro and Small Cells • Network energy saving by a factor of 100
Massive Machine Type Communication (mMTC)	• Connection Density • Coverage • Data rate • Battery Life • Cost • Access Method	• $10^5 – 10^6$ /Km^2 • Long range • 1 – 100 Kb/s • 10 years • M2M ultra low • Asynchronous
Ultra Reliable Low Latency Communications (URLLC)	• Latency • Reliable and available • Data rate • Mobility	• < 1ms • 99.9999% • 50 kb/s – 10mb/s • High Speed

5G ENABLING TECHNOLOGIES /01

1. **Millimetre-Wave Communications:** 5G, with its potential to provide higher capacity, is exploring the opportunity to use the spectrum above 3GHz, mainly the mmWave range **30GHz(10mm) to 300Ghz (1mm).**
2. **Massive Multiple Input – Multiple Output (mMIMO)** - Each base station is equipped with multiple numbers of antennas transmitting concurrently using the same time-frequency resources.
3. **3D Beamforming** - with antenna array for directional signal transmission and reception by intentionally controlling the phase and relative amplitude on the same signal at each antenna leading to:

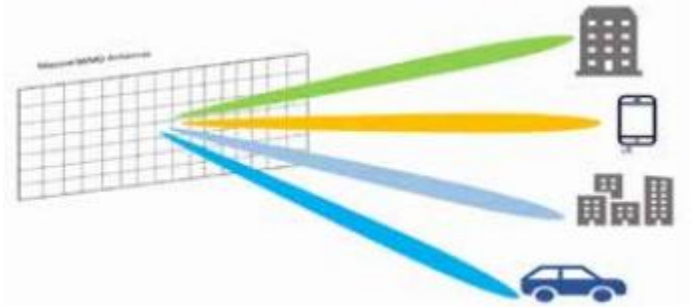
   (a) increased data rate and capacity,

   (b) less intercell and inter-sector interference,

   (c) higher energy efficiency,

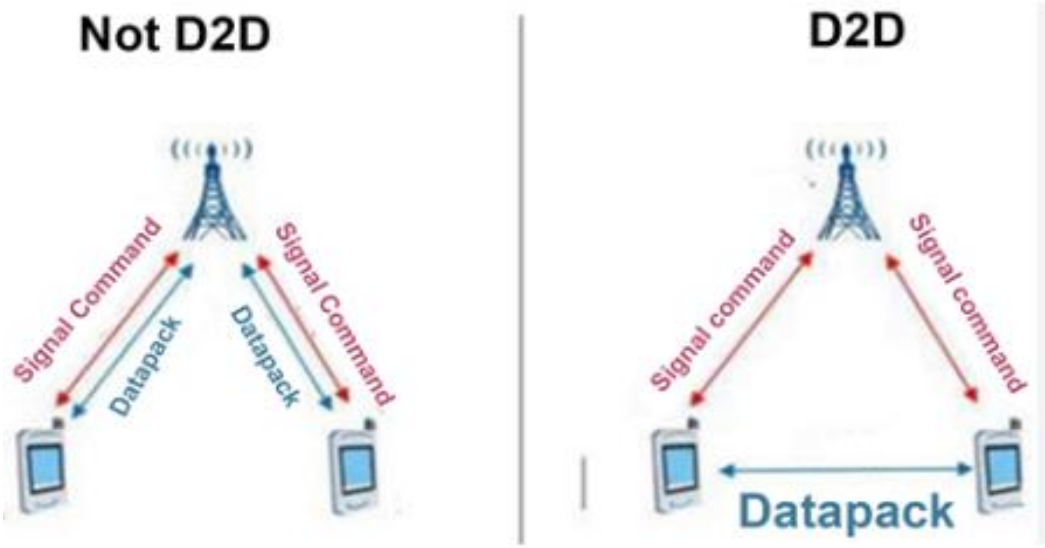
   (d) improved coverage

   (e) increased spectral efficiency.



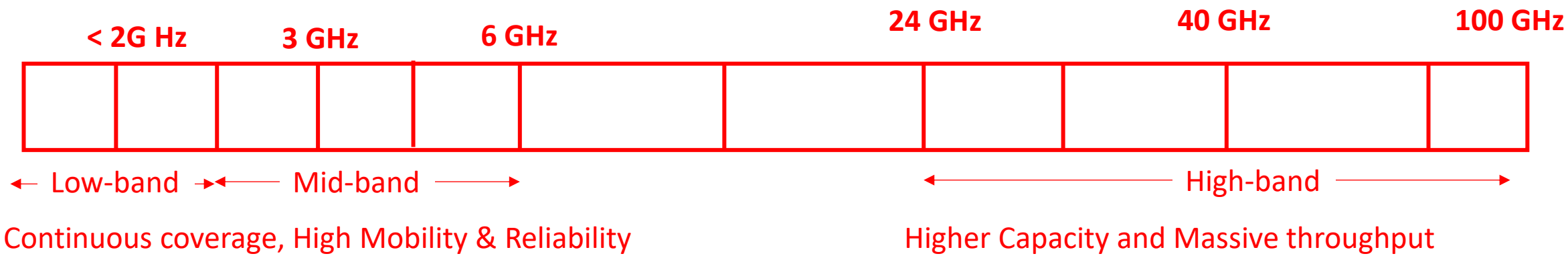
5G ENABLING TECHNOLOGIES /02

4. **Network Function Virtualization (NFV):**
   Decouples network functions from dedicated hardware, allowing for greater flexibility and efficiency in network management.
5. **Software Defined Networking (SDN):**
   Moves the control plane away from network hardware, providing centralized control and programmability.
6. **Device-to-device (D2D) communication:**
   Enables direct communication between devices, reducing reliance on the network infrastructure in certain scenarios.



5G FREQUENCY BANDS / 01

1. **To achieve higher data rate requirement in the order of 10 Gbps**, 5G technology requires wider frequency bands.
2. The specifications are published in the **3GPP Release 15, 16 and 17**.
3. **5G has three different frequency ranges:**
   a) **5G – Low Band: below 2 GHz**
   b) **5G – Mid Band: 2 – 6 GHz**
   c) **5G – High Band: 24 – 100 GHz**



5G FREQUENCY BANDS / 02

1. **5G low-band operates below 2 GHz and provides a broad coverage. spectrum that is also in use by 4G LTE**, essentially providing an LTE 5g architecture for 5G devices that are ready now. Performance of **low-band 5G is therefore similar to 4G LTE and supports use for 4G devices on the market today.**

2. **5G mid-band operates in the 2-6 GHz range and provides a capacity layer for urban and suburban areas. This frequency band has peak rates in the hundreds of Mbps.**

3. **5G high-band (mmWave)** delivers the highest speeds. The band ranges from 24 GHz to approximately 100 GHz. **Signals in this band cannot easily move through obstacles and suffers higher attenuation.** As a result, **5G high-band requires more cells to cover the same area.** Band is is well suited to high-capacity short-distance uses.

ADVANTAGES OF THE HIGH-BAND

1. **Extremely wide bandwidths:** Compared with existing wireless networks, mmWave communications employ much higher frequencies (30-300GHz) as carrier frequencies. Hence, **it has much more abundant spectrum resource (270GHz),** making itself quite alluring under the conditions of intensive spectrum.
2. **Small element sizes:** Owing to short wavelengths, mmWave devices **enable large antenna arrays to be packed in small physical dimension**.
3. **Narrow beams:** With the same antenna size, it is possible to pack more antenna elements at mmWave frequencies than at microwave. Therefore, the formed beam can be narrower, which can further facilitate the development of other applications, such as detection.

ATMOSPHERIC ATTENUATION IN HIGH-BAND

- Attenuation in the High Band is generally much higher than in the lower bands.
- **Some special bands such as 35GHz, 94GHz, 140GHz, and 220GHz, mmWave propagation experiences relatively small attenuation.**
- However, in the **60GHz, 120GHz, 180GHz bands, mmWave signals attenuate severely as high as 15dB/km**, which are known as “attenuation peak”.

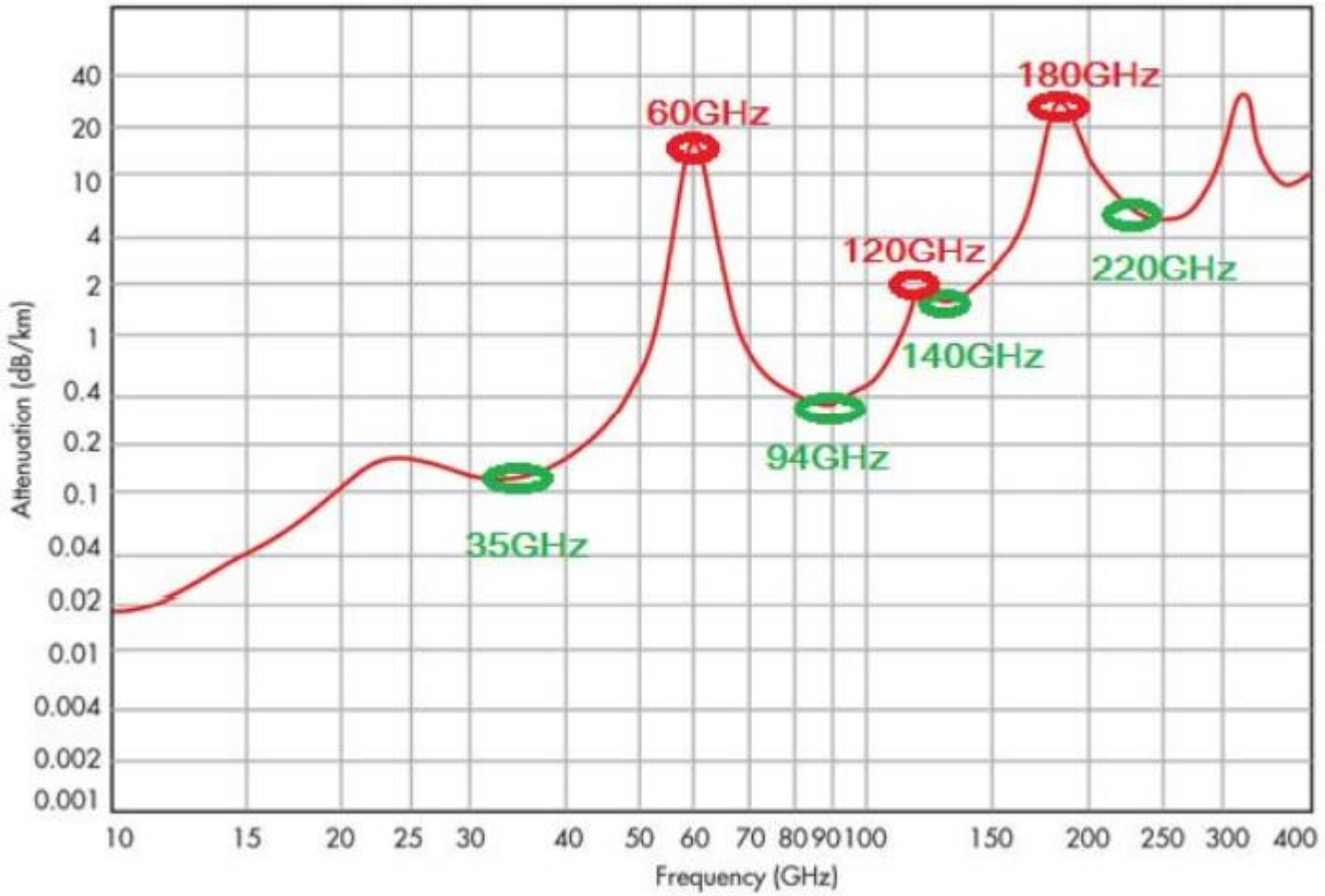


Figure Atmospheric and molecular absorption at mmWave frequencies

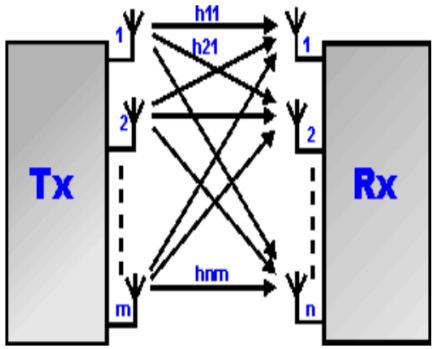
WHY DO WE NEED MASSIVE MIMO?

1. According to the Friis equation which is given below, the received power is inversely proportional to the square of frequency.

$$P_{rx} = \frac{P_t}{4\pi R^2} A_e G_{rx} G_{tx}$$

$$P_{rx} = \frac{P_t}{4\pi R^2} \left(\frac{\lambda^2}{4\pi}\right) G_{rx} G_{tx}$$

3. In order, to maintain the received power as the frequency increases, there is need to increase the antenna gains G_{rx} and G_{tx}.
4. Increasing the number of antennas is the practical solution to increasing G_{rx} and G_{tx}
5. Massive MIMO can also increase capacity through spatial multiplexing.



EXAMPLE OF LOW-BAND 5G PHONE

Samsung Galaxy S20 Ultra 5G

Released 2020, March 06
222g, 8.8mm thickness
Android 10, One UI 2.5
128GB/256GB/512GB storage, microSDXC

4.3%
5,569,453 HITS

682
BECOME A FAN

6.9"
1440x3200 pixels

108MP
4320p

12/16GB RAM
Exynos 990

5000mAh
Li-Po

REVIEW | OPINIONS | COMPARE | PICTURES

Also available with 4G/LTE only

NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE / 5G
	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)
		CDMA 800 / 1900 & TD-SCDMA
	3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100
		CDMA2000 1xEV-DO
	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 18, 19, 20, 25, 26, 28, 29, 30, 38, 39, 40, 41, 46, 48, 66, 71 - SM-G988U
	5G bands	2, 5, 41, 66, 71, 260, 261 SA/NSA/Sub6/mmWave - SM-G988U
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps; 5G (5+ Gbps DL)
LAUNCH	Announced	2020, February 11
	Status	Available. Released 2020, March 06

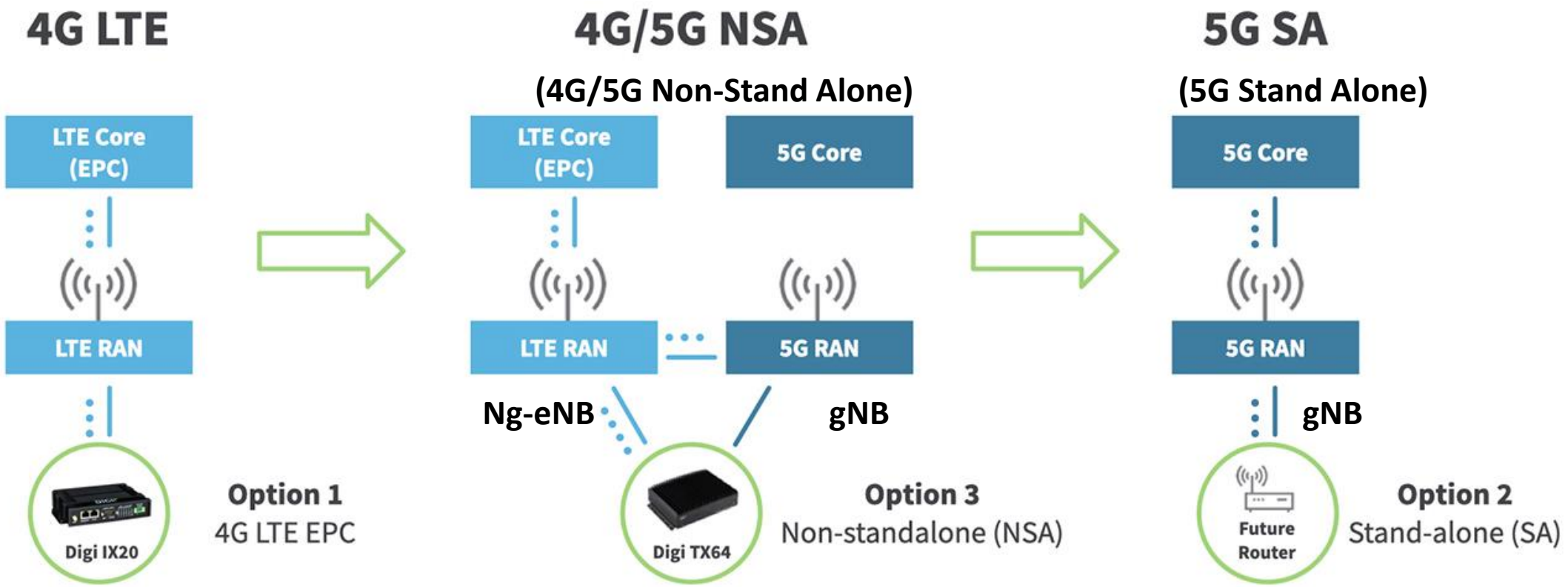
5G BAND	FREQUENCY
2	1900 MHz
5	850 MHz
41	2500 MHz
66	1700/2100 MHz
71	600 MHz

4G BAND	FREQUENCY
1	2100 MHz
2	1900 MHz
3	1800 MHz
4	1700 MHz
5	850 MHz

5G FREQUENCY BANDS IN SELECTED COUNTRIES

COUNTRY	LOW-BAND	MID-BAND	HIGH - BAND
Kenya *(See National Frequency Allocation Table at www.ca.go.ke)*	-	3.4 – 3.6 GHz 4.8 – 4.9 GHz	24.5- 27.5, 37- 43.5 GHz 48 – 50 GHz 66 – 71 GHz
Brazil	-	3.4 – 3.6 GHz	26, 40, 66-71
European Union	700 MHz	1.4 GHz, 2.0 GHz 3.4 GHz – 3.86 GHz	26 – 28 GHz
Japan	-	3.4 – 4.2 GHz 4.4 – 4.9 GHz	28 GHz
USA	600 MHz	2.6 GHz	24, 28, 37, 39, 47 GHz 64 – 71 GHz

5G ARCHITECTURE

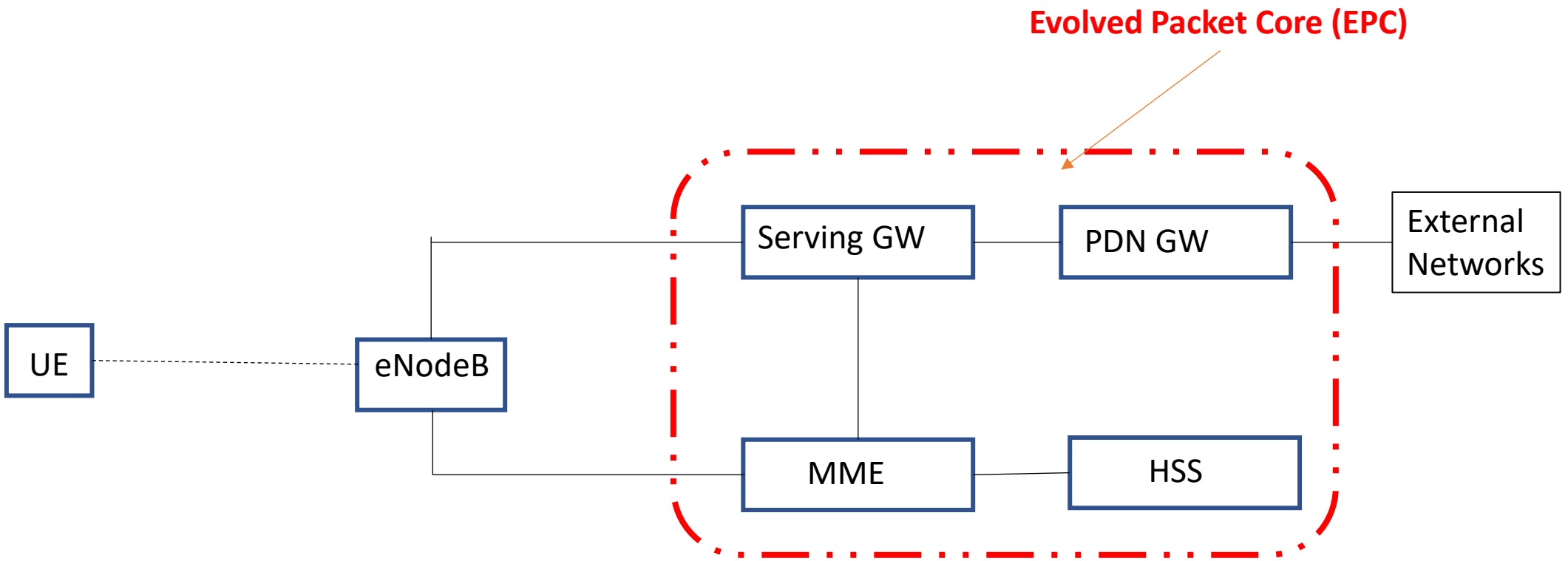


5G NG-RADIO ACCESS NETWORK

The 5G NG-RAN (next generation radio access technology network) can have either a **gNB** or an **ng-eNB** as nodes (here **ng stands for "next-generation**").

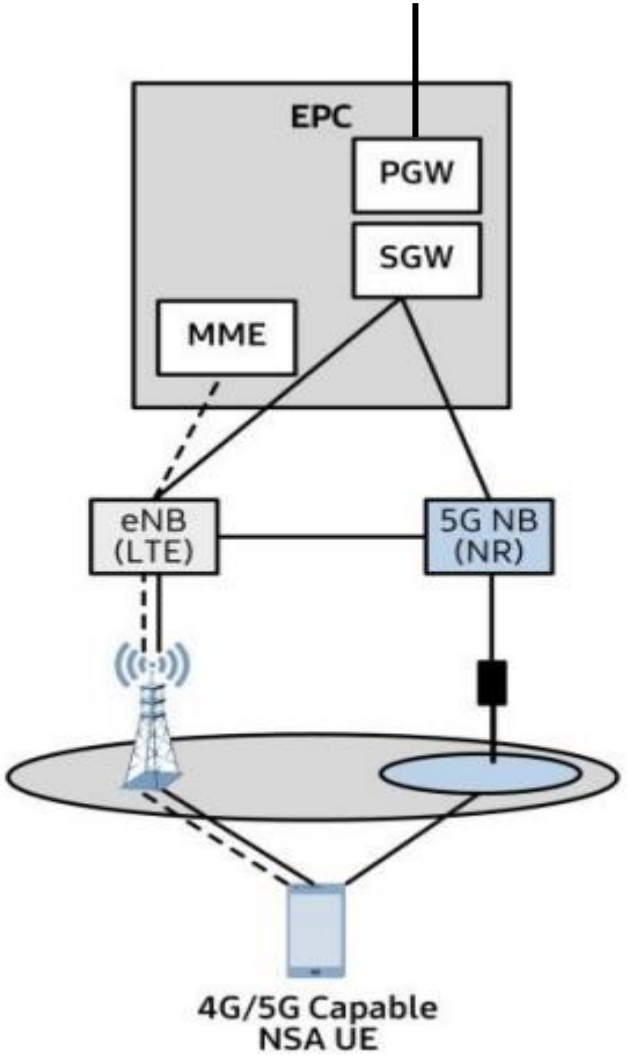
1. **gNB** is the logical 5G radio node, the equivalent of what was called NodeB in 3G-UMTS and eNodeB or eNB (i.e., evolved Node B) in 4G-LTE.
2. **ng-eNB** is essentially an enhanced 4G eNodeB that connects to the 5C Core network via the NG interfaces but still uses 4G LTE air interfaces to communicate with the 5G UE.

4G ARCHITECTURE (RECAP)



5G NON-STANDALONE/01

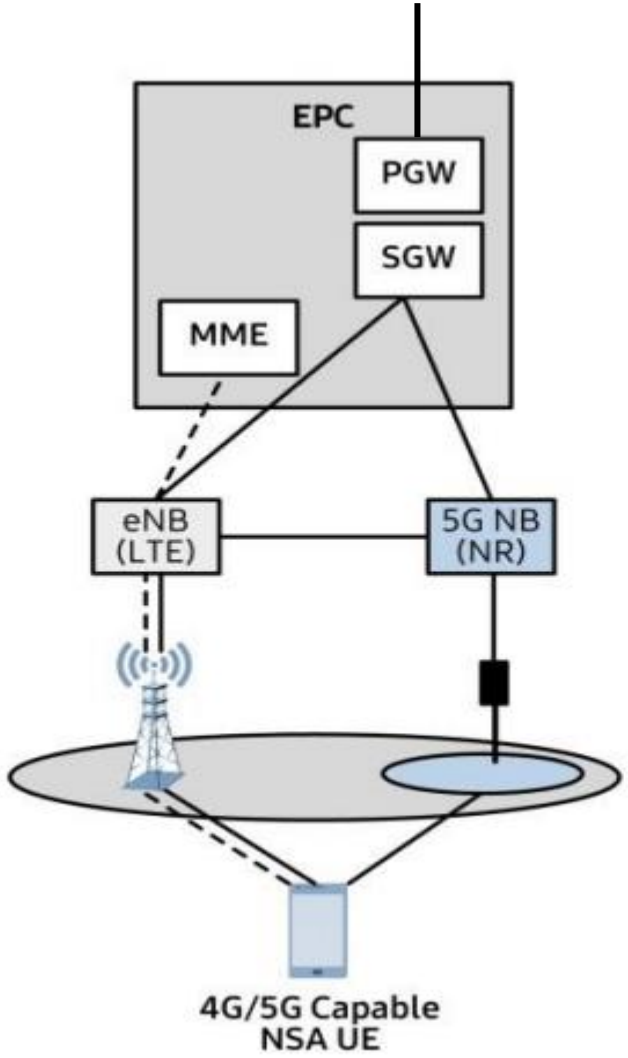
Non-standalone 5G is the first stage of 5G, using a new 5G radio (or 5G NR) access network overlaid on an existing 4G LTE network core.



5G NON-STANDALONE/02

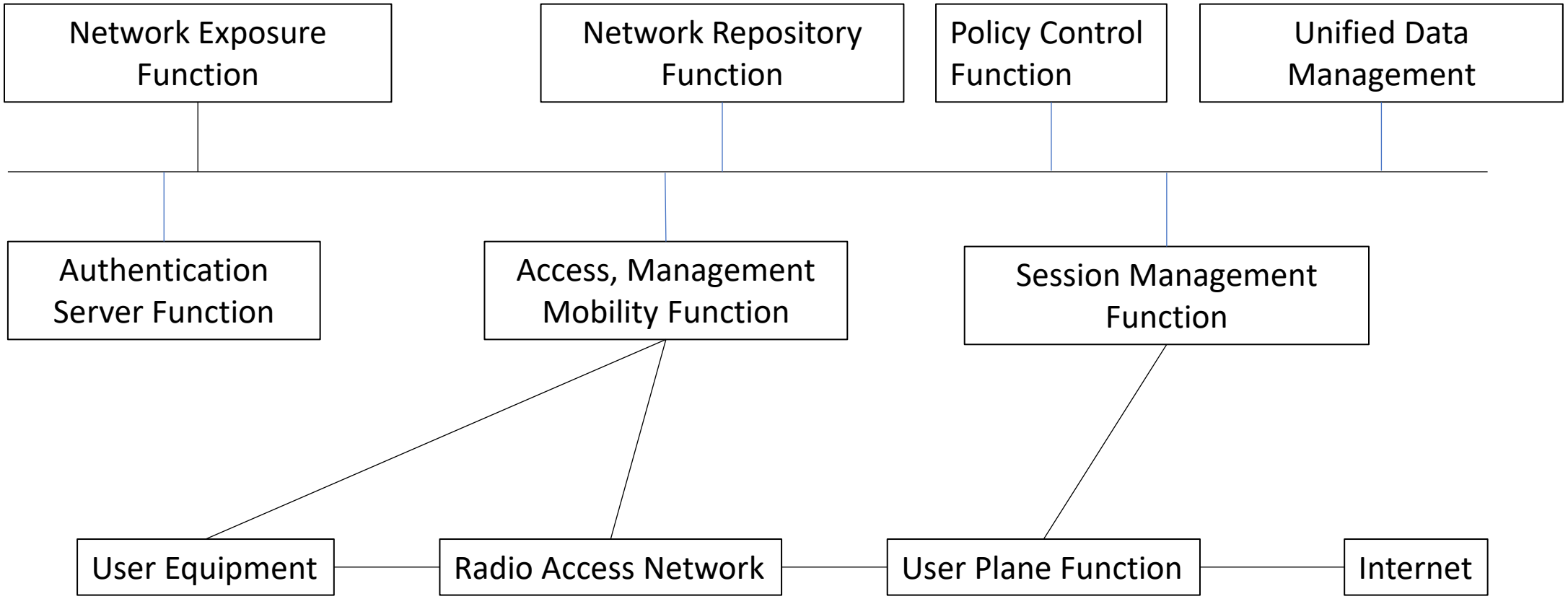
A basic setup for such a scheme is:

1. UE signals to the network requesting to simultaneously connect to the 4G and 5G networks.
2. Core Network checks if the UE is authorized to connect to 4G and 5G networks. The 4G eNodeB is notified that the UE is permitted to connect to the 5G network.
3. The eNodeB then takes a decision to activate a bearer on the 5G gNodeB.
4. The 4G eNodeB and 5G gNodeB communicate to set up the bearer on the 5G gNodeB.
5. The UE is notified about the 5G bearer via the RRC Connection Reconfiguration message.
6. The UE then connects to the 5G network while maintaining the connectivity to the 4G network.



5G ARCHITECTURE DIAGRAM

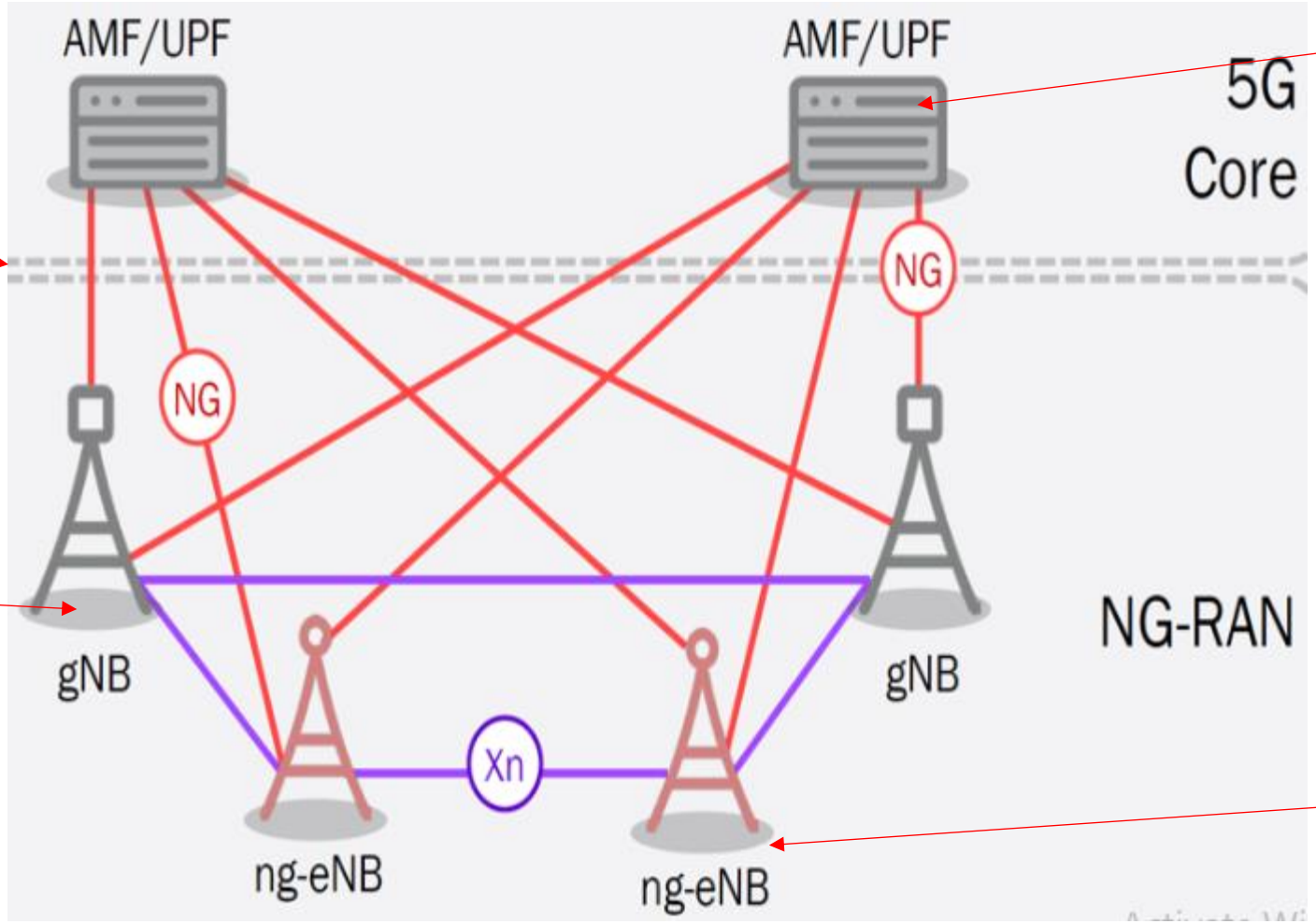
5G was designed from the ground up, and network functions are split up by service. That is why this architecture is also called 5G core **Service-Based Architecture (SBA)**.



5G NG-RAN

5G NR (New Radio) air interface

gNB (Next Generation Node B)



Access and Mobility Management Function (**AMF**)/User Plane Function (**UPF**)

ng-eNB concept makes use of existing 4G radio network, allowing it to coexist with the gNBs.