Wireless Communications Principles

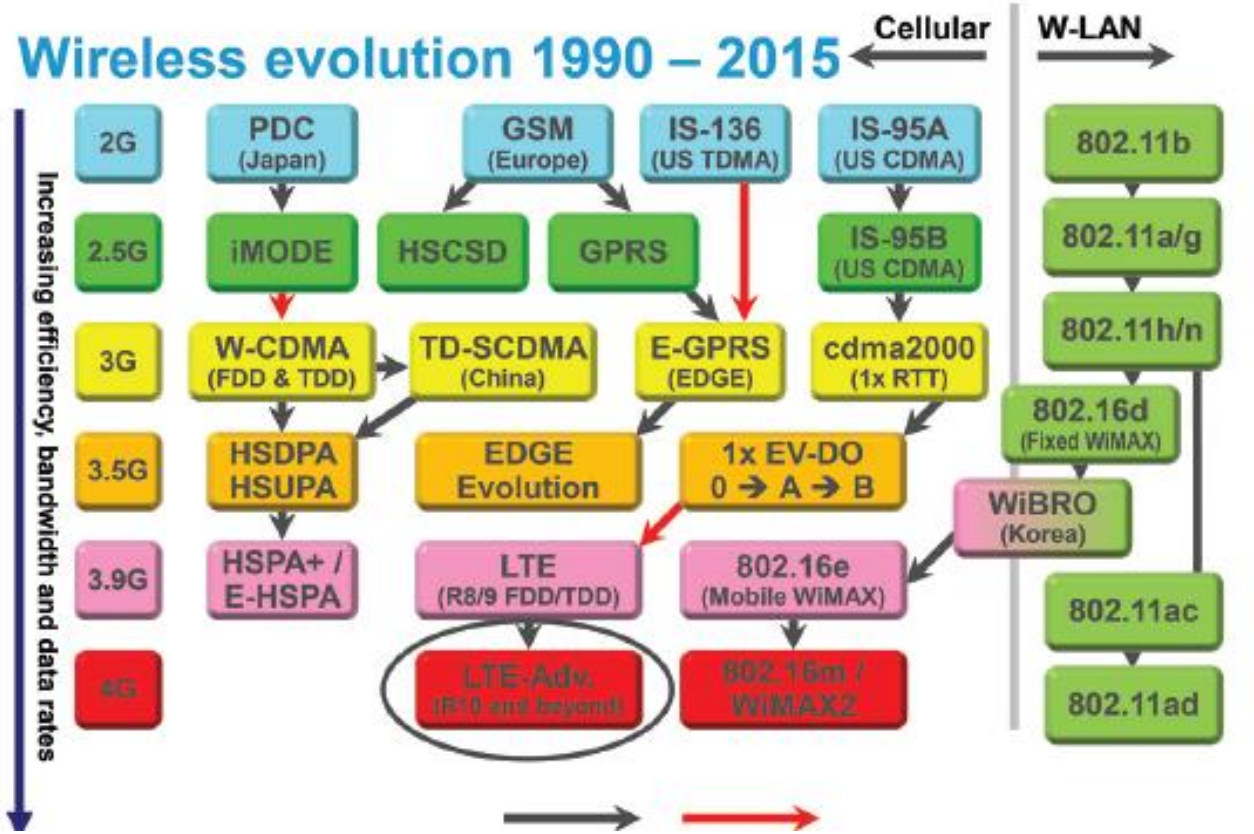
Lecture 6

Introduction of New Cellular Communication Technology

- **Introduction to 4G techniques**
- **Introduction to 5G techniques**

6.1 Evolution of wireless communication standards

- From 2G systems to 3G systems, and to 4G.
- What is 4G Technology? 4G is the fourth generation mobile communication technology standards.
- Only two 4G candidates have been actively developed : LTE-Advanced and IEEE 802.16m.



The evolution LTE and LTE-advanced from 3G systems

- Early 3G systems, of which there were five, did not immediately meet the ITU's peak data rate target of 2 Mbps in practical deployment
- LTE (often referred to as 3.9G) arrived with the publication of the Release 8 specification in 2008
- LTE-Advanced (referred to as 4G) was introduced in Release 10.
- Enhancements to LTE-Advanced were added in Release 11, whose core specifications were completed in September 2012, and in Release 12, on which work began in December 2012.

Comparison among wireless generations

Table 6.1. Comparisons among 1G, 2G, 2.5G,3G, 4G

1G	2G	2.5G	3G	4G
1st generation wireless network	2nd generation wireless network	2.5 generation wireless network	3rd generation wireless network	4th generation wireless network
1.Basic voice service 2.Analog-based protocols (AMPS)	1.Voice 2.Improved coverage and capacity 3.First digital standards (GSM,CDMA IS-95)	1. Voice 2. Higher data rate than 2G 3.Digital standards (GPRS,EDGE et al)	1.Voice with some data consideration (multimedia, text, internet) 2 .First mobile broadband (TD-SCDMA, UMTS WCDMA (3GPP), CDMA 2000(3GPP2))	1. Primarily for data 2.IP-based protocols (LTE) 3.True mobile broadband

The definitions of previous generations in Table 6.1

AMPS : Advanced Mobile Phone System. For example IS-136 can support 48.6kbps data rate.

GSM: Global Systems for Mobile.

GPRS: General Packet Radio Service. promises data rate from 56 kbps to 144kbps---continuous connection to the Internet.

UMTS: Universal Mobile Telecommunications System providing 384kbps rate. 3GPP UMTS (Universal Mobile Telecommunications System). UMTS WCDMA is a wideband CDMA (5MHz) standard based on the network fundamentals of GSM/EDGE,

3GPP: 3rd Generation Partnership Project . 3GPP and 3GPP2 are Worldwide standardization organizations established to gather global expertise, participated by almost all the big companies.

TD-SCDMA (Time-division Synchronous CDMA) : a standard proposed by CATT (China Academy of Telecommunications Technology) and Siemens Corporation. Support up to 384kbps of packet data.

Some System performance comparison between 3G and 4G

Network Architecture: 3G Wide Area Cell Based - 4G Integration of Wireless LAN and Wide area.

Services and Applications: 3G CDMA 2000, UMTS, EDGE etc - 4G Wimax2 and LTE-Advanced

Peak Download Rate: 3G 100 Mbp - 4G 1 Gbps

Peak Upload Rate: 3G 5 Mbps - 4G 500 Mbps

- Both 2G and 3G networks were designed primarily for voice communications rather than data.
- 4G is designed especially for data transmission rather than voice.
- So 4G offers faster access to data using mobile phones.

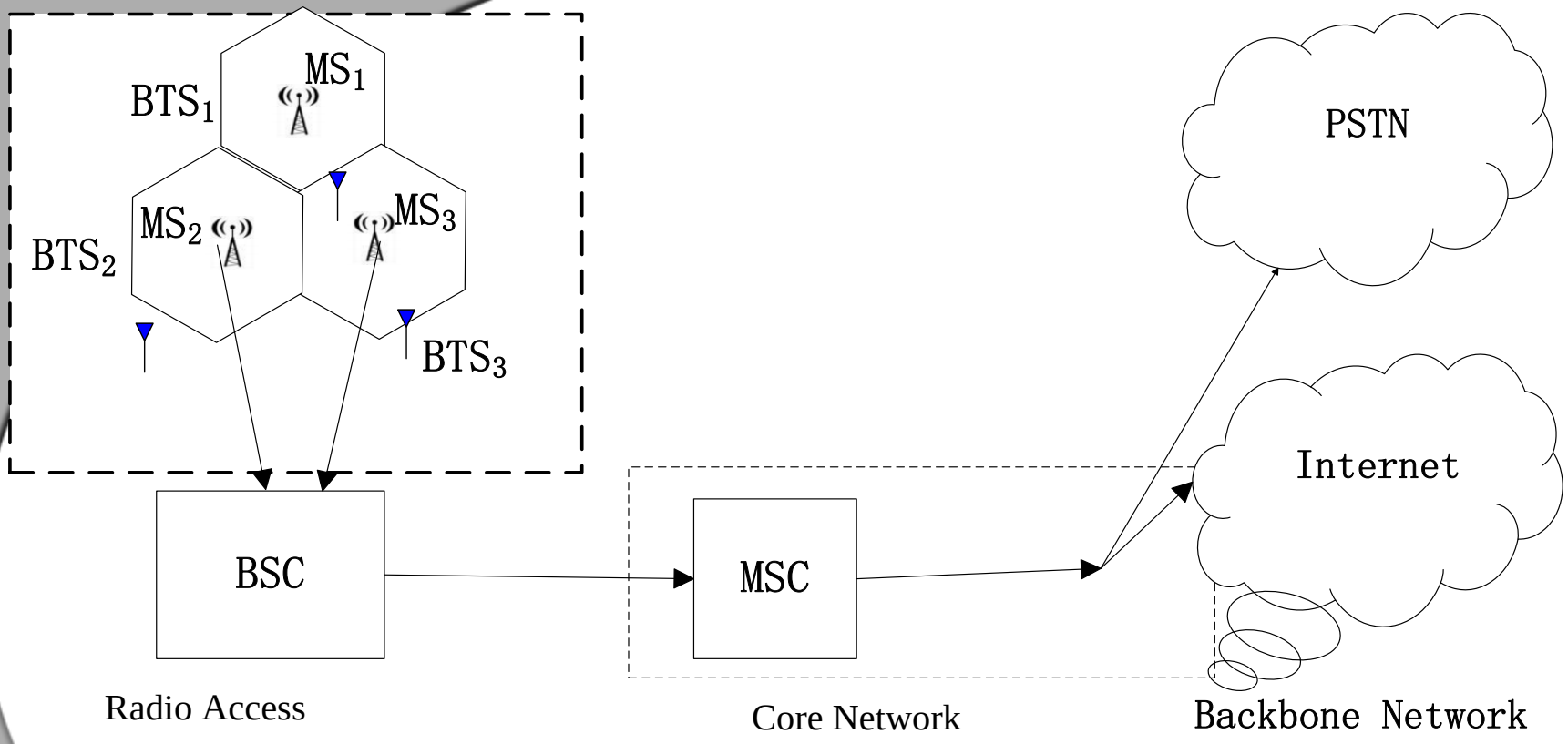
6.2 The GSM and the LTE Network Architectures

6.2.1 The GSM network architecture

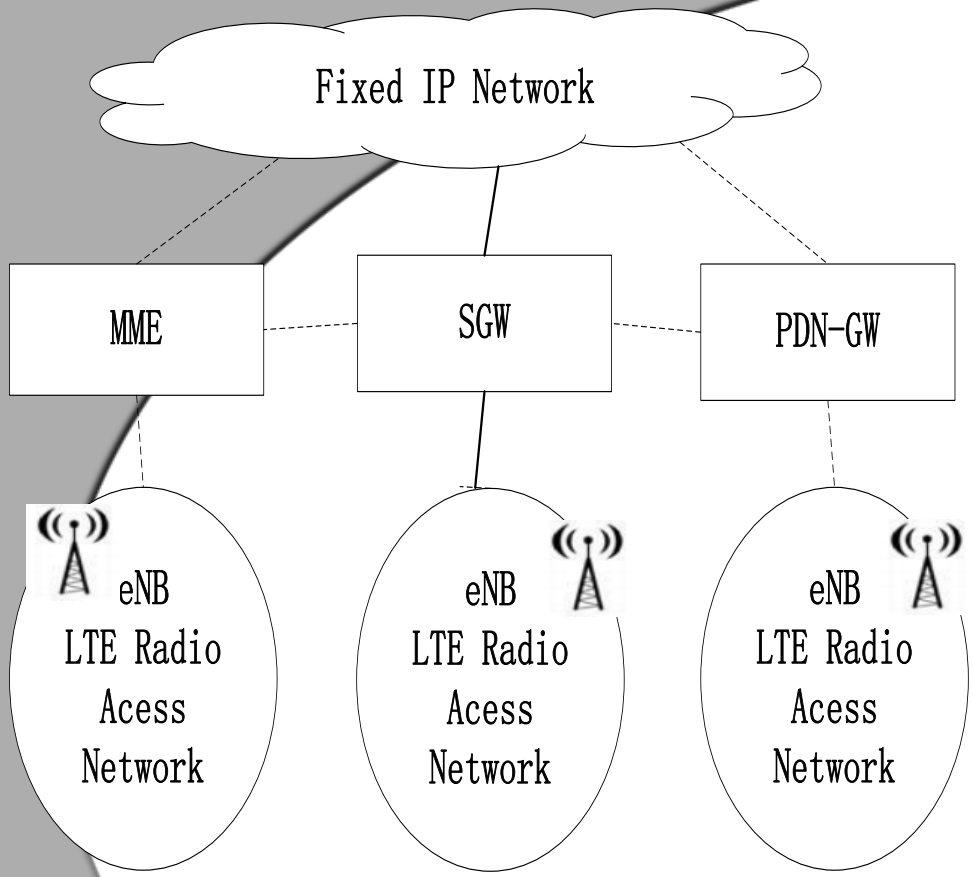
GSM network architecture can be grouped into 4 main areas:

- Mobile station (MS)
- Base-station subsystem (BSS). It consists of two elements: Base Transceiver Station (BTS) and Base Station Controller (BSC).
- Network and Switching Subsystem (NSS). The major elements within the core network include: Mobile Switching services Centre (MSC), Home Location Register (HLR)and Visitor Location Register (VLR) et al.
- Operation and Support Subsystem (OSS). It is used to control and monitor the overall GSM network and it is also used to control the traffic load of the BSS.

Figure 6.2 shows the GSM network architecture. Mobile => base station => BSC or RNC (Radio Network Controller) => MSC



6.2.2 The LTE network architecture



4G is the fourth generation of mobile phone mobile communication technology standards.

Figure 6.3 shows the basic network architecture of the LTE systems, which comprises of two basic networks: radio access network and core network.

★ **Three main components :**

Mobility Management Entity (MME)

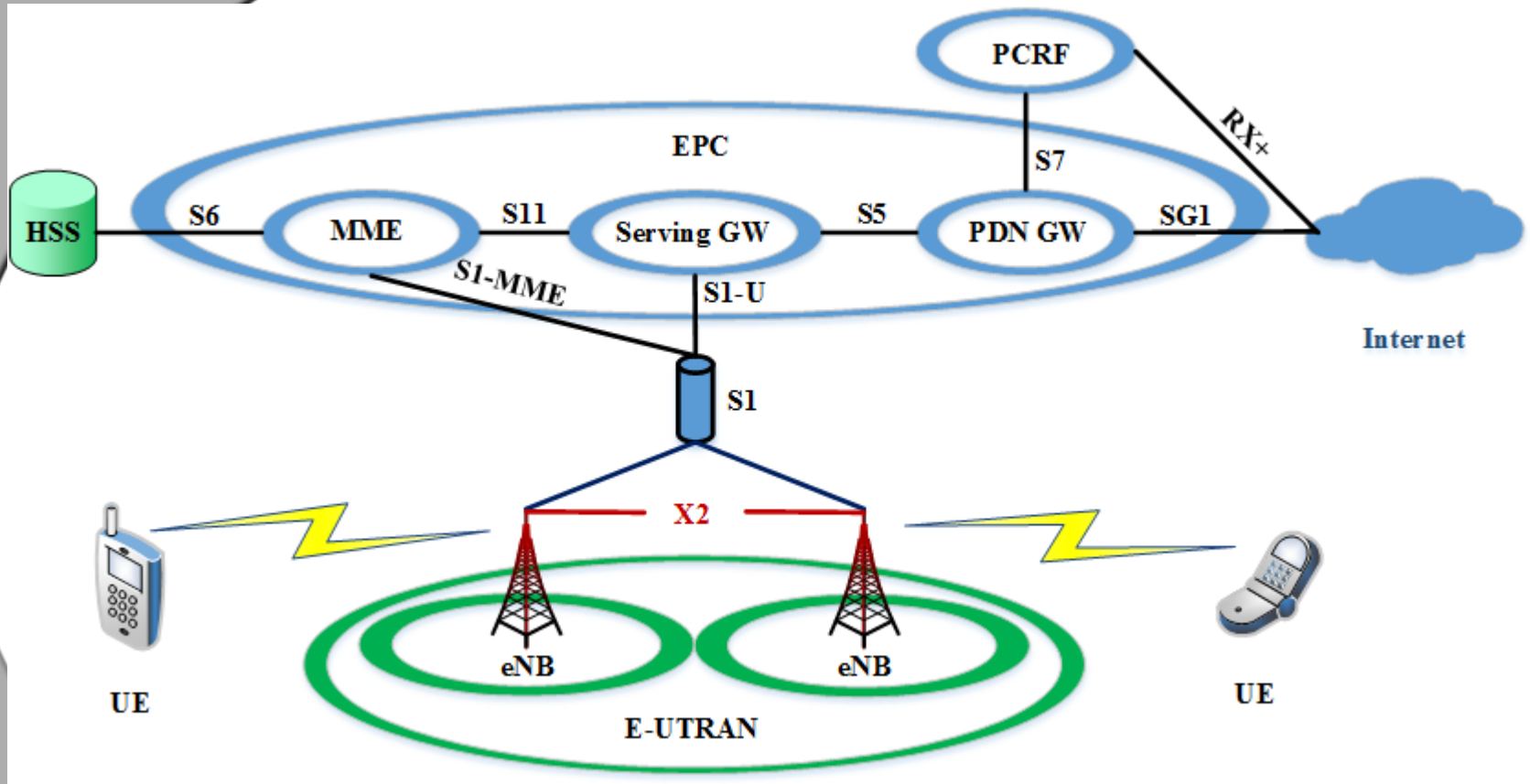
Serving Gateway (SGW)

Packet Data Network Gateway (PDN-GW).

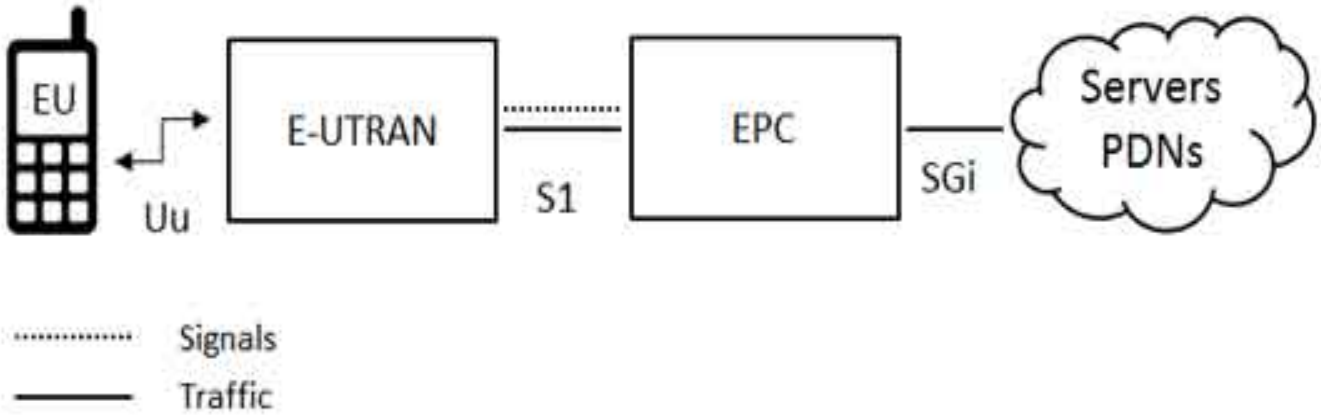
Radio Access Network and Core Network

- **Radio Access Network：** Comprises of Evolved nodeB (**eNB**) radio stations which connects User Equipments (**UE**) to core network through air interface.
- **Core Network：** A parallel 3GPP project called System Architecture Evolution (SAE) defines an all-IP, packet-only core network known as the Evolved Packet Core (**EPC**).
- The combination of the EPC and the evolved RAN (E-UTRA plus **E-UTRAN**) is the evolved packet system (**EPS**).

LTE network has a simplified architecture with a smaller number of network components.



The high-level network architecture of LTE is comprised of following three main components



a) The User Equipment (UE).

b) The Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

c) The Evolved Packet Core (EPC)

6.3 Summary of Release 8 LTE Features

- The baseline LTE radio access network (RAN) and the evolved packet core (EPC) network defined in 3GPP Release 8. According to a June 2014 Global Suppliers Association (www.gsacom.com) report, LTE has been launched successfully in 300 commercial networks in 107 countries.
- China's Ministry of Industry and Information Technology (MIIT) on Dec. 4th, 2013 announced the release of TD-LTE (Time Division-Long Term Evolution) licenses to China Mobile, China Unicom and China Telecom.

6.3.1 The main attributes that differentiate LTE from previous generations

- Single-channel peak data rates of up to 300 Mbps in the downlink and 75 Mbps in the uplink.
- Improved spectral efficiency over legacy systems, particularly for the downlink.
- Full integration of frequency division duplex (FDD) and time division duplex (TDD) access modes.
- Packet-based EPC network to eliminate cost and complexity associated with legacy circuit-switched networks.

6.3.2 Some key technologies introduced in Release 8

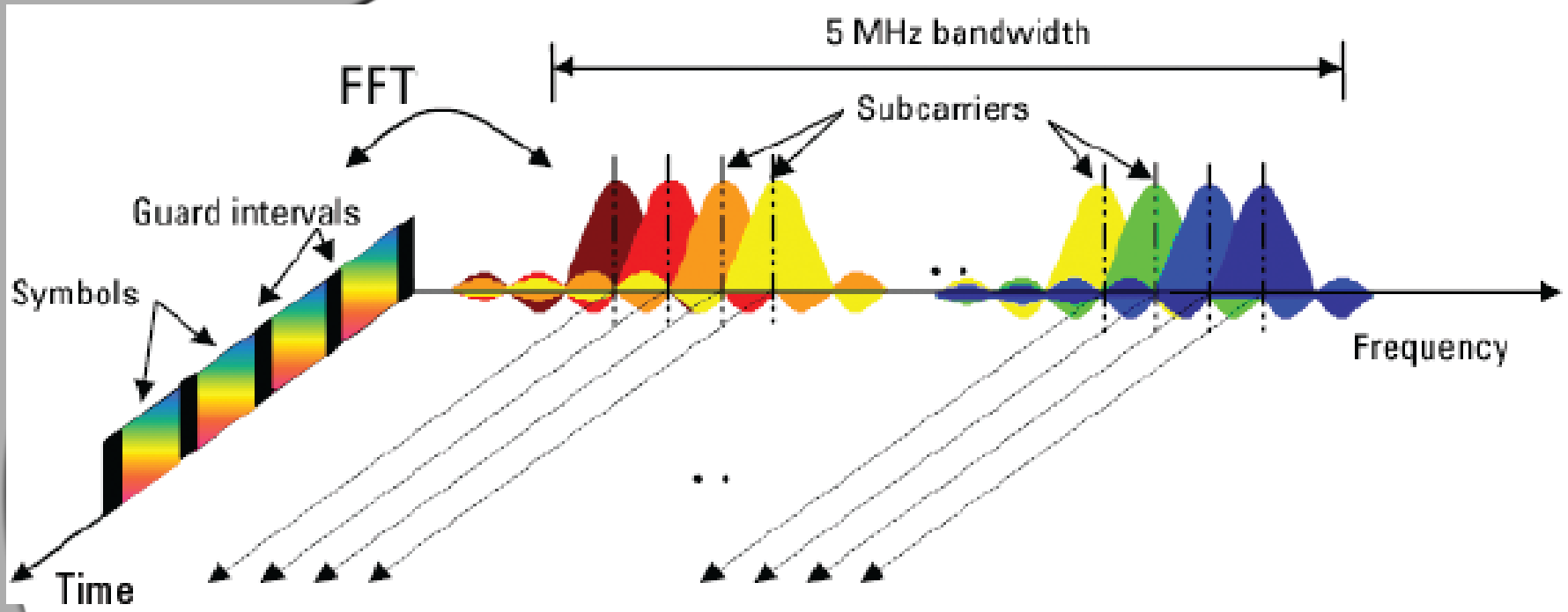
- Adoption of Orthogonal Frequency Division Multiple Access (**OFDMA**) and Single Carrier Frequency Division Multiple Access (**SC-FDMA**) for the downlink and uplink air interfaces to enable narrowband scheduling and efficient support of spatial multiplexing.
- Support for six channel bandwidths from 1.4 MHz to 20 MHz to enable high data rates and also efficient spectrum re-farming for narrowband legacy systems.
- Baseline support for Multiple Input Multiple Output (**MIMO**) spatial multiplexing of up to four layers on the downlink.
- Faster physical layer control mechanisms leading to lower latency.

6.3.3 About MIMO and OFDMA in LTE

- Multiple input multiple output (MIMO): To attain ultra high spectral efficiency by means of spatial processing including multi-antenna and multi-user MIMO.
- Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink, and Single-carrier Frequency Division Multiple Access (SC-FDMA) for the uplink: To exploit the frequency selective channel property without complex equalization.

1) Multiple access technology in the downlink : OFDM and OFDMA

Figure 6.4. OFDM signal represented in frequency and time taken from [25.892]



OFDMA is a variant of Orthogonal Frequency Division Multiplexing (OFDM) scheme

1) Multiple access technology in the downlink : OFDM and OFDMA

OFDM offers a number of distinct advantage

taken from [Keysight Technologies, 3GPP Long Term Evolution]:

— OFDM can easily be scaled up to wide channels that are more resistant to fading.

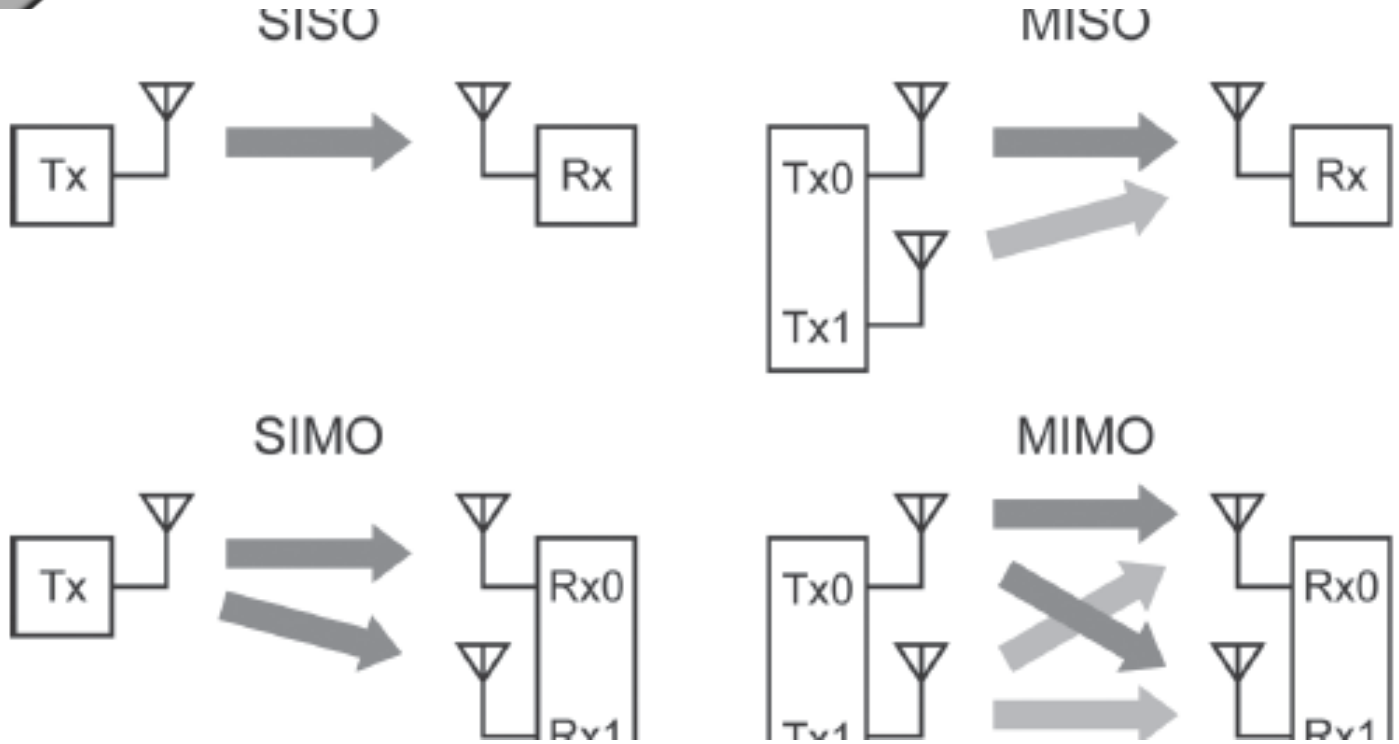
— OFDM channel equalizers are much simpler to implement than are CDMA equalizers.

— OFDM can be made completely resistant to multi-path delay spread.

— OFDM is better suited to MIMO.

2) Overview of multiple antenna techniques

Central to LTE is the concept of multiple antenna techniques, which are used to increase coverage and physical layer capacity. Four ways to make use of the radio channel are : **SISO, MISO, SIMO and MIMO.**



6.4 Summary to Release 10 LTE-Advanced and Release 11

6.4.1 Release 10 LTE enhancements

LTE-Advanced (4G) work item

— Support of wider bandwidths

— Uplink transmission scheme

— Downlink transmission scheme

— Coordinated multi point transmission and reception (CoMP)

— Relaying

6.4.2 Release 11 features for LTE

- Network-based positioning support in LTE
- Service continuity improvements for multimedia broadcast and multicast service (MBMS), for LTE
- Further enhanced non Carrier aggregation (CA)-based Enhanced Inter-cell Interference Coordination (ICIC) for LTE
- LTE RAN enhancements for diverse data applications
- Relays for LTE
- Signaling and procedure for interference avoidance for in-device coexistence
- Coordinated multi-point transmission (CoMP)

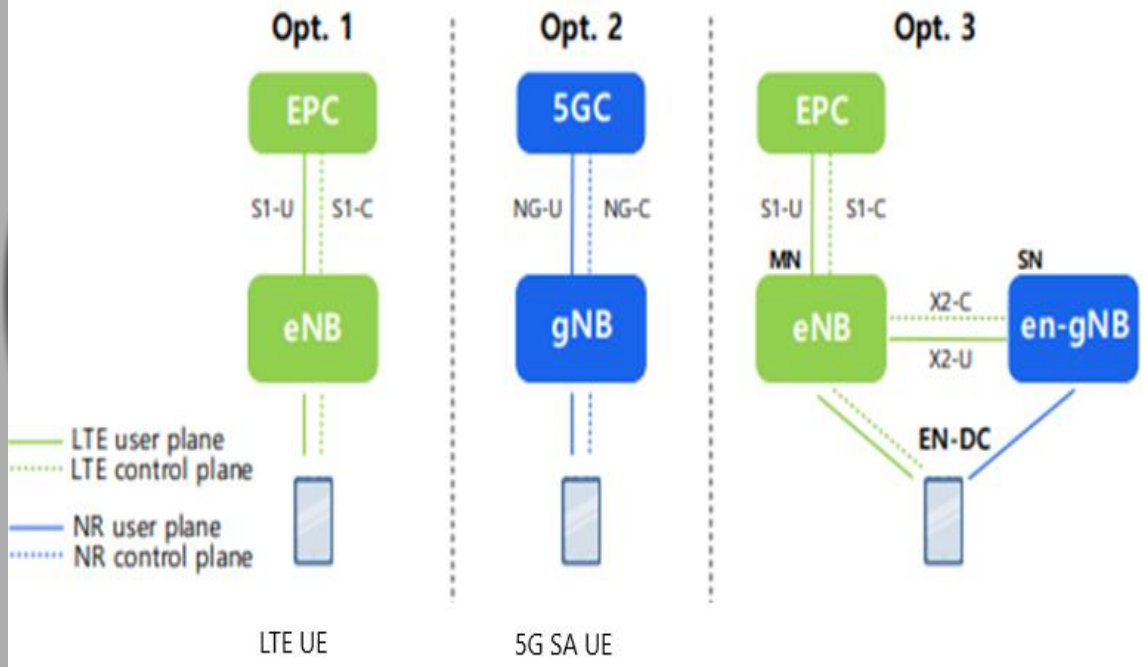
Introduction to 5G Techniques

1. **What is 5G and 5G vs. 6G**
2. **5G key capabilities**
3. **Three applications of 5G**

1. What is 5G and 5G vs. 6G

- ✓ 5G is the English abbreviation of “The fifth generation mobile communication technology”
- ✓ A combination and further development of present cellular technologies such as 2G, 3G and 4G
- ✓ 5G innovation is divided in two categories, that are air interface and network architecture

- ✓ 5G overall system architecture consists of RAN (Radio Access Network), CN (Core Network) comprising EPC (4G Evolved Packet Core) and 5GC (5G CN)
- ✓ In Option 2' SA (Standalone) deployment, the gNB is connected to the 5GC, where 5GC means 5G Core Network



Term	Definition
5GC	5G Core Network
gNB	E-UTRAN NodeB
UE	User equipment
NG-U	user plane protocols of NG interfaces
NG-C	user control plane protocols of NG interfaces

What is new technologies in 5G NR?

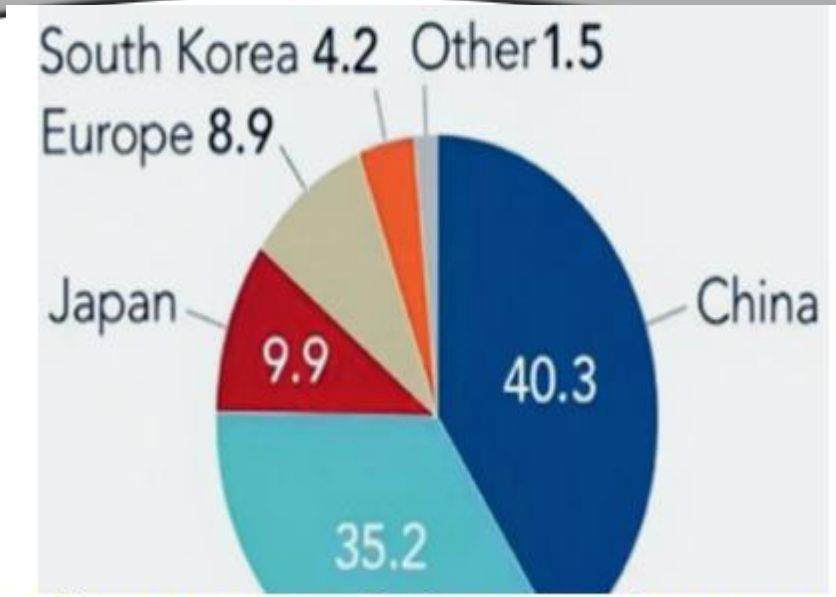
The inclusion of relatively new technologies in 5G NR (New Radio) including

- ✓ the use of new spectrum blocks in higher frequency ranges
- ✓ extensive installation of outdoor small cells
- ✓ a non-terrestrial satellite communication infrastructure
- ✓ massive MIMO (mMIMO) base stations along with the densification of macro-cells and the wireless backhaul network

The present and ongoing 5G standards

5G standards	Data	Enhancements and additions
Release 15	2018	coordinated multi-point (CoMP) for vital reliability and latency improving
Release 16	2020	multi-beam management in multi-user MIMO (MU-MIMO) for reliability enhancement
Release 17	2022	uRLLC for industrial IoT
Release 18	2024	AI&ML Energy Savings NTN（Non-Terrestrial Networks）

5G commercialization and 6G R&D in parallel

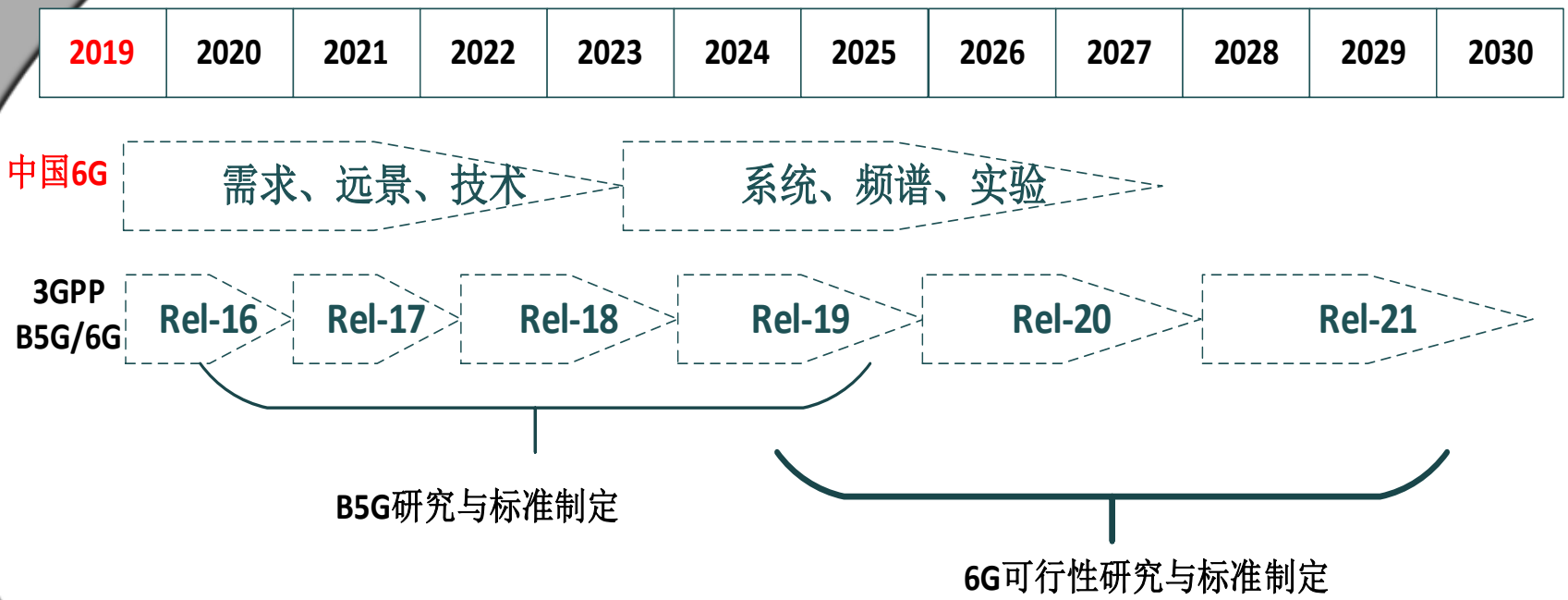


China's 6G patent applications account for 40.3 percent of the world total until Sep. 2021

The 6G infrastructure is expected to be built upon 5G with some critical additions that diverge from the contemporary cellular technologies (Source:AdobeStock)

5G and 6G roadmap

This illustrates the two roadmaps from China‘s 6G Promotion Group and 3GPP’s 6G Group. The usage period of 5G is 2020-2030, and 2030-2040 for 6G



5G vs. 6G

- ✓ The term 6G refers to sixth generation of wireless technology
- ✓ These are difference between 5G and 6G, i.e., Frequency Bands, Data rate, Latency, architecture, Application types etc.

Features	5G	6G
Frequency Bands	Sub 6 GHz, mmwave for fixed access	Sub 6 GHz; mmwave for mobile access exploration of THz bands (above 140 GHz); Non-RF bands (e.g. optical, VLC) etc.
Data rate	1 Gbps to 20 Gbps (Downlink Data Rate - 20 Gbps, Uplink Data Rate - 10 Gbps)	1 Tbps
Latency (End to End Delay)	5 ms (Radio : 1 msec)	< 1 ms (Radio : 0.1 msec)
Architecture	Dense sub 6 GHz smaller BSs with umbrella macro BSs; Mmwave small cells of about 100 meters (for fixed access)	Cell free smart surfaces at high frequencies (mmwave tiny cells are used for fixed and mobile access); Temporary hotspots served by drone mounted BSs or tethered Balloons etc.
Application types	eMBB , URLLC ,mMTC	MBRLLC , mURLLC etc.

China is leading global 5G innovation

- ✓ China is one of the pioneers in 5G R&D and has built more than one million 5G base stations, which is over 70% of the world market by the end of 2021
- ✓ China, which has just opened a 5G mobile network (Oct.31, 2019), begins to develop 6G (Nov. 7, 2019), and look forward to the arrival of 6G in 2030

2. 5G key capabilities

- ✓ The 5G concept from China IMT-2020 (5G) group's White Paper
- ✓ Comparison between 5G and 4G is also presented in this flag

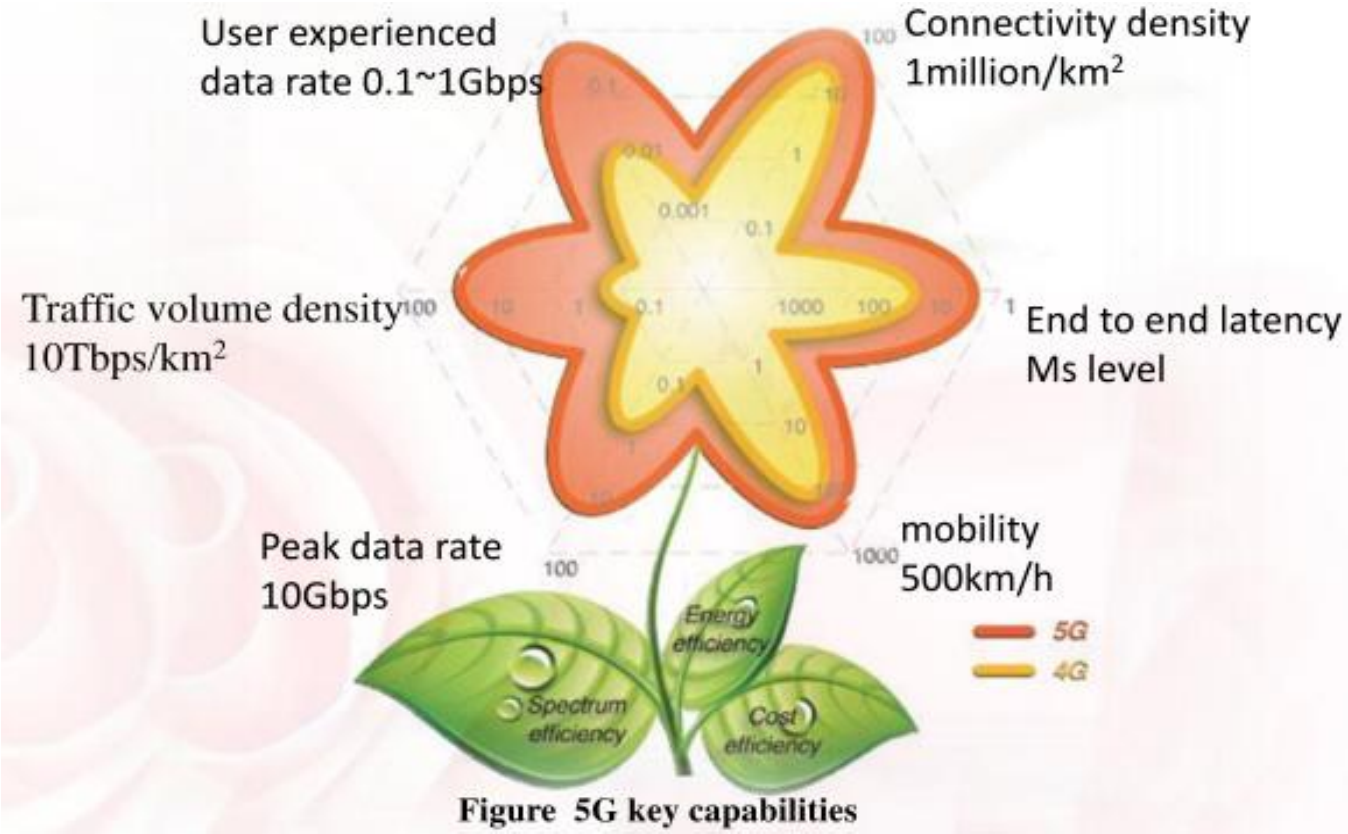


Figure 5G key capabilities

5G key capabilities(continue)

The flag indicators " user experience Gbps data rate " is a set of key technologies including :

- ✓ large-scale antenna array
- ✓ ultra-dense networking
- ✓ new multi-site，full-spectrum access and new network architectures.

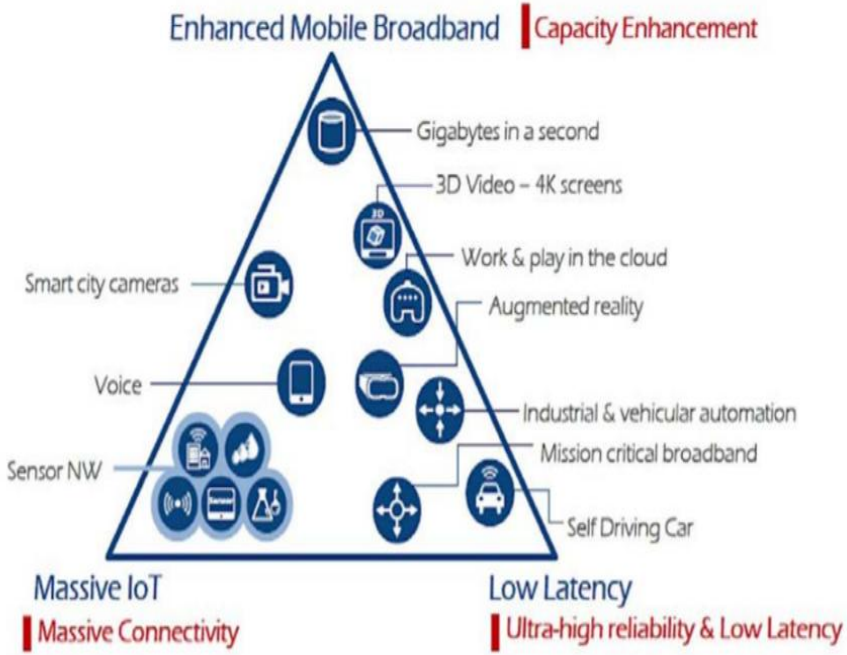
5G key capabilities(continue)

The advantages of 5G over 4G are

- ✓ user experience
- ✓ speed
- ✓ density of connections
- ✓ end to end delay
- ✓ the peak rate
- ✓ mobility

3. Three applications of 5G

The 5G vision has been mainly focused on serving three applications: eMBB, uRLLC, and mMTC



Abbreviations

Table 2. Abbreviations of partial 5G services and scenarios

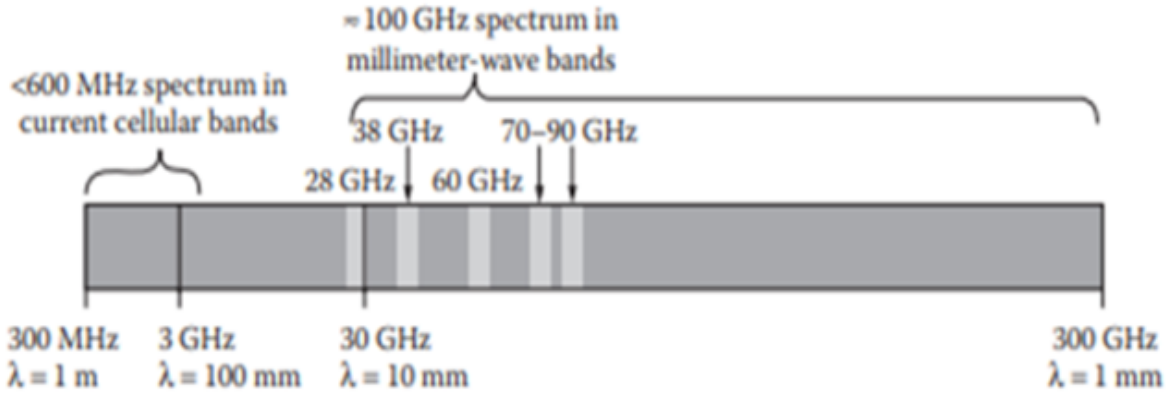
eMBB (enhanced mobile broadband)	a peak data rate of 10-20 Gbps, a spectral efficiency of 10 bps/Hz, **capacity enhancements**
mMTC (massive machine type communications)	10 year battery life for mMTC, **massive connectivity**
URLLC (Ultra reliable and low latency)	1 ms radio latency and hand-off switch time lower than 10 ms, **ultra reliable & low latency**
VR/AR(Virtual reality/ Augmented reality)	虚拟现实/增强现实
Industrial Internet	工业互联网
IoV（Internet of Vehicles）	车联网
Incredible 4K (Ultra HD) Videos	在线4K视频

Description of three applications of 5G

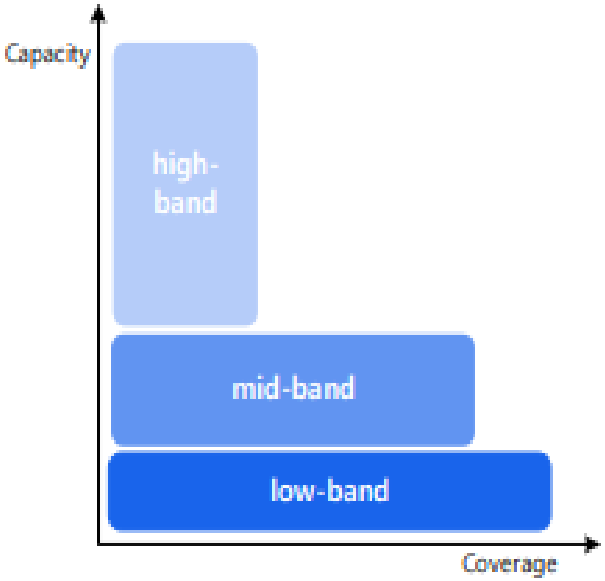
- ✓ eMBB–Goal : Provide extreme high data-rate; service scenario : VR/AR
- ✓ mMTC–Goal : provide wide area coverage and deep penetration for hundreds of device per square of coverage; service scenario : smart factory, emergency
- ✓ uRLLC–Goal : millisecond levels latency requirement and ultra reliability; service scenario : Internet of Vehicles

Millimeter waveform bands for mobile access networks

- ✓ 5G Bands have been broadly divided into two categories: Sub-6 GHz (also called, FR1) and mmWave (FR2 also called,High band)
- ✓ The differences among 5G frequency bands in terms of capacity and coverage



Current spectrum	New spectrum
300MHz-6GHz	24GHz-52GHz
lower band,mid-band	mmWave (High band)



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Summary

5G will provide a multi-gigabit-per-second-based data rate for communication by using massive MIMO, mmWAV (millimeter wave), and new waveforms

There is a great demand for a radical increase in the capacity and bandwidth of different cellular and wireless networks

The end of this course

Thanks for taking this course !