Cellular Wireless Networks: Network Architectures from 2G to 5G

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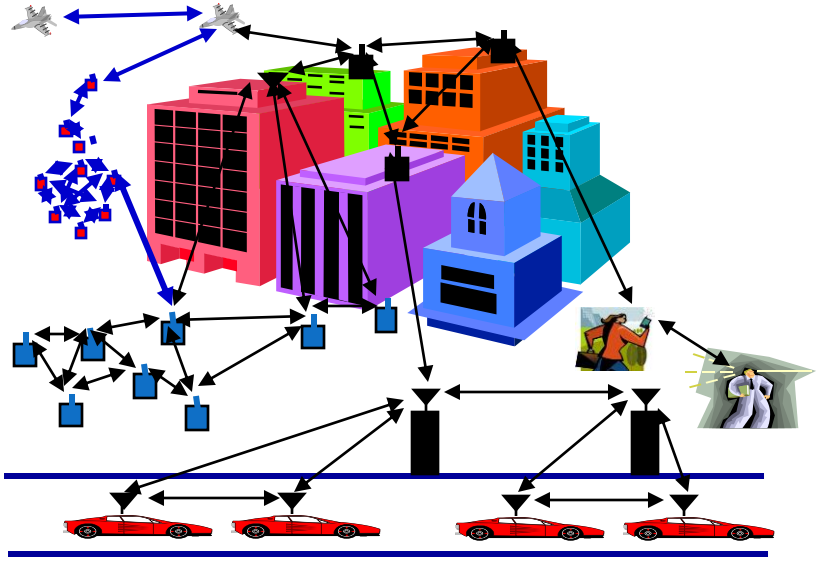
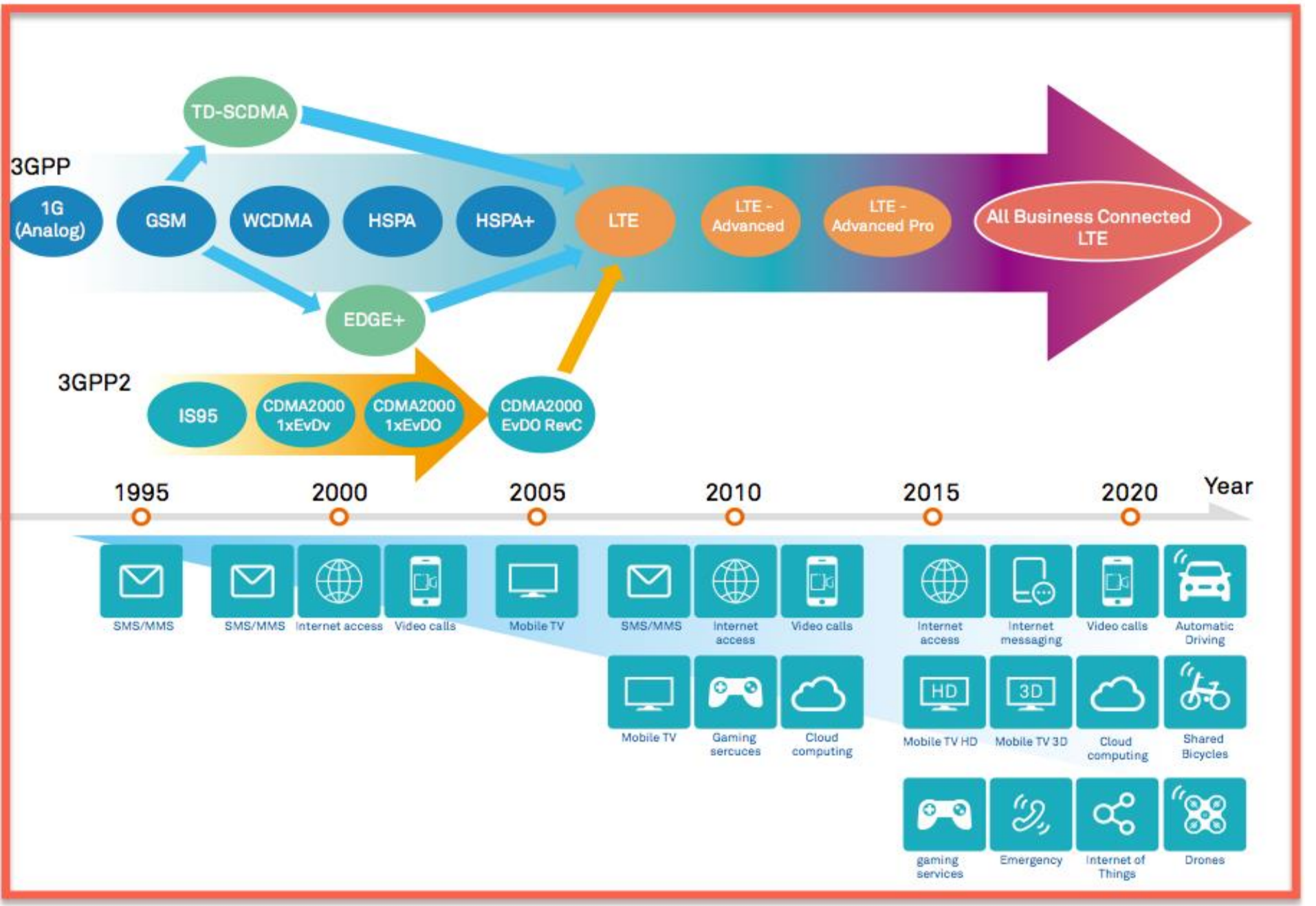


Evolution Path of Cellular Mobile Radio



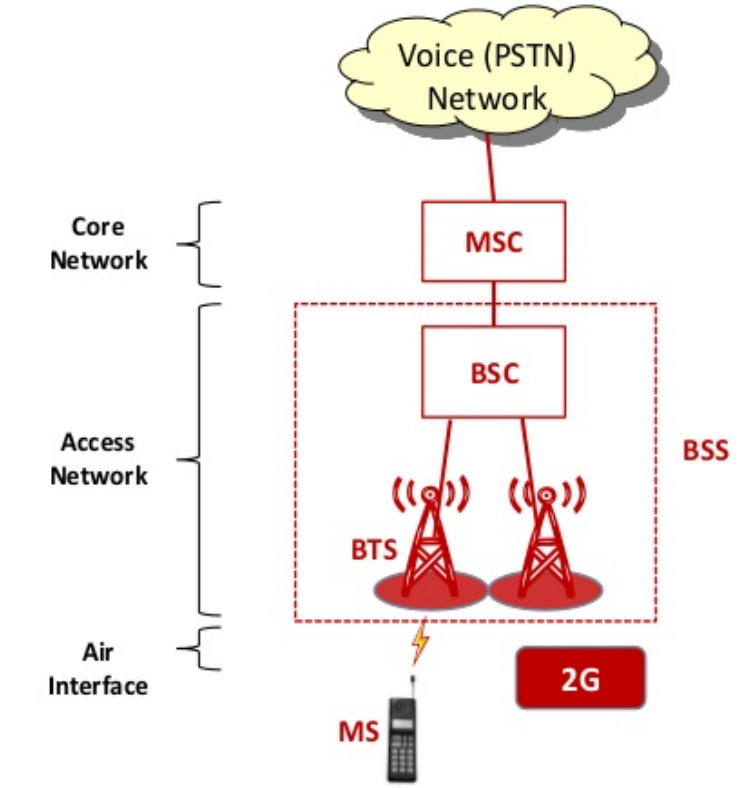
1G (AMPS) NETWORK HIGHLIGTHS

It was the first cellular mobile system used, which was introduced in 1982. It was used for voice services and was based on technology called as Advanced Mobile Phone System (AMPS). The AMPS system was frequency modulated. Its basic features are:

- FDMA Access technique
- Channel capacity - **30 KHz**
- Speed- 2.4 kbps
- Poor voice quality
- Poor battery life
- Large phone size
- Limited capacity
- Poor handoff reliability
- No security at all

The '2G' GSM Network Architecture

MSC = Mobile Switching Centre
BSS = Base Station Subsystem
BSC = Base Station Controller
BTS = Base Transceiver Station
MS = Mobile Station



- Emerged in late 1980s.
- Next to 2G**The main features of 2G are** :
- **TDMA, CDMA based access techniques**
- Channel bandwidth of **200 KHz (GSM)**, **1.25 MHz (CDMA-IS95)**
- Data speed was up to **64kbps**
- 2.5G system (GPRS; EDGE) uses packet switched and circuit switched domain

and provide data rate up to **144 kbps**.

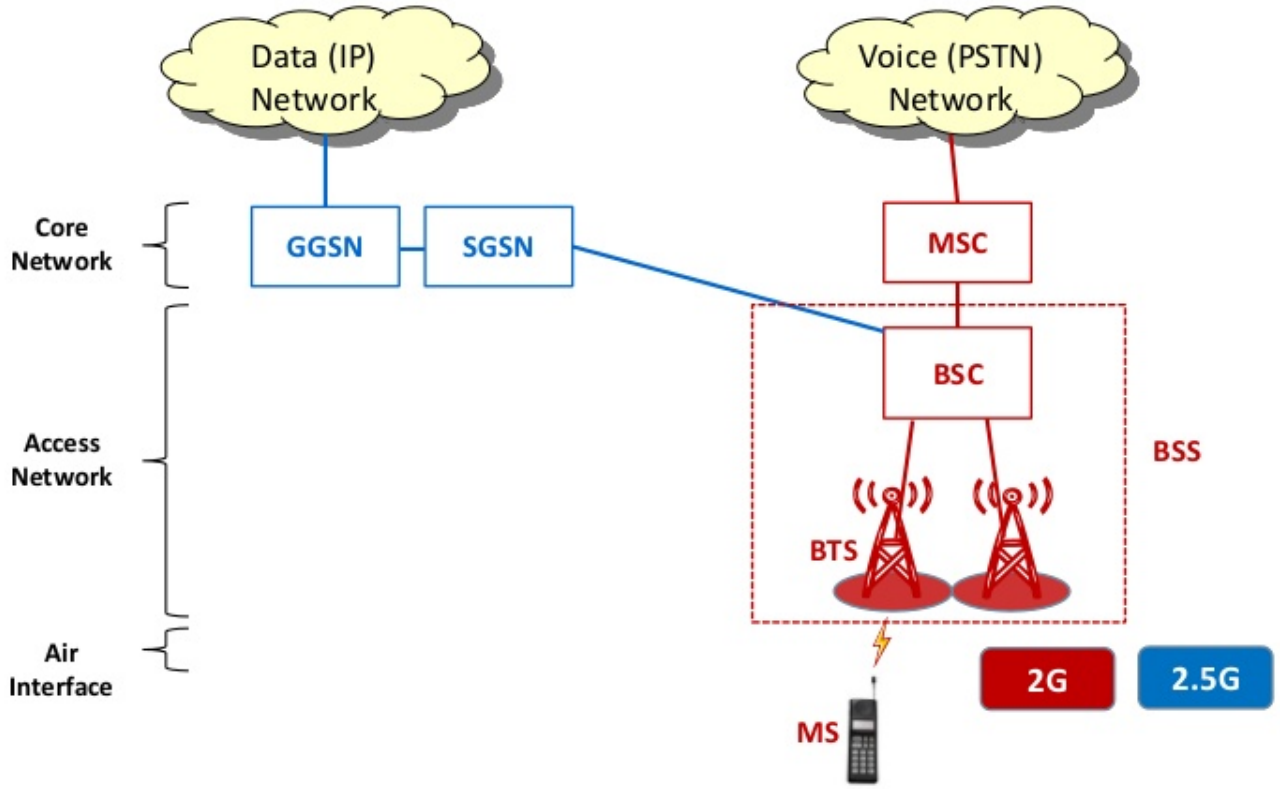
- Uses digital signals
- Enables services such as text messages, picture messages and MMS(Multimedia message)
- Provides better quality and capacity compared to 1G
- Unable to handle complex data such as videos.

Additional features with 2.5 G:

- Send/receive e-mail messages
- Web browsing
- Camera phones become available
- Take a time of 6-9 mins. to download a 3 mins. MP3 song

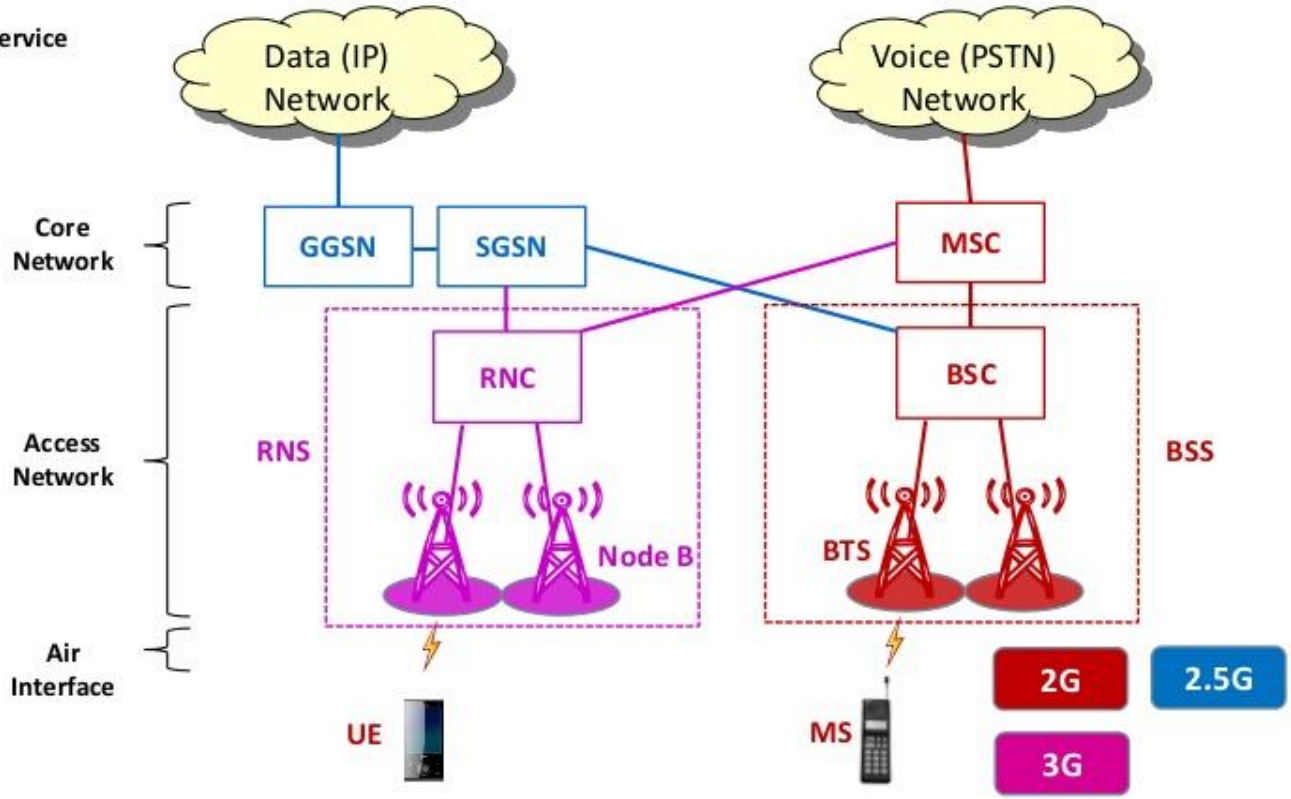
The ‘2.5G’ GPRS Enhancement

GPRS = General Packet Radio Service
SGSN = Serving GPRS Support Node
GGSN = Gateway GPRS Support Node



The ‘3G’ UMTS Network Architecture

UMTS = Universal Mobile Telecommunications Service
RNC = Radio Network Controller
RNS = Radio Network Subsystem
UE = User Equipment



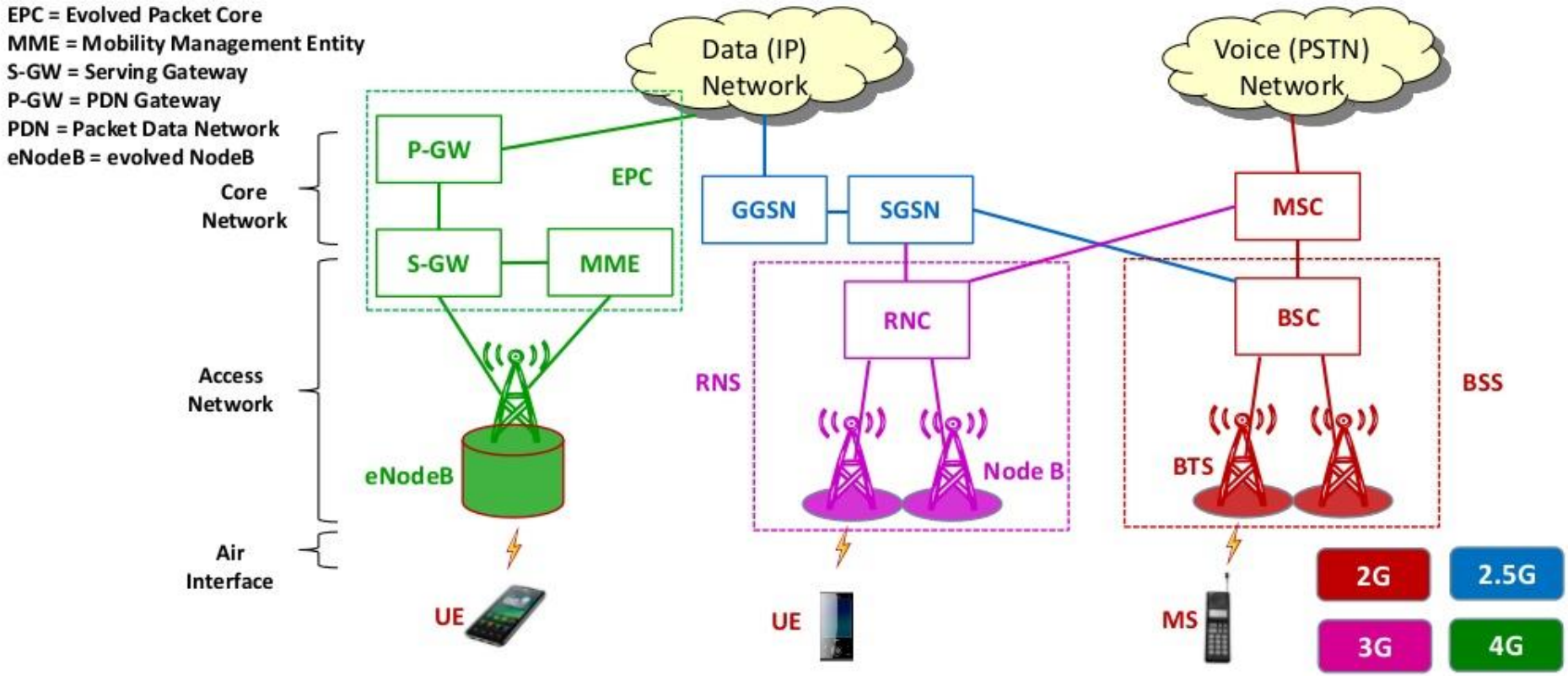
3G UMTS NETWORK HIGHLIGTHS

- Launched in 2000.
- Called as UMTS(Universal Mobile Telecommunication System) or **WCDMA** in Europe, while **CDMA2000** is the name of American 3G variant. Also the IMT2000 accepted a new 3G standard from China, i.e **TD-SCDMA.**
- The aim of this technology was to offer high speedData with Global Roaming. :
- Based **Wideband CDMA (WCDMA) access technique**
- **Channel bandwidth is 5MHz** (Wideband compared to 1G and 2G systems)
- Provides data rate of 2 Mbps
- Accommodate web-based applications and audio and video files, video conferencing/3D gaming, TV streaming/mobile TV/Phone calls
- To download a 3 minute MP3 song only 11 sec-1.5 mins time required.
- Expensive fees for 3G licenses services
- It was challenge to build the infrastructure for 3G while switching from 2G

3.5 G – HSDPA (High-Speed Downlink Packet Access)

- Mobile telephony protocol, also called 3.5G (or "3½ G"), which provides a smooth evolutionary path for UMTS-based 3G networks allowing for higher data transfer speeds.
- Packet-based data service in W-CDMA downlink with data transmission up to 8-10 Mbit/s (and 20 Mbit/s for MIMO systems) over a 5MHz bandwidth in WCDMA downlink.
- HSDPA implementations includes Adaptive Modulation and Coding (AMC), Multiple-Input Multiple Output (MIMO), Hybrid Automatic Request (HARQ), fast cell search, and advanced receiver design.

The ‘4G’ LTE Network Architecture

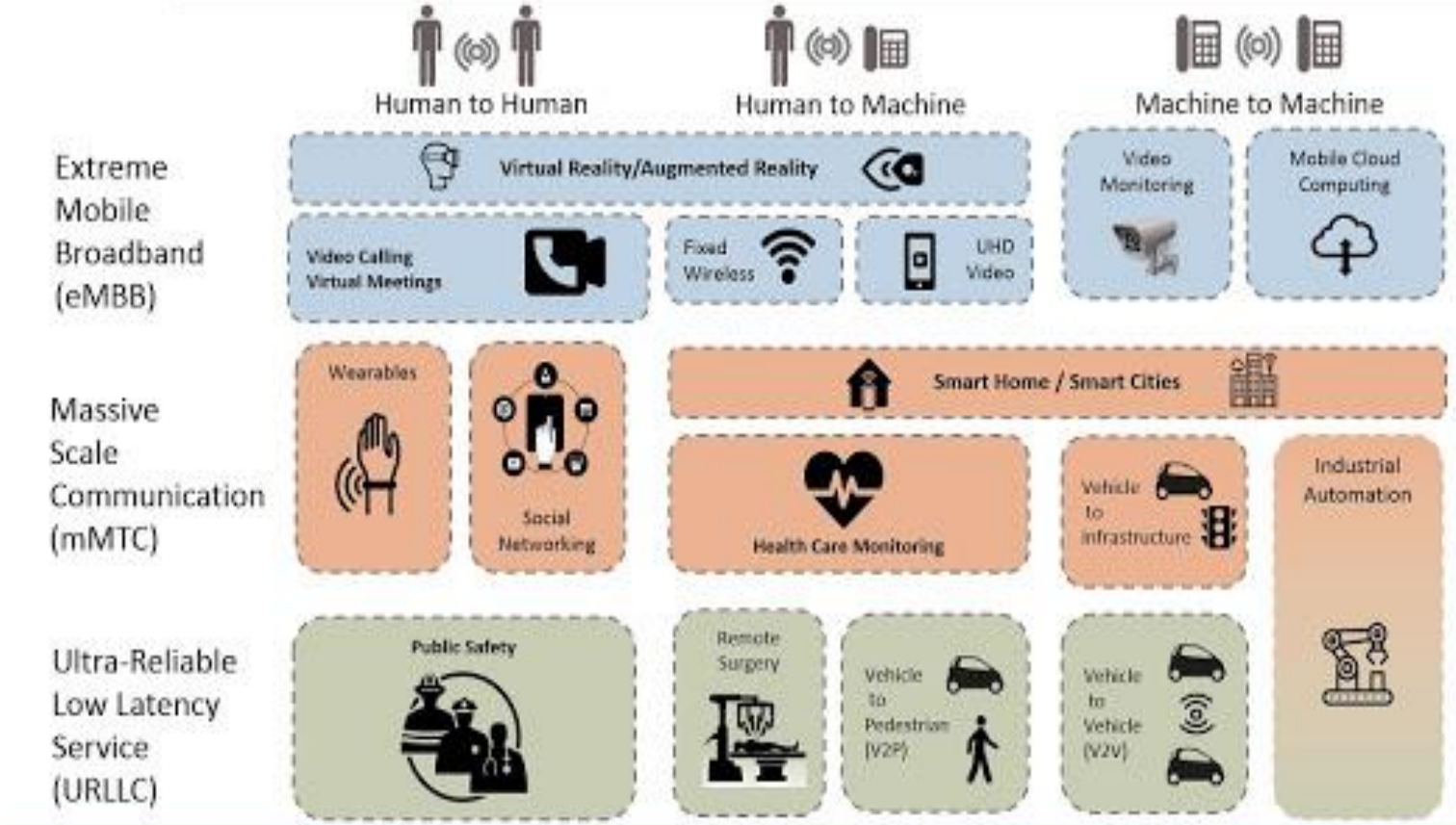


- 4G was developed to accommodate the QoS and rate requirements set by forthcoming applications like wireless broadband access, Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video Broadcasting (DVB), minimal services like voice and data, and other services
- **3GPP LTE Release 10 is named as 4G**
- **Based on OFDMA access technique**
- Capable of providing **data rates up to 150 Mbps downlink and 75 Mbps uplink**
- Inter-operability between different sorts of networks, Wi-Fİ, IEEE 802.16e, LTE.
- Support of IPv6

Technologies' Comparison

	802.16e (WiMAX)	HSPA+ (3.5 G)	LTE (4 G)
FEATURE	TDD, OFDMA, MIMO, 64QAM, BW: 1.25 ~ 20MHz	FDD, WCDMA, MIMO, 64QAM DL, 16QAM UL, BW: 5MHz	FDD, OFDMA, TDD, SC-FDMA, MIMO, 64QAM, 1.4 | 3 | 5 | 10 | 20MHz
DATA RATE	63.36Mbps DL, 2*2 10MHz 28.22Mbps UL, 2*2 10MHz	42Mbps DL, 2*2 5MHz 11.5Mbps UL, 5MHz	150Mbps DL, 2*2 20MHz 75Mbps UL, 2*2 20MHz
STANDARD	2005.12 New spectrum	2008. Q3 3G spectrum	2009. Q3 3G spectrum New spectrum
	IEEE	3GPP	3GPP

Summary of 5G Use Cases



Enhanced MBB
- 20/10 Gbps DL/UL*
- 4 ms user plane latency
- 500 km/h mobility

Massive MTC
- 1 million devices / km²
- 10+ years battery life
- 20 dB coverage enhancement

URLLC
- 1 ms user plane latency
- Highly secure / resilient
- 99.99999% availability

* Peak theoretical rate

Source: 5G Americas

Machine-Type Communications (MTC)

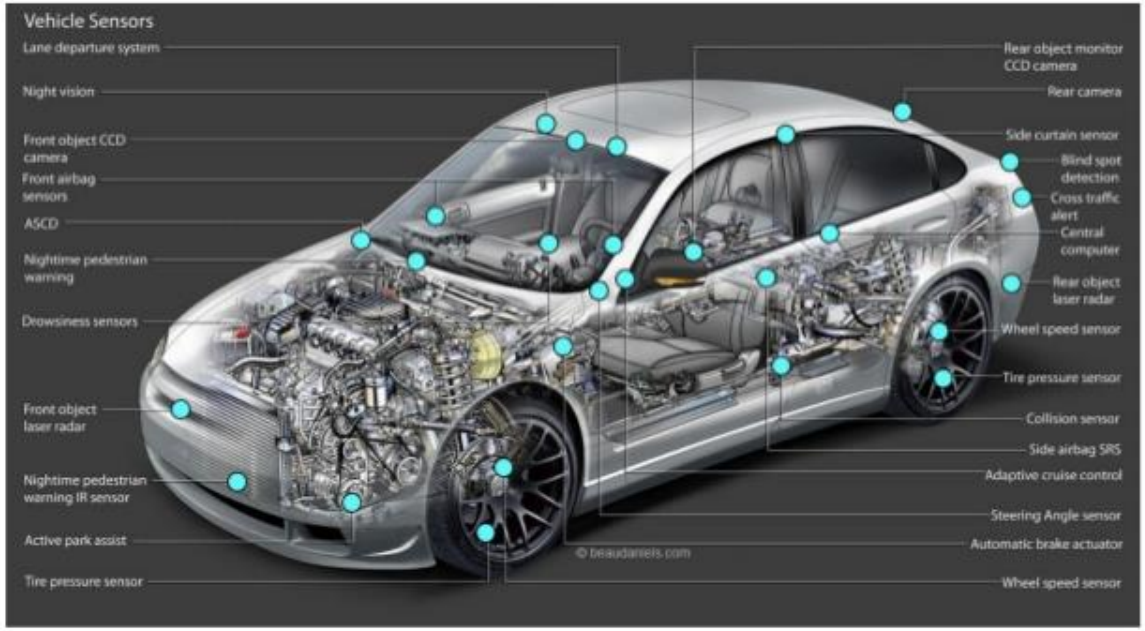
3GPP calls M2M as Machine-Type Communications (MTC).

3GPP started using MTC terminology from Release-10 onwards.

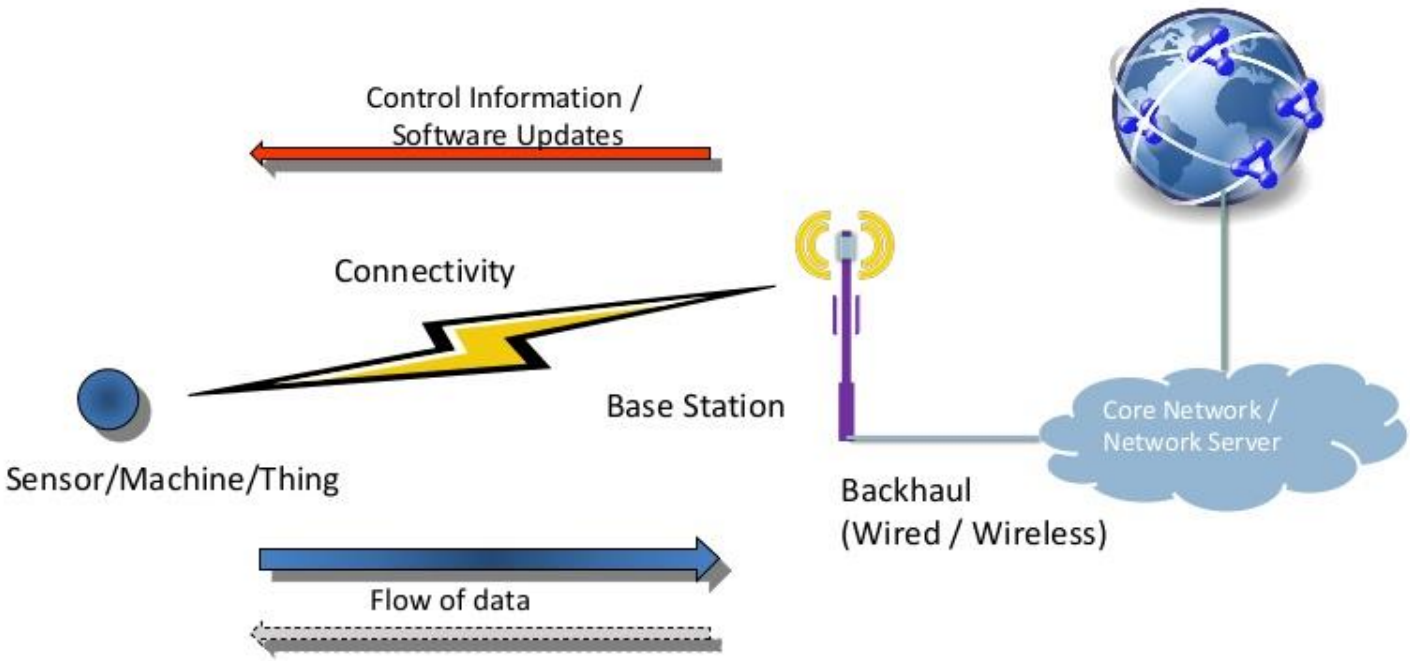
While 3GPP is also defining Narrowband IoT (NB-IoT), its still M2M/MTC.

One of the use cases for 5G is massive MTC (mMTC). The requirement is to handle 1 million devices / km^2

Sensors in your car



High Level Architecture of M2M/IoT



M2M vs IoT

Scenario 2 - Basic connectivity (M2M)

The machine has basic sensors so it can send some kind of notification (on your phone or email or message, etc.) whenever the coffee beans, chocolate powder, milk powder, etc., falls below a certain level.

An app on phone and/or computer may be available

Source: 3G4G Blog

M2M vs IoT

Scenario 3: Advanced connectivity (IoT)

Lets say that the coffee machine is connected to the office system and database.

It knows which employees come when and what is their coffee/drinks consumption pattern

This way the machine can optimize when it needs to be topped up.

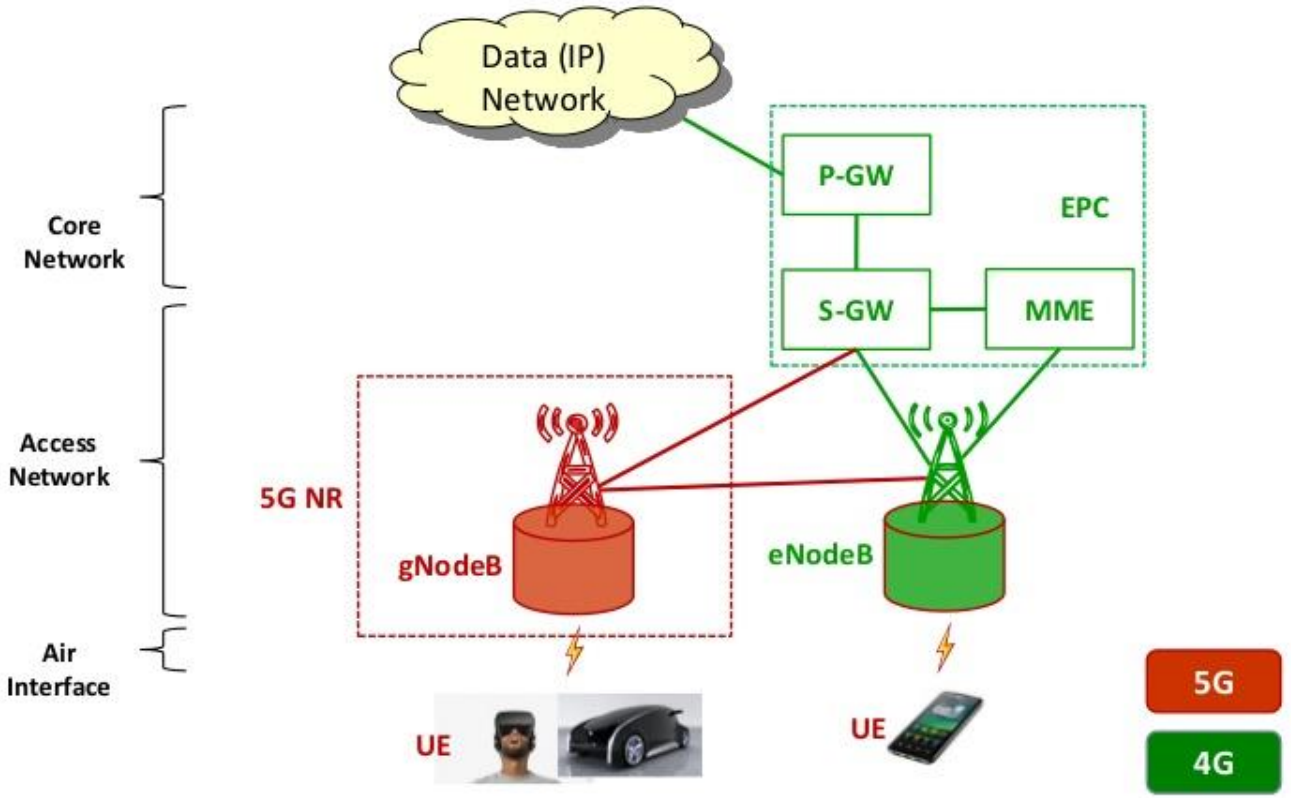
If there is a large meeting/event going on, the coffee machine can even check before the breaks and indicate in advance that it needs topping up

Source: 3G4G Blog

3GPP LTE Release 15 (2018)

The '5G' Phase 1 Network Architecture

gNodeB = next generation NodeB
NR = New Radio



https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview

5G NR vs. LTE eNodeB

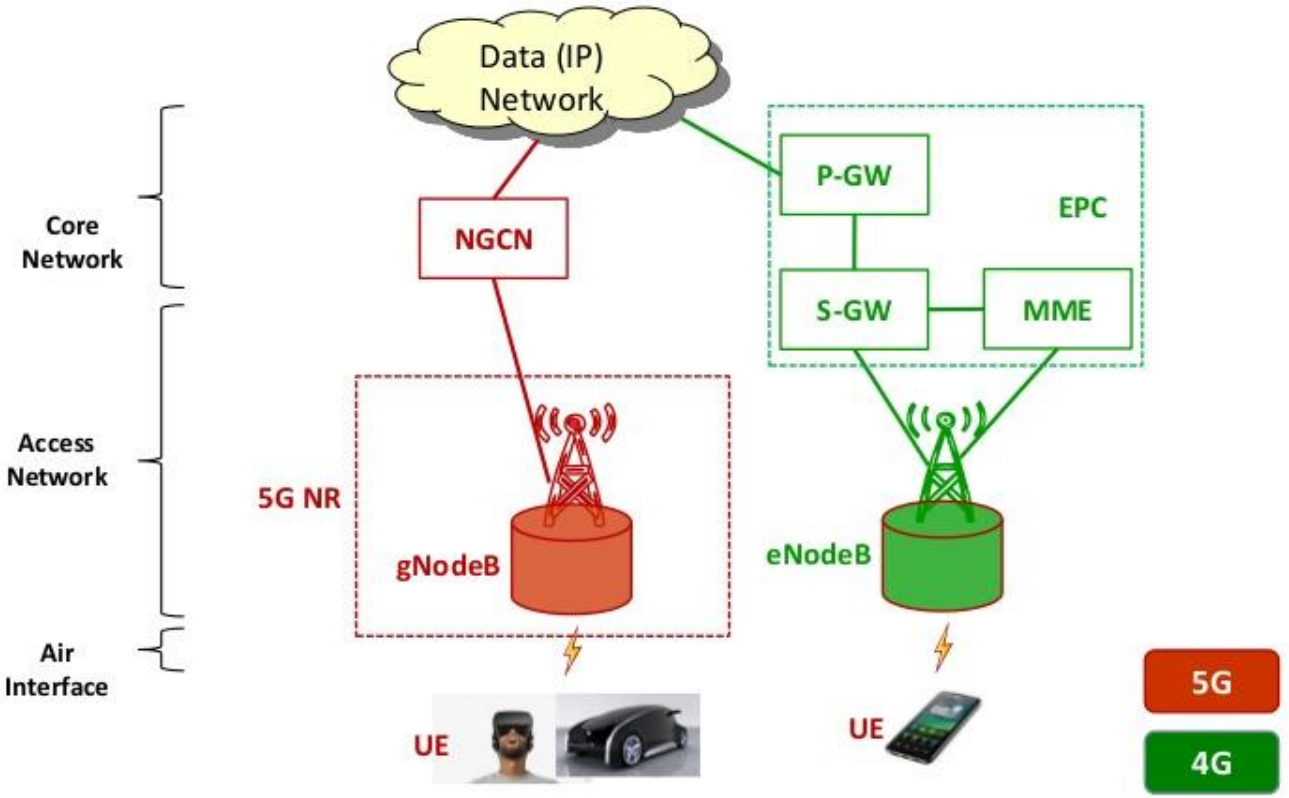
	LTE	NR
Frequency of Operation	Up to 6 GHz	Up to 6 GHz, ~28 GHz, ~39 GHz, other mmWave bands (Upto 52 GHz)
Carrier Bandwidth	Max: 20 MHz	Max: 100 MHz (at <6 GHz) Max: 1 GHz (at >6 GHz)
Carrier Aggregation	Up to 32	Up to 16
Analog Beamforming (dynamic)	Not Supported	Supported
Digital Beamforming	Up to 8 Layers	Up to 12 Layers
Channel Coding	Data: Turbo Coding Control: Convolutional Coding	Data: LDPC Coding Control: Polar Coding
Subcarrier Spacing	15 kHz	15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz
Self-Contained Subframe	Not Supported	Can Be Implemented
Spectrum Occupancy	90% of Channel BW	Up to 98% of Channel BW

The NR modulation and waveforms have some commonalities with LTE but aim to have much higher spectral efficiency. NR supports QPSK, 16 QAM, and 256 QAM with the same constellation mapping as LTE. An OFDM-based waveform is supported. Both CP-OFDM- and DFT-S-OFDM-based waveforms are mandatory for user equipment (UE).

3GPP LTE Release 16 (2020)

The '5G' Phase 2 Network Architecture

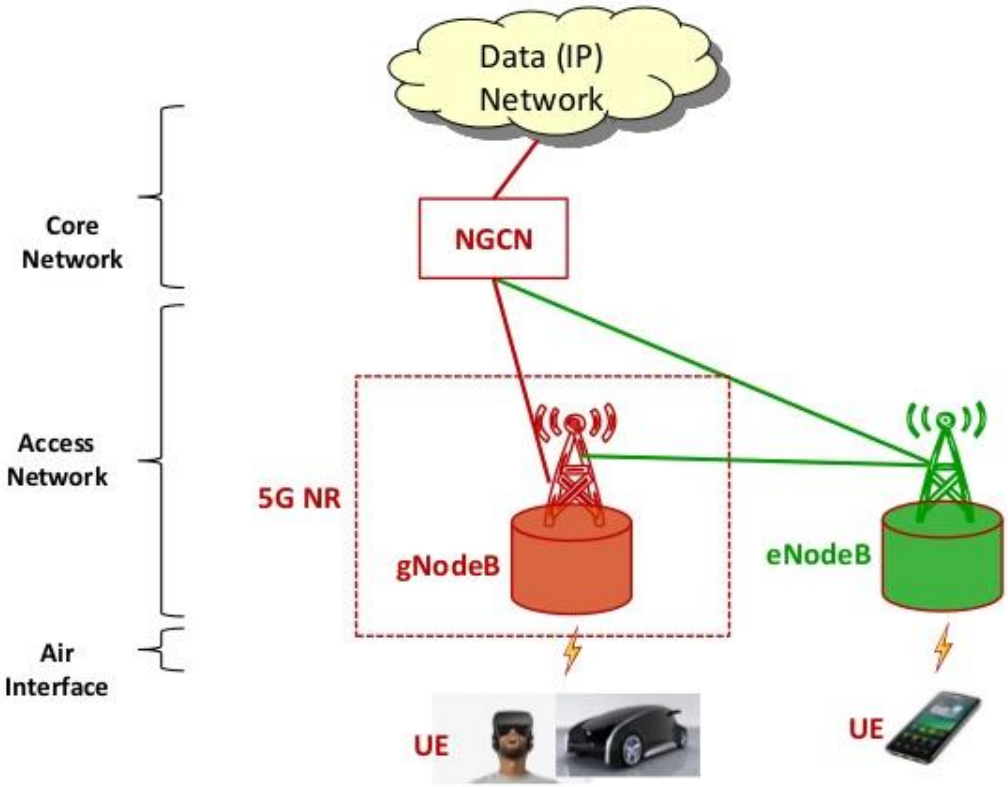
NGCN = Next Generation Core Network
gNodeB = next generation NodeB
NR = New Radio



3GPP LTE Release 17 (2021)

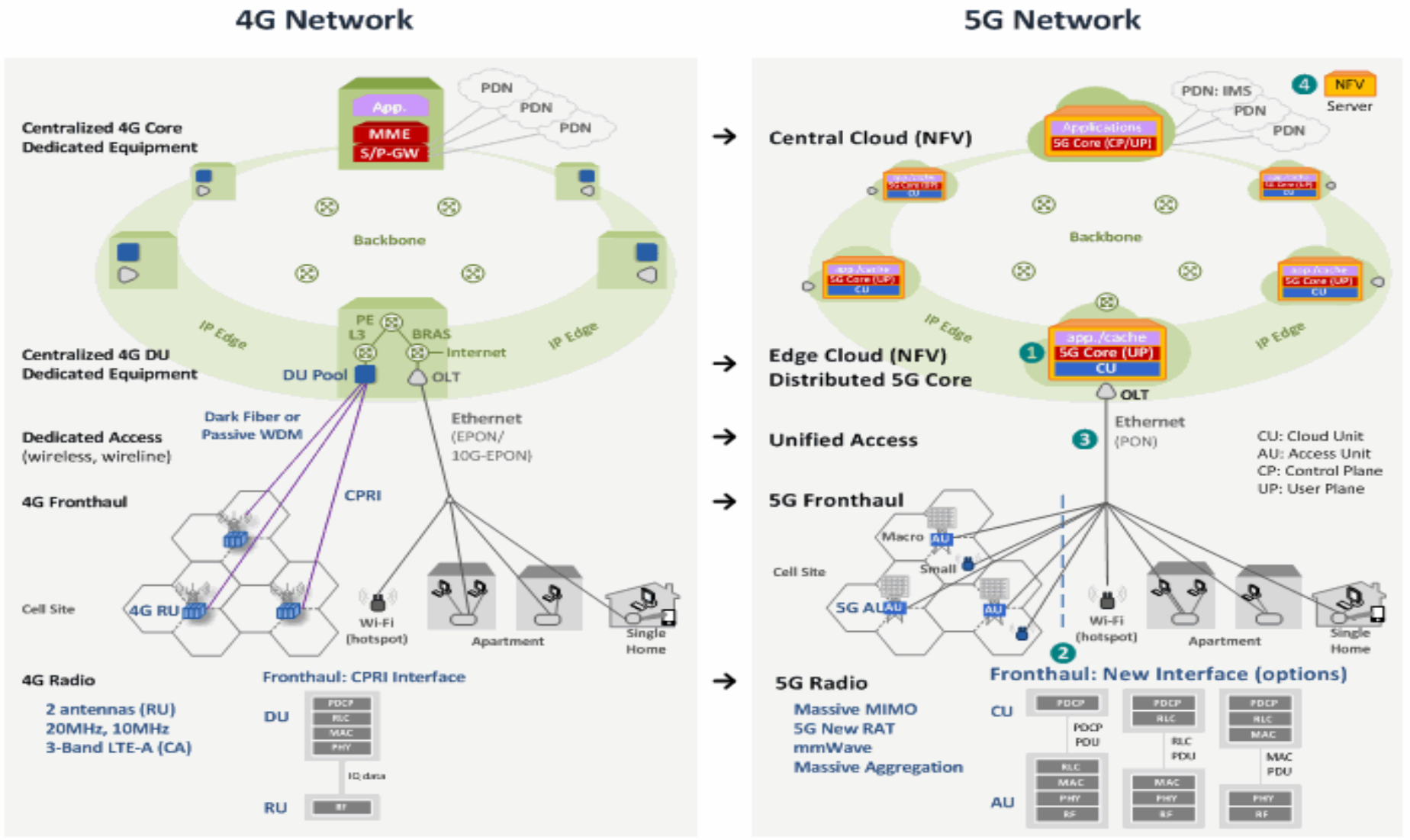
The '5G' Phase 3 Network Architecture

NGCN = Next Generation Core Network
gNodeB = next generation NodeB
NR = New Radio



5G
4G

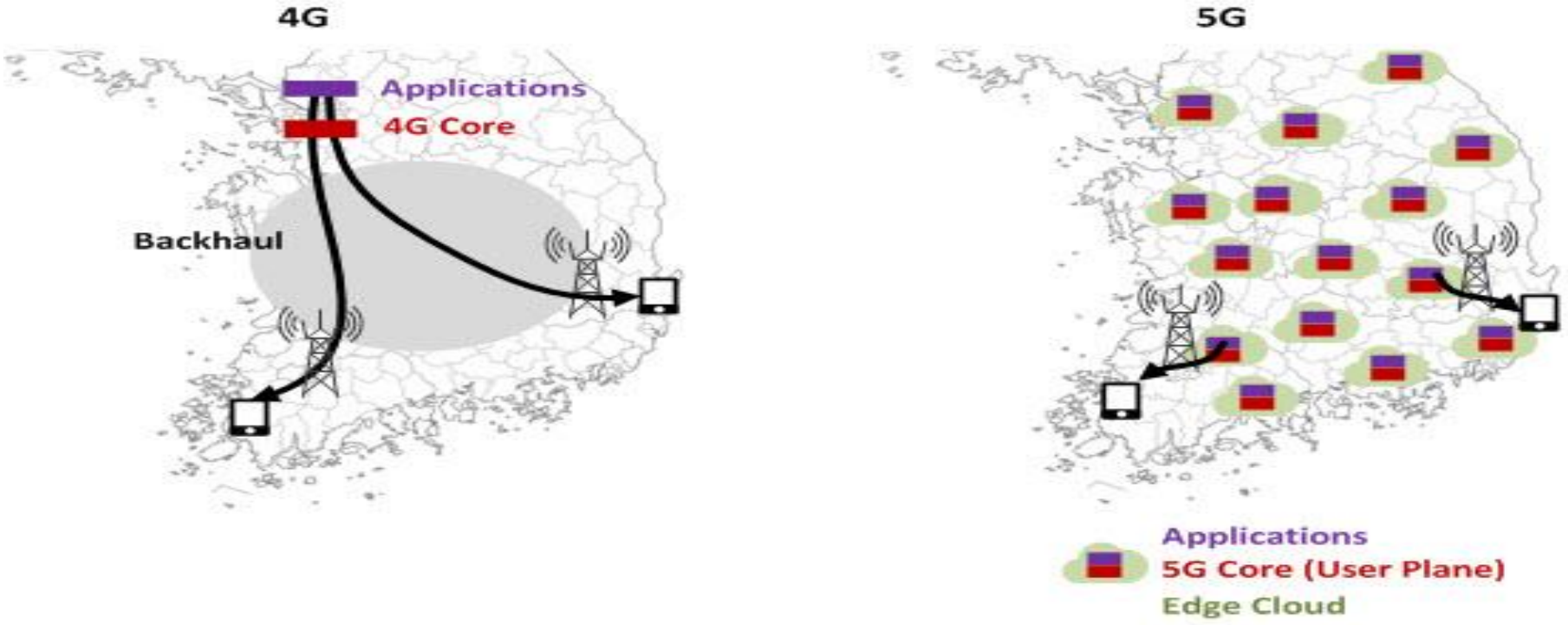
5G Network vs. 4G Network



source: www.netmanias.com

https://www.netmanias.com/en/?m=view&id=blog&no=14828

5G Core Close to Cell Sites



- **5G aimed to provide data rates up to 10/20 Gbps (eMBB use case)**
  - Once the core is distributed to cell sites, and a variety of associated application servers (e.g. video cache) are moved down along with it, backhaul traffic will significantly decrease.

- **5G network is supposed to be able to provide ultra-real time (URLLC) services** like real-time remote control, auto-driving vehicle, etc.
  - These low delays can also be achieved by moving core functions/units closest to users and placing ultra-real time service servers right where the core functions/units are located.

5G RAN

- Currently, in LTE C-RAN baseband signals, IQ data, are transmitted between **DU** and **RU** which are connected via dark fiber or passive WDM, and this requires a tremendous CPRI capacity - over 16 times more than delivered in the form of IP packets

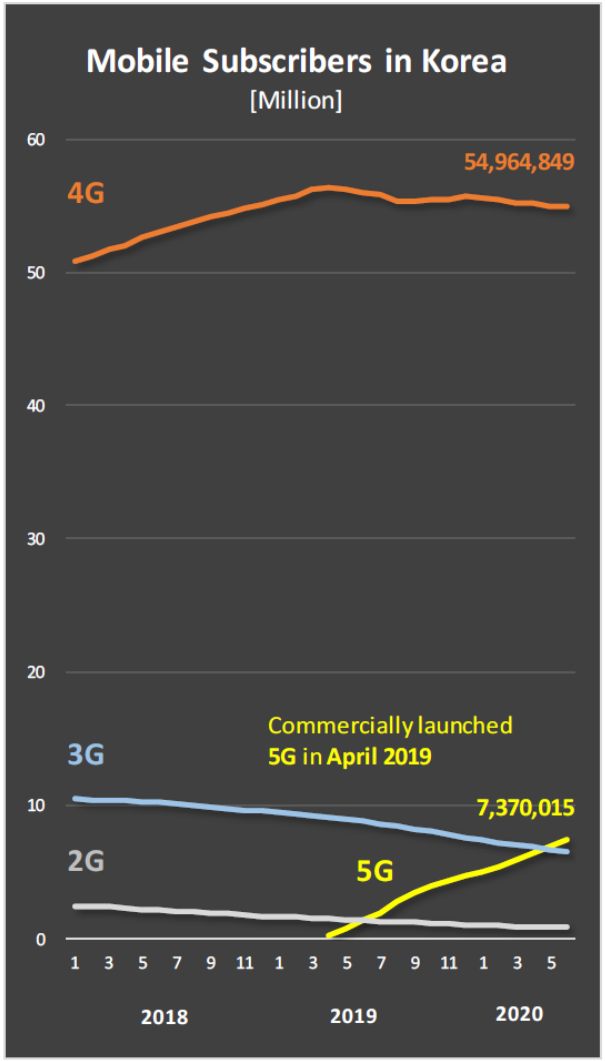
- With 5G, CPRI capacity of tens of Gbps will be required per RU

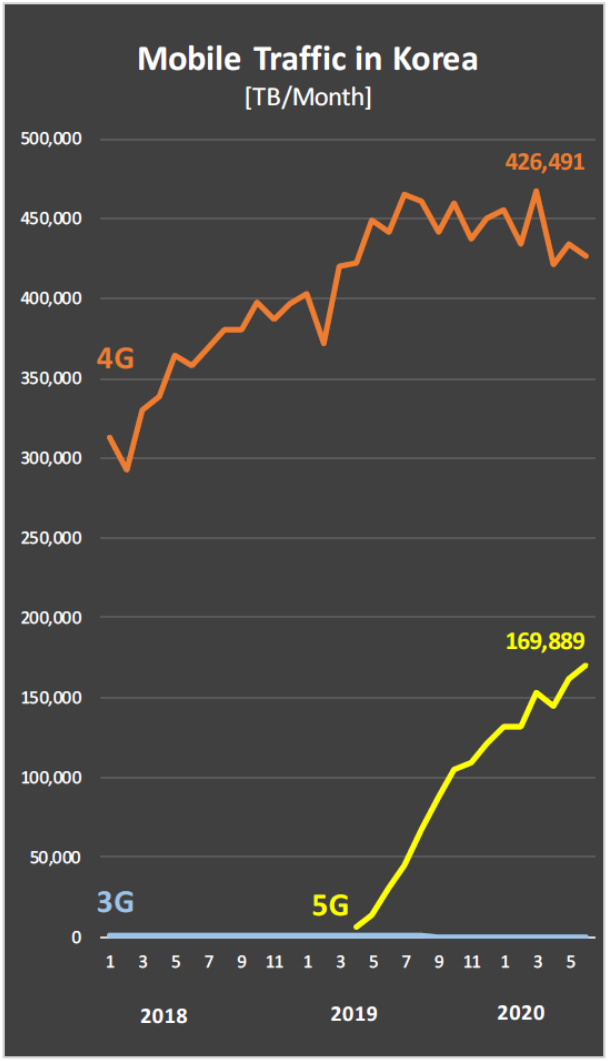
- Massive MIMO, mmWave, New RAT, etc. are used to be used in 5G

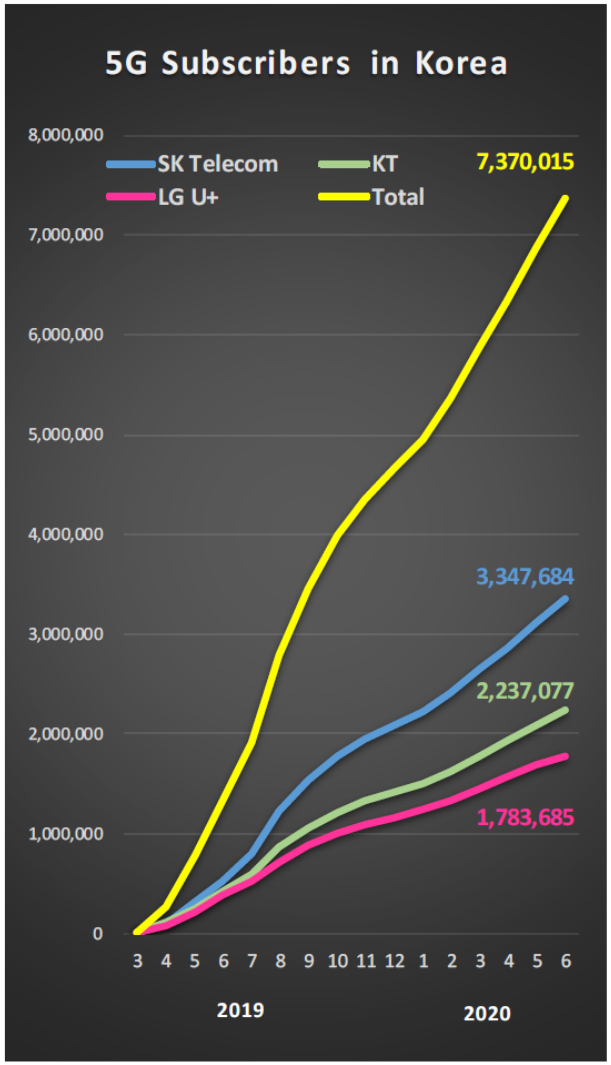
- To address surging costs of CPRI-based fronthaul to be caused because of drastically-increased ultra high capacity of 5G base station, solutions have been proposed such as:**CPRI (IQ data) compression, CPRI over Ethernet, Analog Radio over Fiber, Function split between DU and RU, etc**.

- With baseband functions moving down to cell sites, **Cloud Unit (CU)** and **Access Unit (AU)** are used instead of DU and RU. CU will be installed in edge clouds as virtualized software (commonly known as vRAN) while AU will be installed in cell sites as hardware.

Current 5G Use







Source: Ministry of Science and ICT