White Paper
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IMT-2020

IMT-2020 (5G) Promotion Group

5G Concept

Contents

IMT-2020 (5G) Promotion Group was jointly established in February 2013 by three ministries of China (including MIIT, NDRC, and MOST) based on the original IMT-Advanced Promotion Group. The members include the main operators, vendors, universities, and research institutes in China. The Promotion Group is the major platform to promote 5G technology research in China and to facilitate international communication and cooperation.

Introduction

Ever since its birth in the 1980s, mobile communications have been undergoing more than three decades of explosive growth, and the mobile network has become a basic information network connecting human society. It already has a major impact on people's daily lives, and also become an important engine for economy development and social informatization. Following the large-scale commercialization of 4G, the fifth generation of mobile communications (5G), which is expected to be commercialized towards year 2020 and beyond, has become a focal point for global research and development.

The joint effort of the global mobile industry has made the 5G vision and key requirements more concrete, and the international standardization of 5G is expected to be initiated in 2016. Therefore, it is important and urgent to clarify the concept, technology roadmap, and core technologies, in order to focus the global forces to promote 5G research, development, and standardization.

Starting with 5G vision and requirements, this white paper analyzes and summarizes the main technical scenarios, challenges, and key enabling technologies for 5G. The key features and core technologies are extracted to form 5G concept. On this basis, a suitable 5G technology roadmap is then proposed in the context of the trend of mobile communication standards and industry.

5G Technical Scenarios

Mobile internet and the Internet of Things (IoT) will become the main forces driving the evolution of mobile communications towards 2020 and beyond. 5G will need to fulfill diverse service requirements in all aspects of life in the future, such as residence, work, leisure, and transportation. Ultimate service experiences, including ultra-high-definition video, augmented reality, virtual reality, cloud desktop, and online gaming, will be provided even in scenarios with ultra-high traffic volume density, connection density, and mobility such as dense residential areas, offices, stadiums, open-air public gatherings, subways, highways, high-speed trains, and wide-coverage areas. Moreover, 5G will penetrate into the IoT and a variety of other industries, where it can be integrated with industrial facilities, medical equipments, vehicles, etc., to fulfill diverse service requirements of manufacturing, medicine, transportation, and other vertical industries, achieving a real “Internet of Everything”.

Main technical scenarios of 5G

5G will solve the challenges stemmed from the drastically different performance requirements in a wide range of diversifed scenarios, where different key performance indicators (KPI) such as user experienced data rate, traffic volume density, latency, energy efficiency, and connection density might be challenging. Four typical technical scenarios of 5G are derived from the main application scenarios, service requirements, and key challenges of mobile internet and IoT. They are seamless wide-area coverage scenario, high-capacity hot-spot scenario, low-power massive-connections scenario, and low-latency high-reliability scenario.

Seamless wide-area coverage and high-capacity hot-spot are main scenarios for mobile internet towards 2020 and beyond. It should be noted that they are also the main scenarios of 4G. However, higher performance requirements should be met in 5G era.

- Seamless wide-area coverage is the basic scenario of mobile communications. In this scenario, the main objective is to provide seamless service to end users. The main challenge is to provide more than 100 Mbps user experience data rate anytime and anywhere, even for users moving at high speed or in unsatisfactory wireless environments such as cell edge.
- High-capacity hot-spot scenario mainly targets local hot-spot areas where ultra-high data rates should be provided to users and ultra-high volume traffic need to be handled. The main challenge is to provide 1 Gbps user experienced data rate, tens of Gbps peak data rate, and tens of Tbps/km^2 traffic volume density.

Low-power massive-connections and low-latency high-reliability scenarios mainly target services of IoT and vertical industries where performance requirements cannot be well met by legacy systems. These are extended scenarios for 5G.

- Low-power massive-connections scenario mainly focuses on sensoring and data collecting use cases, such as smart city, environmental monitoring, intelligent agriculture, and forest fire prevention. The charateristics of this scenario include small data packets, low power consumption, and low cost. In general, those kinds of devices are numerous with a wide geographic distribution. To support these applications, 5G needs to support at least 1 million connections per squared kilometer and 100 billion connections in total, in an efficient way that allows the terminals to have ultra-low power consumption and ultra-low cost.

- Low-latency high-reliability scenario mainly focuses on vertical industries such as Internet of Vehicles (IOV) and industrial control. The ms-level end-to-end latency or/and nearly 100% reliability need to be guaranteed in this scenario.

Main technical scenarios and key challenges for 5G

Scenarios	Key Challenges
Seamless wide-area coverage	• 100 Mbps user experienced data rate
High-capacity hot-spot	• User experienced data rate: 1Gbps • Peak data rate: Tens of Gbps • Traffic volume density: Tens of Tbps/km^2
Low-power massive- connections	• Connection density: 10^6 /km^2 • Low power consumption & low cost
Low-latency high-reliability	• Air interface latency: 1 ms • End-to-end latency: ms level • Reliability: nearly 100%

5G Key Technologies

The technical innovation of 5G will come from both wireless and network technologies. In the field of wireless technologies, massive multiple-input multiple-output (MIMO), ultra-dense networking (UDN), novel multiple access, and all-spectrum access have already become the focus of global industry. In the field of network technologies, a new network architecture based on software-defined networking (SDN) and network function virtualization (NFV) becomes the prevailing view worldwide.

In addition, there are some other potential technologies for 5G, such as FBMC, F-OFDM, full duplex, flexible duplex, D2D, Q-ary LDPC codes, network codes, and polar codes.

5G key wireless technologies

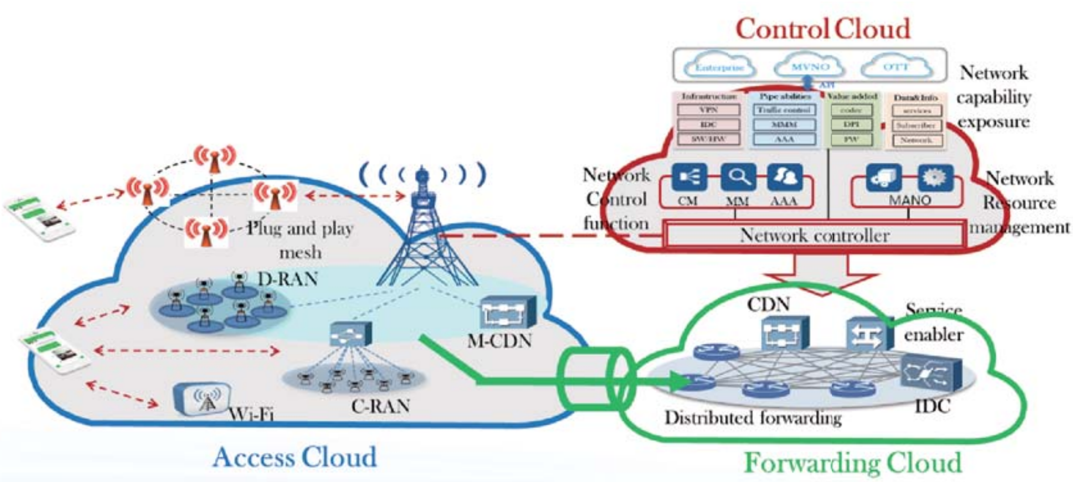
Massive MIMO allows many more antennas than 4G systems to support dozens of independent data streams. This helps to improve the spectral efficiency of multi-user systems by several times. It will play an important role in meeting the capacity requirements of 5G. Before massive MIMO can be deployed for 5G, some key technical issues must be solved, including channel measurement and feedback, reference signal definition, antenna array design, and low-cost implementation.

Ultra-dense networking can theoretically increase the spectral reuse factor infinitely via deploying denser base stations. In practice, even limited by frequency interferences, site availability, and deployment cost, it can still achieve hundreds of times capacity improvement in hot-spot areas. Interference management and suppression, virtual cell, joint access and feedback are important research areas in ultra-dense networking.

Novel multiple access can significantly improve spectral efficiency and access capability of 5G in many scenarios by superpositioning signals of multiple users in space/time/frequency/code domains. Moreover, grant-free based multiple access schemes will significantly reduce signaling overhead, access latency, and power consumption of terminals. Currently, the potential schemes proposed by the industry include sparse code multiple access (SCMA), multi-user shared access (MUSA), pattern division multiple access (PDMA), and non-orthogonal multiple access (NOMA).

All-spectrum access can exploit a variety of spectrum resources for mobile communications, including high and low, paired and unpaired, licensed and unlicensed, contiguous and non- contiguous frequency bands, to increase data rates and system capacity. The frequency bands below 6 GHz are preferred due to their good propagation characteristics. The abundant unused spectrum resources between 6 GHz and 100 GHz can serve as supplementary bands of 5G. The main challenges of all-spectrum access include channel measurement and modeling, unified access for low-frequency and high-frequency bands, unified high-frequency access & backhaul, and implementation of radio frequency (RF) components.

5G Network Architecture



5G network architechture

Compared to legacy networks, the 5G network will utilize SDN, NFV, and cloud computing to achieve a more flexible, intelligent, efficient, and open network. The 5G network architecture will consists of three clouds: access cloud, control cloud, and forwarding cloud.

The access cloud supports multiple radio access technologies, integrates both centralized and distributed architectures, and adapts to all sorts of backhaul links. These features facilitate more flexible deployment and more efficient radio resource management.

The control and data forwarding functions of 5G network will be substantially decoupled, turning into the centralized and unified control cloud and the flexible and efficient forwarding cloud. The control cloud is responsible for local and global network control functions, such as service session, mobility, and Quality of Experience (QoE). It also provides open service interfaces to utilize network capability, in order to meet a wide range of diverse service requirements and improve service deployment efficiency. The forwarding cloud, based on general hardware platform, can efficiently transmit massive data with high reliablity and low latency in a load-balanced way, through efficient control and resource schedule by the control cloud.

This new 5G network architecture based “three clouds” is the trend for future mobile network. In addition to the demands of new services and scenarios, the smooth evolution of the current mobile networks should also be taken into account. The migration to the new network architecture will require an intermediate stage to allow some local changes. The convergence of communications and information technologies will gradually spread from core networks to radio access networks, and ultimately the entire network will be transformed.

Relationships between 5G scenarios and key technologies

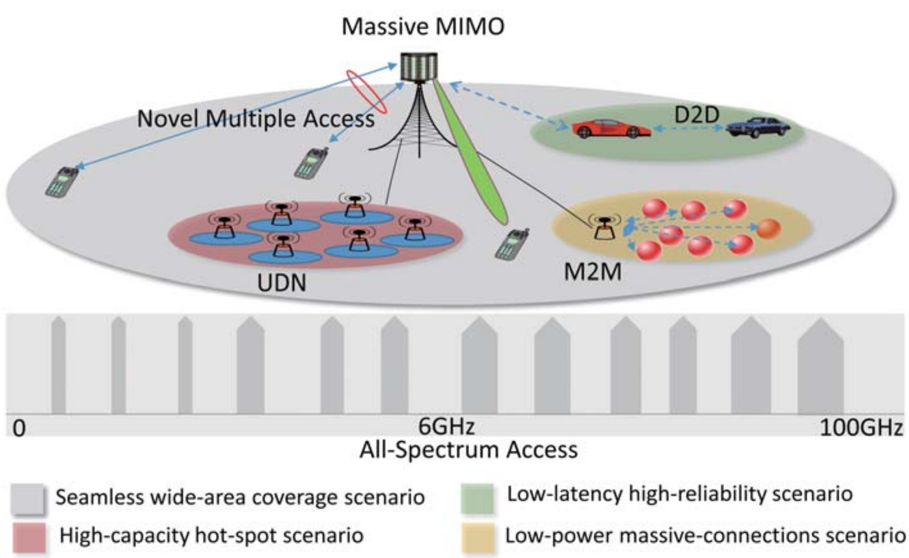
The four main technical scenarios of 5G, including seamless wide-area coverage, high-capacity hot-spot, low-power massive-connections, and low-latency high-reliability have performance requirements that are both very different and challenging. The compatibility between different technologies should be considered, in order to select suitable combinations of key technologies to meet these requirements of specific scenarios.

In seamless wide-area coverage scenario, sites for base stations and spectrum resources are limited. In order to achieve 100 Mbps user experienced data rate, significant spectral efficiency improvement is required, and more spectrum in low-frequency bands need to be allocated. In this scenario, massive MIMO is one of the most important technologies, and novel multiple access can be combined with massive MIMO to further enhance spectrum efficiency and multi-user access capability. As for the network architecture, a more stable user experienced data rate can be achieved by integrating various radio access technologies and utilizing centralized coordination of network resources and enhanced QoS control technology.

In high-capacity hot-spot scenario, the main challenge is to provide extremely high user experienced data rate and handle ultra-high traffic volume density. Ultra-dense networking can significantly improve spectrum reuse factor and enhance spectrum efficiency. All-spectrum access can fully utilize both low-frequency and high-frequency resources to obtain higher system capacity. Massive MIMO and novel multiple access can be combined with ultra-dense networking and all-spectrum access to further improve spectral efficiency.

In low-power massive-connections scenario, the key challenge is to connect massive devices with extremely low power consumption and low cost. The novel multiple access technique can provide multi-fold improvement in connection capability by superpositioning signals from multiple users. It can also dramatically reduce the signaling overhead through grant-free based multiple access schemes and allow terminals to sleep longer for power reduction. The new multicarrier technologies including Filtered-OFDM and FBMC have advantages in utilizing fragmented spectrum, supporting narrow bands and small packet transmission, and reducing power consumption and cost. Moreover, D2D can also be utilized in this scenario since it can further reduce power consumption by avoiding long-distance transmission between base stations and mobile terminals.

In low-latency high-reliability scenario, latency raised by air interface, network forwarding and retransmission should be minimized. Hence, shorter radio frames and more optimized signaling processes need to be adopted. Novel multiple access and D2D are candidate technologies to reduce the delay due to signal interaction and data relaying. In addition, advanced coding, modulation, and retransmission schemes can be used to enhance transmission reliability. From the network architecture's perspective, the control cloud should optimize transmission routes and make service data available at the edge of forwarding cloud and access cloud. Consequently, the network transmission latency can be dramatically reduced.

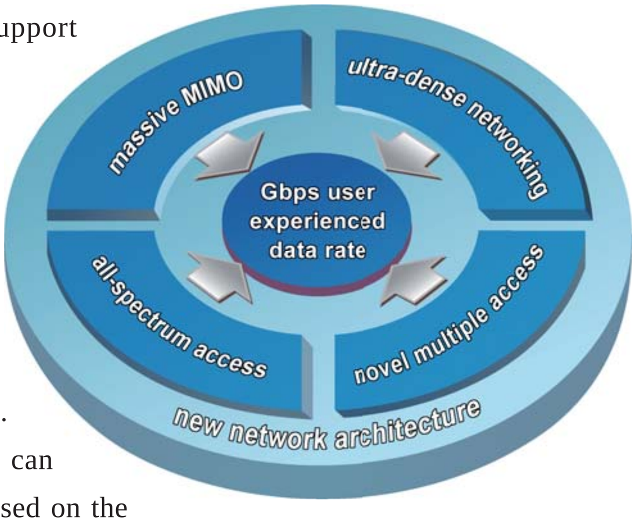


Main scenarios and suitable technologies for 5G

5G Concept

In the history of mobile communications, each generation is featured by an iconic KPI and a key technology. For example, 1G systems use FDMA and can provide analog voice service only. 2G systems are mainly based on TDMA and can provide both digital voice and low-data-rate services. 3G systems, marked by CDMA, can achieve the peak data rates from 2 Mbps to tens of Mbps, and support multimedia services. On the basis of OFDMA technology, 4G sytems can achieve the peak data rates from 100 Mbps to 1Gbps, and support various mobile broadband (MBB) services.

Due to the diverse service requirements, 5G will be characterized by more key capabilities than previous generations. Among them are user experienced data rate, connection density, end-to-end latency, energy efficiency, and mobility. Instead of peak data rate – the core KPI of the previous generations, user experienced data rate has been identified as the most important metric. The consensus view is that user experienced data rate can reflect the real-world data rates perceived by users. Based on the requirements of typical technical scenarios, the user experienced data rate of 5G should reach Gbps level.



5G concept

It is difficult for 5G to meet the extensive range of performance requirements in different scenarios by utilizing a single technology. Furthermore, in recent years, the wireless technology innovations show the diversified development trend. In addition to novel multiple access, massive MIMO, ultra-dense networking, all-spectrum access, and new network architecture are considered as the main technologies for 5G that will fulfill the requirements of the main technical scenarios.

According to the analysis on the key capability and technologies, 5G concept can be defined as “One iconic KPI + A group of key technologies”. The iconic KPI is Gbps user experienced data rate, and the group of key technologies include massive MIMO, ultra-dense networking, novel multiple access, all-spectrum access, and new network architecture.

5G Technology Roadmap

By analyzing the technical features, standard evolution, and industry development, the 5G technology roadmap can be identified. It consists of two technology routes: New air interface and 4G evolution.

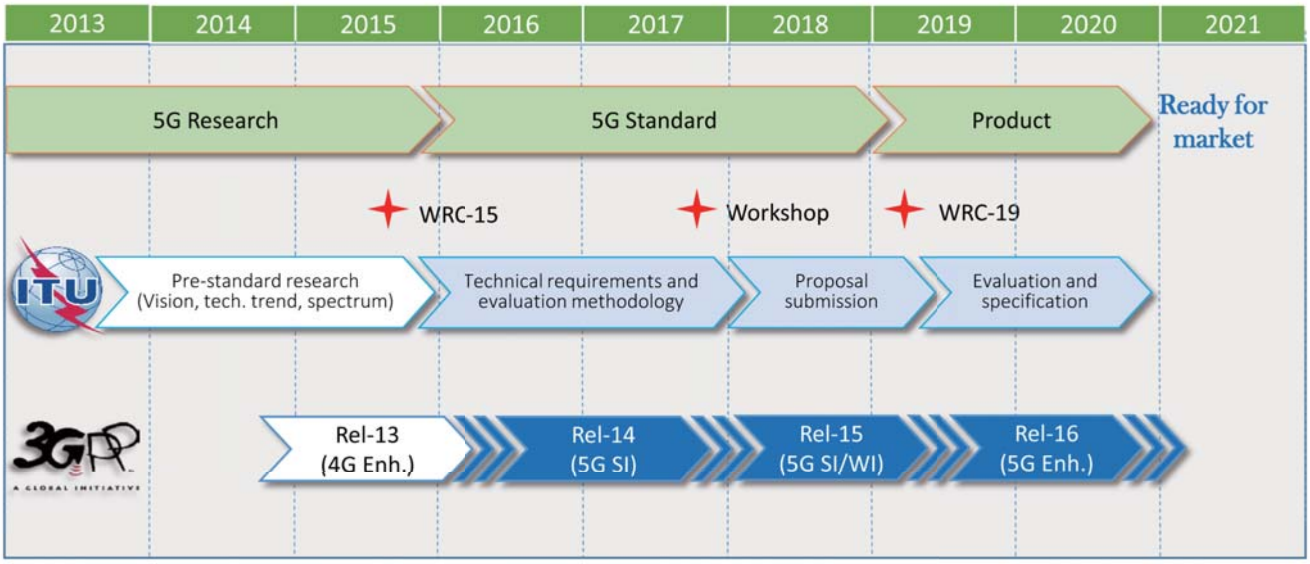
The new air interface targets new scenarios and new frequency bands, especially for IoT services and high frequency bands. This requires a totally new air interface design and innovative technologies without the need to consider backward compatibility with 4G. It can fulfill the service requirements and challenges that 4G evolution cannot support.

The 4G evolution will introduce new enhanced technologies on the basis of 4G framework. It will further improve the performance of 4G systems with backward compatibility. The requirements of 5G scenarios and services can be met to some extent by this route.

In addition, wireless local area network (WLAN) has become an important supplement of mobile communications, which mainly provides data offloading in hot-spot areas. The standardization of the next-generation WLAN standard (802.11ax) was launched in early 2014 and is expected to be completed in 2019. Looking towards 2020 and beyond, the next-generation WLAN will be tightly integrated with 5G, to jointly provide services to end users.

Currently, developing globally unified 5G standards has become a common voice for industry worldwide. The ITU has already initiated the research work for 5G standards, and set up the work plan for IMT-2020 (5G). The pre-standard research for 5G is scheduled to be completed in mid-2015, and the technical performance requirements and evalution methodology research will start in 2016. The call for 5G standard proposals will be kicked off in late 2017. The 5G specification is expected to be completed by the end of 2020.

As the major international standard organization in the field of mobile communications, 3GPP will take charge of the development of 5G technical specifications. 3GPP Release 14 is considered to be the best time to initialize the study items for 5G standards, and the 5G standard work items can be launched in Release 15. The enhancement and optimization of 5G standards can be carried out in Release 16 and beyond.



Time plan for 5G

Conclusions

To meet the service requirements of mobile internet and IoT towards 2020 and beyond, 5G will focus on the four main technical scenarios: Seamless wide-area coverage, high-capacity hot-spot, low-power massive-connections, and low-latency high-reliability. The key enabling technologies, including massive MIMO, ultra-dense networking, novel multiple access, all-spectrum access, and new network architecture should be introduced through two technology routes: the new air interface and the 4G evolution. 5G can not only provide Gbps user experienced data rate, but also guarantee consistent service experience in all kinds of scenarios.

IMT-2020 (5G) Promotion Group is willing to strengthen cooperation with global organizations, enterprises, universities, and research institutes to jointly define the 5G concept and technology roadmap, and work together to promote globally unified 5G standardization and industrialization.

Abbreviations

3GPP	Third Generation Partnership Project
5G	The Fifth Generation Mobile Communication System
CDMA	Code Division Multiple Access
D2D	Device-to-Device
FBMC	Filter Bank Multi-Carrier
FDMA	Frequency Division Multiple Access
F-OFDM	Filtered-Orthogonal Frequency Division Multiplexing
ITU	International Telecommunication Union
LDPC	Low Density Parity Check
MIMO	Multiple-Input Multiple-Output
MUSA	Multi-User Shared Access
NOMA	Non-Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplex Access
PDMA	Pattern Division Multiple Access
SCMA	Sparse Code Multiple Access
TDMA	Time Division Multiple Access
WLAN	Wireless Local Area Network

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