An Overview of 5G Requirements

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Abstract Mobile Internet and IoT (Internet of Things) are the two main market drivers for 5G. There will be a massive number of use cases for Mobile Internet and IoT, such as augmented reality, virtual reality, remote computing, eHealth services, automotive driving and so on. All these use cases can be grouped into three usage scenarios, i.e., eMBB (Enhanced mobile broadband), mMTC (Massive machine type communications) and URLLC (Ultra-reliable and low latency communications). Eight key capabilities including peak data rate, latency and connection density, etc., are defined to meet the requirements of usage scenarios. Based on the usage scenarios, several typical deployment scenarios including indoor hotspots, dense urban, urban macro, rural and high-speed scenarios are specified, together with the detailed technical requirements for 5G. Both the deployment scenarios and technical requirements are essential guidance for 5G technical design.

1 Introduction

A mobile and connected society is emerging in the near future, which is characterized by a tremendous amount of growth in connectivity, traffic volume and a much broader range of use scenarios [1]. Some typical trends are summarized as follows:

- Explosive growth of data traffic: There will be an explosive growth in traffic. The global data traffic will increase by more than 200 times from 2010 to 2020, and about 20,000 times from 2010 to 2030;
- Great increase in connected devices: While smart phones are expected to remain as the main personal devices, the number of other kinds of devices, including wearable devices and MTC devices will continue to increase;
- Continuous emergence of new services: Different kinds of services, e.g., services from enterprises, from vertical industries and Internet companies, etc. will be exploited.

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The fifth-generation (5G) mobile communications system will emerge to meet new and unprecedented demands beyond the capability of previous generations of systems.

There are two phases of 5G requirements research by different organizations. Phase 1 focuses on 5G use cases and high-level key capabilities of 5G networks, and can be regarded as the 5G vision stage. In Phase 1, ITU has released the vision recommendation [2] and defined the key capabilities of 5G. 3GPP started the smarter program [4] and studied 5G use cases and requirements. NGMN completed a 5G whitepaper and defined a large number of 5G use cases and requirements [5]. IMT-2020 (5G) Promotion Group released the 5G vision and requirements whitepaper in May 2014 [1], which aims to contribute to the ITU-R work in Phase 1. Phase 2 focuses on 5G deployment scenarios and detailed technical requirements. There are two important reports in Phase 2. One is the IMT-2020 technical performance requirements from ITU-R which will be completed by February 2017 [3], while the other is the scenarios and requirements technical report from 3GPP which will be completed in March 2017 [6]. NGMN has started the relevant work at the beginning of 2015 and drafted several liaisons to 3GPP and ITU by March 2016 [7, 8]. IMT-2020 (5G) PG plans to complete the evaluation scenarios and the KPI report in the first half of 2016, and will have an impact on the work of ITU and 3GPP in Phase 2 (Fig. 1).

The rest of this chapter is organized as follows. The outcomes of Phase 1, i.e., 5G use cases and high-level key capabilities are introduced in Sects. 2 and 3, respectively. The latest status of Phase 2 including deployment scenarios

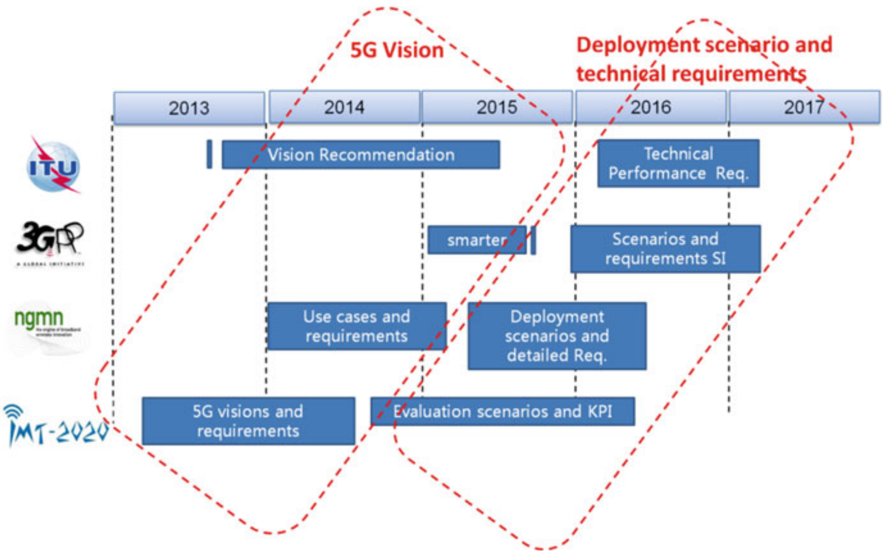

Fig. 1 Overview of 5G requirements research by different organizations

and detailed technical requirements are presented in Sects. 4 and 5, respectively. Section 6 presents the operational requirements, while Sect. 7 draws concluding remarks.

2 Use Cases and Challenges

It is foreseen that there will be a huge number of use cases in the upcoming 5G era. In [1], an overall vision for 5G life is illustrated in Fig. 2. 5G will penetrate into every single element of our future society and create an all-dimensional, user-centered information ecosystem. 5G will break the limitation of time and space to enable an immersive and interactive user experience. 5G will also shorten the distance between human and things, and implement a seamless integration to achieve easy and smart interconnection between people and all things. 5G will enable us to realize the vision—“Information is a finger away, and everything will be kept in touch”.

There are a great many use cases proposed by different organizations [1, 9–11]. Mobile Internet and the Internet of Things (IoT) are the two main market drivers in the future development of mobile communications [1], and they will trigger a large range of use cases.

Fig. 2 Overall vision of 5G

2.1 Use Cases of Mobile Internet

Mobile Internet is disrupting the traditional business model of mobile communications, enabling unprecedented user experiences and making a profound impact on every aspect of people's work and life. Looking ahead to 2020 and beyond, mobile Internet will promote the continued evolution of the way human interacting information, and provide users with ultimate experience through more immersive services including but not limited to:

- Video services, such as immersive Ultra High Definition (UHD) and three-dimensional (3D) video
- Augmented reality
- Virtual reality
- Video/photo sharing in stadium/open air gathering
- Online gaming applications
- Mobile cloud/desktop cloud
- Tactile Internet
- Remote computing
- 3D connectivity: aircraft
- 3D connectivity: drones
- Collaborative robots
- Broadcast-like services, like local, regional and national news and information
- Smart office

The future development of Mobile Internet will trigger the growth of mobile traffic by a magnitude of thousands in the future, and promote a new wave of upgrades and a revolution in mobile communications technologies and the telecommunications industry as a whole. Looking ahead to 2020 and beyond, there will be an explosive growth in mobile data traffic. It is estimated by IMT-2020 (5G) Promotion Group that the global mobile data traffic will grow by more than 200 times from 2010 to 2020, and by nearly 20,000 times from 2010 to 2030. In China, the growth rate is projected to be even higher, with mobile data traffic expected to grow by more than 300 times from 2010 to 2020 and by more than 40,000 times from 2010 to 2030. For developed cities and hotspots in China, the growth of mobile data traffic will exceed the average projected. For example, from 2010 to 2020 in Shanghai, the mobile data traffic is projected to grow by 600 times. In Beijing and during this same period, it is estimated that hotspot traffic may grow by up to 1000 times. The above estimation is shown in Fig. 3.

There is some traffic anticipation work by ITU-R and the results are detailed in Report ITU-R M.[IMT.2020BEYOND TRAFFIC] [12]. This report contains global IMT traffic estimates beyond 2020 from several sources. These estimates anticipate that global IMT traffic will grow by 10–100 times from 2020 to 2030. The main drivers behind the anticipated traffic growth include increased video usage, device proliferation and application uptake. These are expected to evolve over time, and this evolution will differ between countries due to social and economic differences.

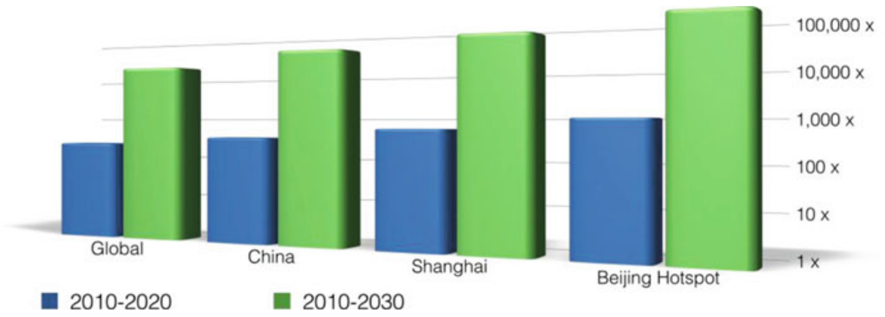

Fig. 3 2010–2030 growth of mobile data traffic

Traffic asymmetry aspects for this period are also presented by ITU-R. It is observed that the current average traffic asymmetry ratio of mobile broadband is in favor of the downlink, and this is expected to increase due to a growing demand for audio-visual content.

Mobile Internet is aiming at people-oriented communications with a focus on the user experience. Towards 2020 and beyond, the increasing popularity of ultra-high definition (UHD), 3D and video immersion will significantly drive up the data rates. For example, with a hundredfold compression, the transmission of 8K (3D) video will require a transmission rate close to 1 Gbps. Services, such as augmented reality, desktop cloud, and online gaming will not only pose a challenge to uplink and downlink data transmission rates but also generate a stringent requirement for the so-called “imperceptible latency”. In the future, vast amounts of individuals and office data will be stored in the cloud. Such massive data activity will require transmission rates to be comparable to optical fiber communications, which will lead to enormous traffic challenges for mobile communications networks particularly in hotspot areas. Over-the-top (OTT) services, such as social networking, will be counted among leading applications going forward, and the associated frequently-occurring small packets will devour signaling resources. At the same time, consumers will continue to demand better experiences on mobile communications wherever they are. A consistent service experience is expected in all scenarios, including ultra-dense scenarios such as stadiums, open-air gatherings and concerts, and high-speed moving scenarios such as high-speed trains, vehicles and subways.

The total number of devices connected by global mobile communications networks will reach 100 billion in the future. By 2020, it is predicted that the number of mobile terminals around the world will surpass ten billion, of which China will contribute over two billion, as shown in Fig. 4.

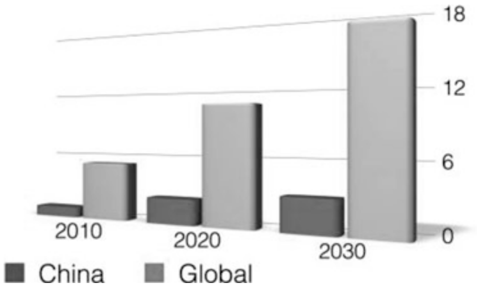

Fig. 4 2010–2030 growth of mobile device

2.2 Use Cases of Internet of Things

The IoT has extended the scope of mobile communications services from interpersonal communications to interconnection between tings (smart devices), and between people and things, allowing mobile communications technologies to penetrate into broader industries and fields. By 2020 and beyond, applications such as mobile health, Internet of Vehicles (IoV), smart home, industrial control, and environmental monitoring will drive the explosive growth of IoT applications, facilitating hundreds of billions of devices to connect to a network creating a true “Internet of Everything”. This will give rise to emerging industries of a unprecedented scale and instill infinite vitality to mobile communications. Meanwhile, the massive number of interconnected devices and the diversified IoT services will also pose new challenges to mobile communications. The potential IoT use cases include:

- Smart Grid and critical infrastructure monitoring
- Environmental monitoring
- Smart agriculture
- Smart metering
- eHealth services
- Remote object manipulation like remote surgery
- Automotive driving/Internet of vehicles
- Smart wearables, like sports and fitness
- Sensor networks
- Mobile video surveillance
- Smart cities
- Smart transportation
- Smart home
- Industrial control

IMT-2020 (5G) Promotion Group has estimated the number of IoT devices in future years as shown in Fig. 5. It is projected that the total number of devices connected by the global mobile communications network will reach 100 billion in the future. By 2020, the number of mobile terminals around the world will surpass ten billion, of which China will contribute over two billion. The number of IoT

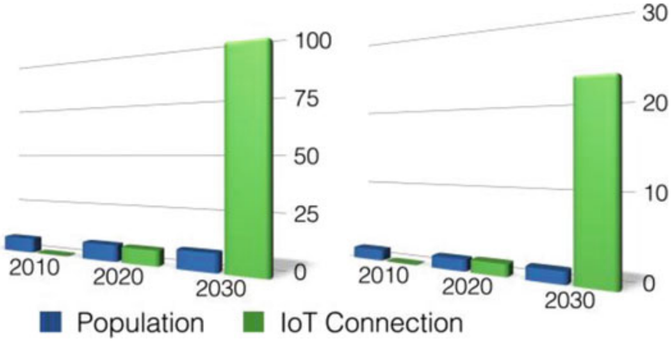

Fig. 5 2010–2030 growth of IoT connections

connections will also expand rapidly, reaching the size of global population of seven billion by 2020. By 2030, the number of global IoT connections will reach 100 billion. Among all types of terminals, smart phones will contribute most traffic, and IoT terminals will contribute less, even though the number of devices is much larger.

IoT is focused on communications between things and between things and people, involving not only individual users, but also a large number of various vertical industrial customers. IoT services types and relevant requirements of IoT services are very diverse. For services such as the smart home, smart grid, environmental monitoring, smart agriculture, and smart metering, the network will be required to support a massive amount of device connections and frequently-occurring small data packets. Services like video surveillance and mobile health will have strict requirements on transmission rates, while services such as IOV and industrial control will demand millisecond-level latency and nearly 100 % reliability. In addition, many IoT devices may be deployed in remote, or in areas where transmission losses can be a problem, such as indoor corners, basements and tunnels. Therefore, the coverage of mobile communications networks need to be further enhanced. In order to penetrate into more IoT services, 5G should be more flexible and more scalable, to support massive device connections and meet diverse user requirements.

Users expect better and yet more cost-effective services and experiences with mobile Internet and IoT. In addition to satisfying cost and experience demands, 5G will also need to meet extremely high security requirements, particularly for services such as e-banking, security monitoring, safe driving, and mobile health. 5G will also be able to support lower power consumption to build greener mobile communication networks and to enable much longer terminal battery life, especially for some IoT devices.

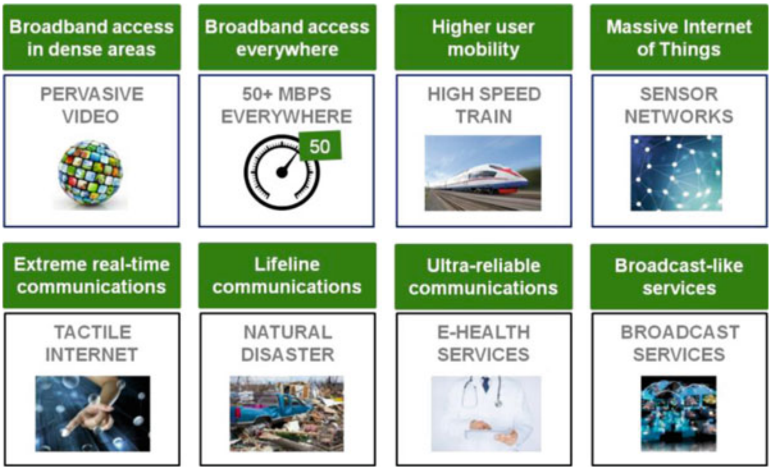

Fig. 6 5G use case families and related use case examples

2.3 Classification of 5G Use Cases

5G will support a large variety of use cases which are emerging now or will emerge in the future. Different use cases have varying characteristic and requirements. It is helpful to group countless emerging use cases into several use case families. Use cases in each use case family share similar characteristic and requirements.

NGMN has developed 25 use cases for 5G as representative examples, which are grouped into eight use case families. The following diagram [5] illustrates the eight use case families with one example use case given for each family, and these families and their corresponding use case examples are described in Fig. 6.

ITU-R has concluded three usage scenarios (use case groups) addressing different use case characteristics in Fig. 7 [2]:

– Enhanced mobile broadband: Mobile broadband addresses human-centric use cases for access to multi-media content, services and data. The demand for mobile broadband will continue to increase, leading to enhanced mobile broadband. The enhanced mobile broadband usage scenario will come with new application areas and requirements in addition to existing mobile broadband applications for improved performance and an increasingly seamless user experience.
– Ultra-reliable and low latency communications: This use case has stringent requirements for capabilities such as throughput, latency and availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.

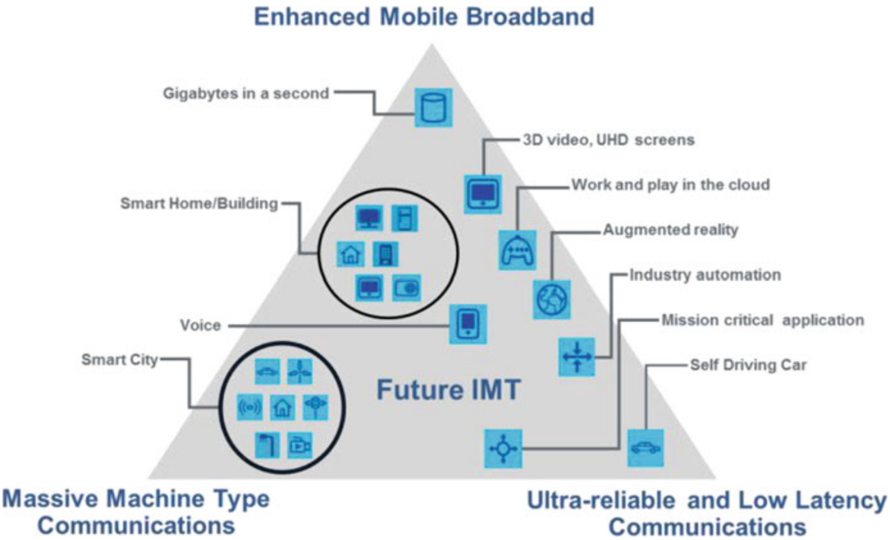

Fig. 7 5G usage scenarios

– Massive machine type communications: This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be of low cost, and have a very long battery life.

Similarly, IMT-2020 (5G) Promotion Group has proposed four technical scenarios for 5G in Fig. 8 which are well in line with the three usage scenarios from ITU-R. The main difference is that the eMBB scenario from ITU-R is divided into two technical scenarios, i.e., the seamless wide-area coverage scenario and high-capacity hot-spot scenario.

For the seamless wide-area coverage scenario, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However, the data rate requirement may be relaxed compared to the hotspot scenario. For the high-capacity hot-spot scenario, i.e., for an area with high user density, very high traffic capacity is needed, while the requirement for mobility is low and the user data rate is higher than that of wide area coverage. For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However, the data rate requirement may be relaxed compared with the hotspot.

Figure 9 shows the mapping from the eight use case families proposed by NGMN to the three usage scenarios defined by ITU-R. The eMBB usage scenario consists of broadband access in dense areas, broadband access everywhere, higher user mobility and broadcast-like services. URLLC consists of extreme real-time communications, lifeline communications and ultra-reliable communications. mMTC corresponds to massive Internet of Things.

Fig. 8 Technical scenarios for 5G

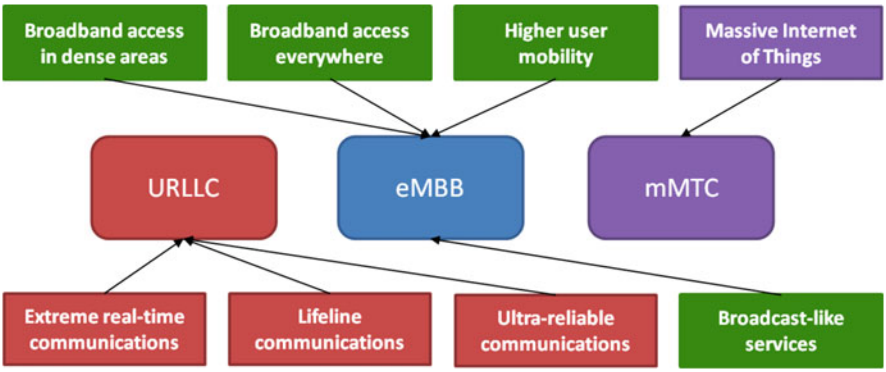

Fig. 9 Mapping eight use case families to three use scenarios

3 High-Level Key Capabilities

IMT-2020 (5G) PG groups the 5G high-level requirements into several performance indicators and efficiency indicators. The key performance indicators for 5G include the user experienced data rate, connection density, end-to-end delay, traffic volume density, mobility, and peak date rate. Their definitions are listed in Table 1. The value for each performance indicator and the relevant scenario are illustrated in Fig. 10.

Table 1 5G Performance indicators

Performance indicators	Definition
User experienced data rate (bps)	Minimum achievable data rate for a user in real network environment
Connection density (/km^2)	Total number of connected devices per unit area
End-to-end latency (ms)	Duration between the transmission of a data packet from the source node and the successful reception at destination node
Traffic volume density (bps/km^2)	Total data rate of all users per unit area
Mobility (km/h)	Relative speed between receiver and transmitter under certain performance requirement
Peak date rate (bps)	Maximum achievable data rate per user

Several problems are anticipated if today's networks are used to handle the explosive development of mobile Internet and IoT:

- The energy efficiency level, overall cost per bit and complexity of network deployment and maintenance cannot effectively handle 1000 times traffic growth and the massive number of connected devices in the next decade;
- Co-existence of multiple radio access technologies (RAT) causes increased complexity and degraded user experience;
- Existing networks can not realize accurate monitoring of network resources and effective awareness of services, and therefore they cannot intelligently fulfill the diversified requirements of future users and services;
- Widely distributed and fragmented spectrum will cause interference and co-existence complexity.

To solve these problems, 5G should have the following capabilities to achieve sustainability. In terms of network construction and deployment, 5G networks need to:

- Provide higher network capacity and better coverage, while decreasing the complexity and cost of network deployment, especially the deployment of ultra-dense networks.
- Have a flexible and scalable architecture to adapt to the diverse needs of users and services.
- Make flexible and efficient use of various spectrum resources, including paired and unpaired spectrum, re-farmed spectrum and new spectrum, low-frequency and high-frequency bands, and licensed and unlicensed bands.
- Have stronger device-connection capabilities to deal with the access requirements of huge amounts of IoT devices.

In terms of operation and maintenance (O&M), 5G needs to:

- Improve network energy efficiency and the O&M cost-per-bit to cope with data traffic growth and the diverse needs of various services and applications.

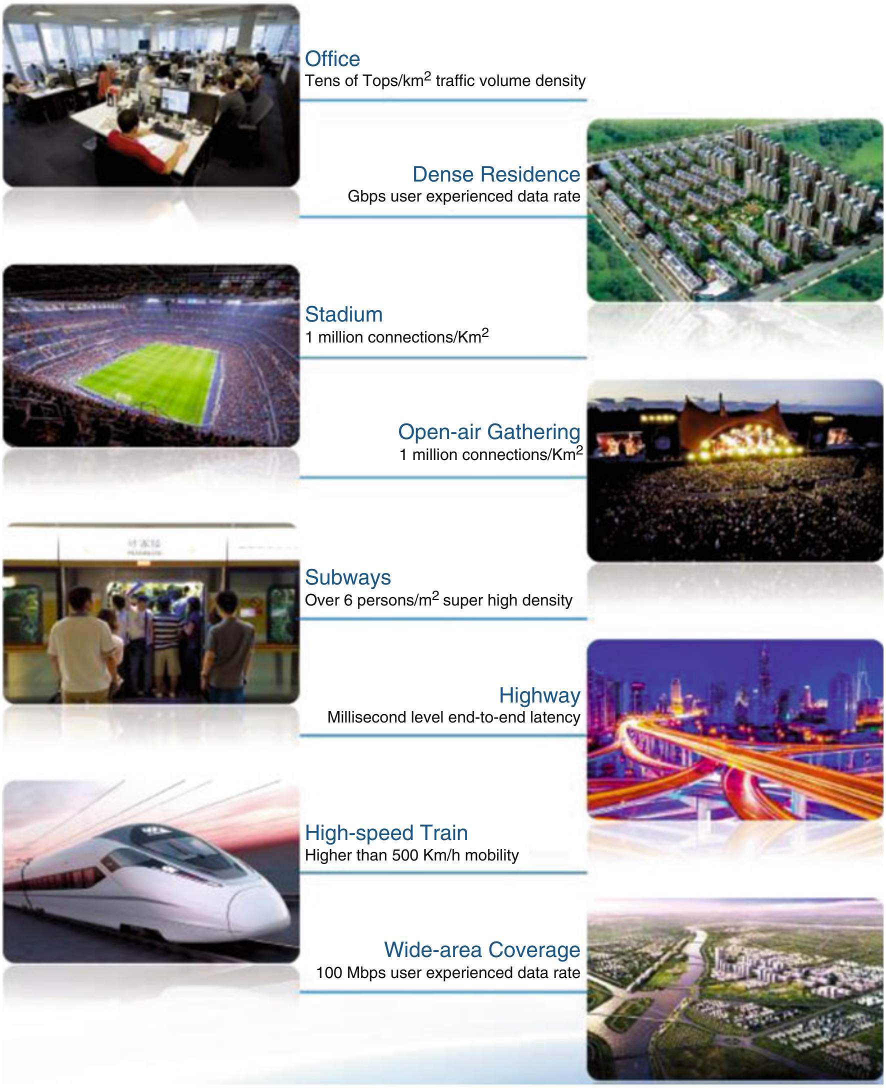

Fig. 10 Challenging scenarios and performance indicators

- Reduce the complexity caused by the co-existence of multiple radio access technologies, network upgrades, and the introduction of new features and functions, to improve users' experience.
- Make intelligent optimization based on awareness of users behaviors and services contents
- Provide a variety of network security solutions to meet the needs of all types of devices and services of mobile internet and IoT.

Table 2 5G Key efficiency indicators

Efficiency indicators	Definition
Spectrum efficiency (bps/Hz/cell or bps/Hz/km^2)	Data throughput per unit of spectrum resource per cell (or per unit area)
Energy efficiency (bit/J)	Number of bits that can be transmitted per joule of energy
Cost efficiency (bit/¥)	Number of bits that can be transmitted per unit cost

Spectrum utilization, energy consumption and cost are the three key factors which must be addressed in sustainable mobile communication networks. In order to achieve sustainability, 5G needs to make significant improvements in the following aspects (Table 2):

- Spectrum efficiency: 3–5 times
- Energy efficiency: 100+ times
- Cost efficiency: 100+ times

5G systems must dramatically outperform previous generation systems. 5G should support

- User experienced data rate: 0.1–1 Gbps
- Connection density: one million connections per square kilometer
- End-to-end latency: millisecond level
- Traffic volume density: tens of Gbps per square kilometer
- Mobility: higher than 500 km per hour
- Peak data rate: tens of Gbps

Among these requirements, the user experienced data rate, connection density and end-to-end latency are the three most fundamental ones. Meanwhile, 5G needs to significantly improve the efficiency of network deployment and operations. Compared with 4G, 5G should have 3–5 times improvement on spectrum efficiency and more than 100 times improvement on energy and cost efficiency.

The performance requirements and efficiency requirements define the key capabilities of 5G, which can be illustrated as a "blooming flower" depicted in Fig. 11. The petals and leaves rely on each other. The petals represent the six key capabilities in terms of performance and can fulfill the diverse requirements of future services and scenarios. The leaves represent the three key capabilities in terms of efficiency, and can guarantee the sustainable development of 5G. The top of each petal means the maximum value of the corresponding capability.

The key capabilities of IMT-2020 defined by ITU-R are shown in Fig. 12, compared with those of IMT-Advanced. The values for each key capability are shown in Table 3.

All key capabilities may to some extent be important for most use cases, and the relevance of certain key capabilities may be significantly different, depending on the use cases/scenario. The importance of each key capability for the usage scenarios

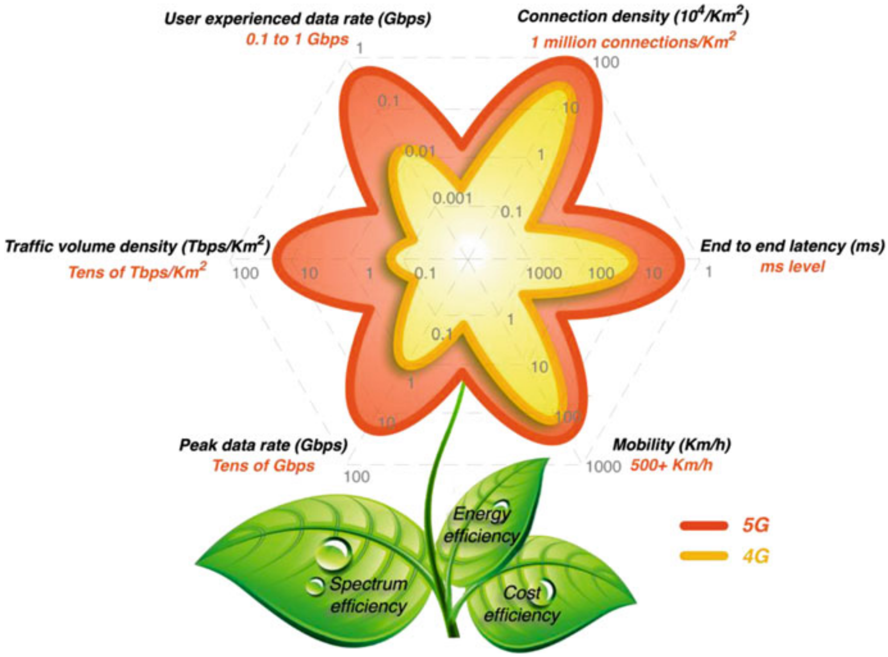

Fig. 11 5G key capabilities

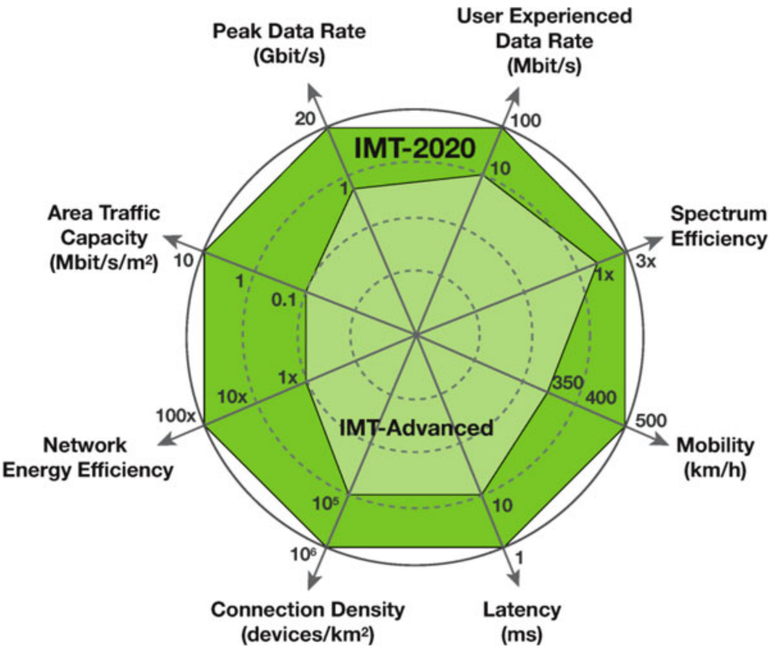

Fig. 12 Enhancement of key capabilities from IMT-Advanced to IMT-2020

Table 3 5G Key capabilities and values from ITU-R

Key capabilities	Values
Peak data rate	20 Gbps
User experienced data rate	0.1–1 Gbps
Latency	1 ms over-the-air
Mobility	500 km/h
Connection density	10^6/km^2
Energy efficiency	100 times compared with IMT-Advanced
Spectrum efficiency	3–5 times compared with IMT-Advanced
Area traffic capacity	10 Mbit/s/m^2

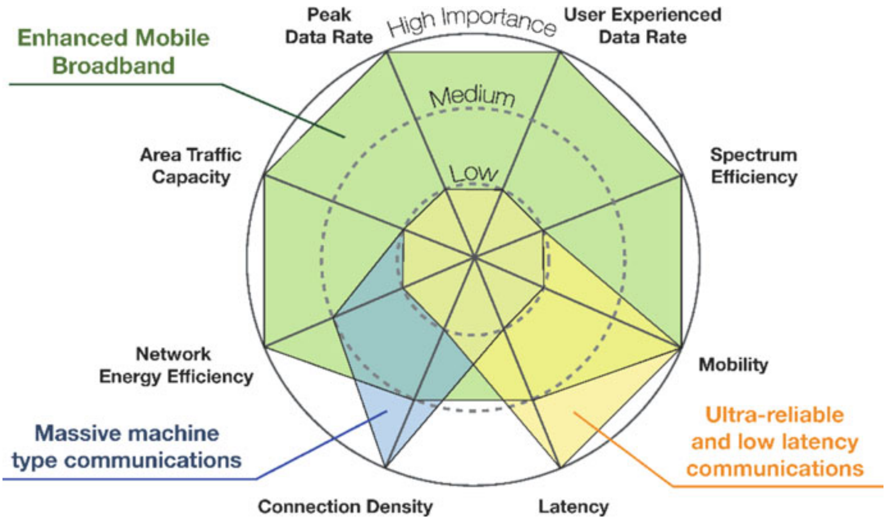

Fig. 13 Importance of key capabilities in different usage scenarios

enhanced mobile broadband, ultra-reliable and low latency communication and massive machine-type communication is illustrated in Fig. 13. This is done using an indicative scaling in three steps as "high", "medium" and "low".

In the enhanced mobile broadband scenario, the user experienced data rate, area traffic capacity, peak data rate, mobility, energy efficiency and spectrum efficiency all have high importance, but mobility and the user experienced data rate would not have equal importance simultaneously in all use cases. For example, in hotspots, a higher user experienced data rate, but a lower mobility, would be required than in the wide area coverage case.

In the ultra-reliable and low latency communications scenarios, low latency is of highest importance, e.g., safety critical applications. Such capability would be required in some high mobility cases as well, e.g., transportation safety, while high data rates could be less important.

In the massive machine type communication scenario, high connection density is needed to support a tremendous number of devices in the network that may transmit only occasionally, at low bit rate and with zero/very low mobility. A low cost device with long operational lifetime is vital for this usage scenario.

4 Deployments Scenarios

Use cases will be delivered across a wide range of environments. To facilitate the study of 5G requirements and provide guidance to 5G technical design, several typical deployment scenarios need to be specified.

3GPP has started study on scenarios and requirements for next generation access technologies [6] in December 2015. After three months' study, there are totally 10 deployment scenarios specified for 5G in RAN plenary meeting in March 2016. 7 deployment scenarios including indoor hotspot, dense urban, rural, urban macro, high speed, extreme rural for the provision of minimal services over long distances and extreme rural with extreme long range are proposed mainly for eMBB, 1 deployment scenario, urban coverage for massive connection is proposed for mMTC, 2 deployment scenarios including highway scenario (for Internet of vehicles) and urban grid for connected car are proposed for URLLC. Some eMBB deployment scenarios may possibly be reused to evaluate mMTC and URLLC, or some specific evaluation tests (e.g., link-level simulation) can be developed to check whether the requirements can be achieved.

High-level descriptions on deployment scenarios including carrier frequency, aggregated system bandwidth, network layout including Inter-Site-Distance (ISD), UE distribution, UE moving speed and service profile are proposed in the following sections.

- Indoor hotspots

The indoor hotspot deployment scenario focuses on small coverage per cell and high user throughput or user density in buildings. The key characteristics of this deployment scenario are high capacity, high user density and consistent user experience indoor.

This scenario represents indoor offices with a total area of 120 m $\times$ 50 m. 12 small cells are deployed with an ISD of 20 m. The BS antenna height is 3 m. The carrier frequency options include 4 GHz, around 30 and 70 GHz. The bandwidth for 4 GHz is up to 200 MHz. The bandwidth for around both 30 and 70 GHz is up to 1 GHz. 10 users per cell are distributed uniformly and all users are indoors with 3 km per hour velocity. Full buffer and/or burst traffic model is assumed.

- Dense urban

The dense urban heterogeneous deployment scenario focuses on macro cells with micro cells and high user densities and traffic loads in city centres and dense urban areas. The key characteristics of this deployment scenario are high traffic loads, outdoor and outdoor-to-indoor coverage. This scenario will be interference-limited, using macro TRPs with or without micro cells. A continuous cellular layout and the associated interference shall be assumed.

The ISD for the macro cells is 200 m. There are 3 micro cells per macro cell. The macro BS antenna height is 25 m and micro BS antenna height is 10 m. The carrier frequency for macro cell is 4 GHz. The carrier frequencies for micro cell include 4 GHz, around 30 GHz and around 70 GHz. The bandwidth for 4 GHz is up to 200 MHz and bandwidth for both around 30 GHz and around 70 GHz is up to 1 GHz. Full buffer and/or burst traffic model is assumed. 10 UEs are distributed per micro sector. 80 % users are indoor with a moving speed of 3 km per hour and 20 % is in cars with a velocity of 30 km per hour.

- Urban macro

The urban macro homogeneous deployment scenario focuses on large cells and continuous coverage. The key characteristics of this scenario are continuous and ubiquitous coverage in urban areas. This scenario will be interference-limited, using macro TRPs (i.e. radio access points above rooftop level).

The ISD in this scenario is 500 m. The BS antenna height is 35 m. The carrier frequency is 4 GHz, 2 GHz, and around 30 GHz. The bandwidth for 4 GHz is up to 200 MHz and bandwidth for 2 GHz is up to 100 MHz. Full buffer and/or burst traffic model is assumed. 10 UEs are distributed per cell. 80 % users are indoor with 3 km per hour velocity and 20 % is in cars with 30 km per hour velocity.

- Rural

The rural deployment scenario focuses on larger and continuous coverage. The key characteristics of this scenario are continuous wide area coverage supporting high speed vehicles. This scenario will be noise-limited and/or interference-limited, using macro TRPs.

The ISD in this scenario is 1732 m or 5000 m. The BS antenna height is 35 m. The carrier frequency is 700 MHz. The bandwidth is up to 20 MHz. Full buffer and/or burst traffic model is assumed. 10 UEs are distributed per cell. 50 % users are indoors with 3 km per hour velocity and 50 % is in cars with 120 km per hour velocity.

4 GHz and 2 GHz frequency are also considered in this scenario.

- High speed

The high speed deployment scenario focuses on continuous coverage along track in high speed trains. The key characteristics of this scenario are consistent user experience with very high mobility. In this deployment scenario, dedicated linear deployment along railway line is considered and UEs are located in train carriages. If the antenna of relay node for eNB-to-Relay is located at top of one carriage of the train, the antenna of relay node for Relay-to-UE could be distributed to all carriages.

- Extreme rural for the provision of minimal services over long distances

The extreme rural deployment scenario is defined to allow the provision of minimal services over long distances for low average revenue per user (ARPU) and low density areas including both humans and machines. The key characteristics of this scenario are macro cells with very large area coverage supporting basic data and voice services, with low to moderate user throughput and low user density.

- Extreme rural with extreme long range

The extreme rural long range deployment scenario is defined to allow for the provision of services for very large areas such as wilderness or areas with only highways. The key characteristics of this scenario are macro cells with very large area coverage supporting basic data speeds and voice services, with low to moderate user throughput and low user density.

- Urban coverage for massive connection

The urban coverage for massive connection scenario focuses on large cells and continuous coverage to provide mMTC. The key characteristics of this scenario are continuous and ubiquitous coverage in urban areas, with very high connection density of mMTC devices. This deployment scenario is for the evaluation of the KPI of connection density.

- Highway scenario

The highway deployment scenario focuses on scenario of vehicles on highways with high speeds. The main KPIs evaluated under this scenario include reliability/availability under high speeds/mobility (and thus frequent handover operations).

- Urban grid for connected car

The urban macro deployment scenario focuses on the scenario of highly dense deployed vehicles placed in urban areas. It can cover the scenario where freeways lead through an urban grid. The main KPI evaluated under this scenario are reliability/availability/latency in high network load and high UE density scenarios.

5 Detailed Technical Requirements

- Peak data rate

Peak data rate is the highest theoretical data rate which is the received data rate assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e., excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

The target for peak data rates are 20 Gbps for downlink and 10 Gbps for uplink.

- Peak spectral efficiency

Peak spectral efficiency is the highest theoretical data rate (normalized by bandwidth), which is the received data rate assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e., excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

The targets for peak spectral efficiency are 30 bps/Hz for downlink and 15 bps/Hz for uplink.

Higher frequency bands imply higher bandwidths but lower spectral efficiency, while lower frequency bands results in lower bandwidths but higher spectral efficiency. Thus, the peak data rate cannot be directly derived from the peak spectral efficiency and bandwidth multiplication.

- Bandwidth

Bandwidth means the maximal aggregated total system bandwidth. It may be supported by a single or multiple RF carriers.

The value for this KPI is for further study.

- Control plane latency

Control plane latency refers to the time to move from a battery efficient state (e.g., IDLE) to the start of continuous data transfer (e.g., ACTIVE).

The target for control plane latency should be 10 ms.

- User plane latency

The time taken to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both the uplink and downlink directions, where neither device nor base station reception is restricted by DRX.

For URLLC the target for user plane latency should be 0.5 ms for UL and 0.5 ms for DL. Furthermore, if possible, the latency should also be low enough to support the use of next-generation access technologies as a wireless transport technology that can be used within the next-generation access architecture.

For other cases, the target for user plane latency should be 4 ms for UL and 4 ms for DL.

- Latency for infrequent small packets

For infrequent application layer small packet/message transfer, the time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point at the mobile device to the radio protocol layer 2/3 SDU egress point in the RAN, when the mobile device starts from its most “battery efficient” state.

- Mobility interruption time

Mobility interruption time means the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transition.

The target for mobility interruption time should be zero.

This KPI is for intra-system mobility.

- Inter-system mobility

Inter-system mobility refers to the ability to support mobility between the IMT-2020 system and at least one IMT system.

- Reliability

Reliability can be evaluated by the success probability of transmitting e.g., 20 bytes within 1 ms, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a certain channel quality (e.g., coverage-edge).

The target for reliability should be $1–10^{-5}$ within 1 ms.

- Coverage

"Maximum coupling loss" (MCL) on the uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160 bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in uplink and downlink.

The target for coverage should be 164 dB.

- UE battery life

The UE battery life is determined by the battery life of the UE without recharge. For mMTC, the UE battery life in extreme coverage depends on the activity of mobile originated data transfer consisting of 200 bytes UL per day followed by 20 bytes DL from MCL of 164 dB, assuming a stored energy capacity of 5 Wh.

The target for UE battery life is beyond 10 years.

- UE energy efficiency

UE energy efficiency means the capability of a UE to sustain much better mobile broadband data rate while minimizing the UE modem energy consumption.

- Cell/Transmission Point/TRP spectral efficiency

TRP spectral efficiency is defined as the aggregate throughput of all users (the number of correctly received bits, i.e., the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time) divided by the channel bandwidth divided by the number of TRPs. A three-sector site consists of 3 TRPs. In case of multiple discontinuous "carriers" (one carrier refers to a continuous block of spectrum), this KPI should be calculated per carrier. In this case, the aggregate throughput, channel bandwidth, and the number of TRPs on the specific carrier are employed.

The target considered as a starting point for eMBB deployment scenarios is in the order of 3× IMT-Advanced requirements for full buffer.

- Area traffic capacity

Area traffic capacity means total traffic throughput served per geographic area (in Mbit/s/m^2). This metric can be evaluated by two different traffic models, i.e., full buffer model and non-full buffer model.

Full buffer model:

The total traffic throughput served per geographic area (in Mbit/s/m^2). The computation of this metric is based on full buffer traffic.

Non-full buffer model:

The total traffic throughput served per geographic area (in Mbit/s/m^2). Both the user experienced data rate and the area traffic capacity need to be evaluated at the same time using the same traffic model.

The area traffic capacity is a measure of how much traffic a network can carry per unit area. It depends on the site density, bandwidth and spectrum efficiency. In the special case of a single layer single band system, it may be expressed as:

$$\begin{aligned}\text{area capacity } \left(\text{bps/m}^2\right) = {} & \text{site density } \left(\text{site/m}^2\right) \times \text{bandwidth } (\text{Hz}) \\ & \times \text{spectrum efficiency } (\text{bps/Hz/site})\,.\end{aligned}$$

Based on the above, it is proposed to use the spectrum efficiency results together with the assumptions on the available bandwidth and site density in order to derive a quantitative area traffic capacity KPI for information.

- User experienced data rate

User experienced data rate can be evaluated for non-full buffer traffic and for full buffer traffic. Non-full buffer simulations are preferred for the evaluation of this KPI.

For non-full buffer traffic, the user experienced data rate is 5 % of the user throughput. User throughput (during active time) is defined as the size of a burst divided by the time between the arrival of the first packet of the burst and the reception of the last packet of the burst.

The target values for the user experienced data rate are associated with non-full buffer evaluation. The non-full buffer user experienced data rate target is applicable at the non-full buffer area traffic capacity traffic level.

For full buffer traffic, the user experienced data rate is calculated as:

$$\text{user experienced data rate} = 5\% \text{ user spectrum efficiency} \times \text{bandwidth}$$

To improve user experienced data rates, 3GPP can develop standards with means for high 5 % user spectrum efficiency. To this end, 5 % user spectrum efficiency gains in the order of three times that IMT-Advanced are proposed. Furthermore, 3GPP can develop standards with means for large bandwidth support. Towards this end, it is proposed that at least 1 GHz aggregated bandwidth shall be supported.

The available bandwidth and site density, which both have a strong impact on the available user experienced data rates, are however beyond the control of 3GPP.

Based on this, the full buffer experienced user data rate is evaluated for information without numerical requirements.

- 5th percentile user spectrum efficiency

5th percentile user spectrum efficiency means the 5 % point of the cumulative distribution function (CDF) of the normalized user throughput. The (normalized) user throughput is defined as the average user throughput (the number of correctly received bits by users, i.e., the number of bits contained in the SDU delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz. The channel bandwidth for this purpose is defined as the effective bandwidth multiplies the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio. In the case of multiple discontinuous "carriers" (one carrier refers to a continuous block of spectrum), this KPI should be calculated per carrier. In this case, the user throughput and channel bandwidth on the specific carrier are employed.

The target considered as a starting point for eMBB deployment scenarios is in the order of 3× IMT-Advanced requirements for full buffer.

- Connection density

Connection density refers to the total number of devices fulfilling specific QoS per unit area (per km^2). QoS definition should take into account the amount of data or access request generated within a time X (to be studied in future) that can be sent or received within a given time, Y (to be studied in future), with Z% (to be studied in future) probability.

The target for connection density should be 1,000,000 device/km^2 in the urban environment.

- Mobility

Mobility means the maximum user speed (km/h) at which a defined QoS can be achieved.

The target for mobility target is 500 km/h.

- Network energy efficiency

The capability is to minimize the RAN energy consumption while providing much better area traffic capacity.

Qualitative KPIs as the baseline and quantitative KPI are for further study.

6 Requirements for RAN Architecture

The RAN design for the Next Generation Radio Access Technologies shall be designed to fulfill the following requirements:

- The RAN architecture shall support tight interworking between the new RAT and LTE.
- Considering high performing inter-RAT mobility and aggregation of data flows via at least dual connectivity between LTE and new RAT. This shall be supported for both collocated and non-collocated site deployments;
- The RAN architecture shall support connectivity through multiple transmission points, either collocated or non-collocated;
- The RAN architecture shall enable the separation of control plane signaling and user plane data from different sites;
- The RAN architecture shall support interfaces supporting effective inter-site scheduling coordination;
- Different options and flexibility for splitting the RAN architecture shall be allowed;
- The RAN architecture shall allow for deployment flexibility e.g., to host relevant RAN, CN and application functions close together at the edges of the network, when needed, e.g., to enable context aware service delivery, low latency services, etc;
- The RAN architecture shall allow for C-plane/U-plane separation;
- The RAN architecture shall allow deployments using Network Function Virtualization;
- The RAN architecture shall allow for the RAN and the CN to evolve independently;
- The RAN architecture shall allow for the operation of Network Slicing;
- The RAN architecture shall support sharing of the RAN between multiple operators;
- The design of the RAN architecture shall allow for rapid and efficient deployment of new services;
- The design of the RAN architecture shall allow the support of 3GPP defined service classes (e.g. interactive, background, streaming and conversational);
- The design of the RAN architecture shall enable lower CAPEX/OPEX with respect to current networks to achieve the same level of services;
- RAN-CN interfaces and RAN internal interfaces (both between new RAT logical nodes/functions and between new RAT and LTE logical nodes/functions) shall be open for multi-vendor interoperability;
- The RAN architecture shall support operator-controlled sidelink (device-to-device) operation, both in coverage and out of coverage.

7 Chapter Summary

Mobile Internet and IoT are the two main market drivers in the future development of mobile communications, and they will provide a broad range of prospects for 5G. There will be a massive number of use cases in 5G era, such as augmented reality, virtual reality, remote computing, eHealth services, automotive driving and so on. All these use cases can be grouped into three categories, i.e., eMBB, mMTC and URLLC. To facilitate the study of 5G requirements and provide guidance to 5G technical design, several typical deployment scenarios are specified including indoor hotspots, dense urban, urban macro, rural and high-speed scenarios.

This chapter also presents high-level key capabilities and detailed technical requirements for 5G. 5G will be able to sustainably satisfy the requirement of thousands of times mobile data traffic growth. 5G will provide users with fiber-like access data rate and "zero" latency user experience. It will be capable of connecting 100 billion devices. 5G will be able to deliver a consistent experience across a variety of scenarios including the cases of ultra-high traffic volume density, ultra-high connection density and ultra-high mobility. 5G will also be able to provide intelligent optimization based on services and user awareness, and will improve energy and cost efficiency by over a hundred times, enabling us all to realize the vision of 5G—"Information a finger away, everything in touch".

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