

Article

What is 5G? Emerging 5G Mobile Services and Network Requirements

Heejung Yu ¹ , Howon Lee ^{2,*} and Hongbeom Jeon ³

¹ Department of Information and Communication Engineering, Yeungnam University, Gyeongsan 38541, Korea; heejung@yu.ac.kr

² Department of Electrical, Electronic and Control Engineering, Hankyong National University, Anseong 17579, Korea

³ Infra Laboratory, KT Corporation, Seoul 06763, Korea; hbjeon@kt.com

* Correspondence: hwlee@hknu.ac.kr; Tel.: +82-31-670-5198

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Abstract: In this paper, emerging 5G mobile services are investigated and categorized from the perspective of not service providers, but end-users. The development of 5G mobile services is based on an intensive analysis of the global trends in mobile services. Additionally, several indispensable service requirements, essential for realizing service scenarios presented, are described. To illustrate the changes in societies and in daily life in the 5G era, five megatrends, including the explosion of mobile data traffic, the rapid increase in connected devices, everything on the cloud, hyper-realistic media for convergence services and knowledge as a service enabled by big-data analysis, are examined. Based on such trends, we classify the new 5G services into five categories in terms of the end-users' experience as follows: immersive 5G services, intelligent 5G services, omnipresent 5G services, autonomous 5G services and public 5G services. Moreover, several 5G service scenarios in each service category are presented, and essential technical requirements for realizing the aforementioned 5G services are suggested, along with a competitiveness analysis on 5G services/devices/network industries and the current condition of 5G technologies.

Keywords: 5G services; 5G network; technical requirements; network architecture

1. Introduction

Information and communication technologies (ICT) have been regarded as key ingredients for social and economic development because they have created new benefits and conveniences that were not experienced before. Since 4G wireless network services were introduced, people have been able to experience broadband services with their mobile devices (e.g., smart phones and tablet PCs), and the end-user experience has become nearly equivalent to that of wired connections. In spite of such advanced 4G wireless network technologies, it is hard to provide mobile services that require high speed, rapid response, high reliability and energy efficiency. Hence, these features have become essential requirements for future services in the 5G era. The current 4G/LTE networks cannot provide instantaneous cloud services, tactile Internet, enhanced vehicle-to-everything (eV2X), Internet of things (IoT) and communication with drones and robots while guaranteeing quality of experience to mobile users. Furthermore, LTE networks can provide high-quality video experience to only a limited number of mobile users simultaneously.

By introducing new contents, such as 360-degree videos and holograms, and new service concepts, such as smart transportation and machine-type communications, future 5G services can be developed in several directions such as unlimited data transmission, a massive number of active connections and new types of mobile devices, especially sensors, powered by sustainable energy sources. The scope of 5G services is not limited to personal communications, but extends to the areas of societies including

mobile phones, wearable devices, sensors, actuators, vehicles, robots, and so on. Therefore, 5G networks can be regarded as the key infrastructure that innovates societies, as well as ICT industries.

Research on 5G services and their technical requirements has been performed by the International Telecommunication Union-Radiocommunication Sector (ITU-R), the 3rd Generation Partnership Project (3GPP) and the Next Generation Mobile Networks (NGMN) Alliance. In the ITU-R Working Party (WP) 5D, 5G is defined by the name of International Mobile Telecommunications-2020 (IMT-2020), and various 5G services are presented in a vision document [1]. The proposed usage scenarios are grouped into three categories: enhanced mobile broadband (eMBB), massive machine-type communications (mMTC) and ultra-reliable and low-latency communications (URLLC). Peak data rate, area traffic capacity, network energy efficiency, connection density, latency, mobility, spectrum efficiency and user-experienced data rate are selected as key performance indicators (KPIs), which can be regarded as technical requirements. The details are discussed in Section 3.

The existing approaches for categorizing 5G services are still based on the technical viewpoint of network operators and service providers even though the final goal of 5G services is to maximize the satisfaction of end-users. Therefore, there is a mismatch of viewpoints between the goal and the categorization of 5G services. To overcome this mismatch, the main features of 5G services in terms of end-user experience are proposed in this paper by analyzing the megatrend of future mobile services. As a result of this analysis, 5G services are categorized according to the following five features: immersiveness, intelligence, omnipresence, autonomy and publicness. Each category includes typical 5G services as follows.

- Immersive 5G services: virtual reality/augmented reality (VR/AR), massive contents streaming
- Intelligent 5G services: user-centric computing, crowded area services
- Omnipresent 5G services: Internet of things
- Autonomous 5G services: smart transportation, drones, robots
- Public 5G services: disaster monitoring, private security/public safety, emergency services

To provide 5G services effectively, innovative changes in both wireless technologies and core networks are needed. For each service category, the required technologies are examined by analyzing the limitations of current 4G networks for a given service case. Then, qualitative and quantitative description for seven KPIs are provided. Additionally, three different types of requirements for 5G core networks are investigated. Functional, architectural and operational requirements are classified, and critical ones for each service group are suggested.

For the preparation of the 5G network infrastructure, we first analyze the megatrend of mobile services. Based on this analysis, detailed service scenarios are defined and categorized depending on the characteristics of such services. Finally, the technical requirements for both the wireless communication and the core network sides are examined and proposed in this paper.

2. Analysis on the Megatrend of Mobile Services

In this section, various changes to our daily life that are brought by 5G services are described by investigating five megatrends of mobile services as follows:

- Explosion of mobile data traffic
- Rapid increase in connected devices
- Everything on the cloud
- Hyper-realistic media for convergence services
- Knowledge as a service enabled by big data analysis

As mobile multimedia contents streaming and social networks have become more popular, the demand for mobile traffic has continuously increased. In addition to this, new types of multimedia services such as augmented reality, virtual reality and holograms, which all require huge traffic volumes, have emerged. According to [2], the amount of mobile data traffic in 2020 (30.6 exabytes per month, 1 EB = 1,000,000 TB) will be 8.3-times higher than in 2015 (3.7 exabytes per month).

In addition to mobile traffic volume, the number of mobile devices has increased exponentially by introducing new types of devices such as wearable devices, sensors, vehicles, drones and robots. In particular, this trend has accelerated because many machines with sensors and/or actuators are connected to communication networks for IoT services [3]. Globally, it is expected that the market of mobile handsets and other IoT devices, which are connected to the Internet, may increase from USD7.9 billion in 2015 to USD11.6 billion in 2020 [2,4]. The increase of active connections requires another direction of network evolution.

To access mobile networks with high computing power through simple portable devices, mobile cloud computing has emerged as one of the most essential technologies [5]. It is expected that the portion of mobile cloud traffic with respect to total mobile traffic will increase from 35% in 2013 to 70% by 2020 [6]. Furthermore, most mobile services in the 5G era are expected to be integrated with the mobile cloud computing system.

Unlike current 2D multimedia, hyper-realistic media services like AR, VR and multi-point view are enabled by the development of mobile networks and media technologies. Interactive services based on 3D holograms are also expected to become more popular. These hyper-realistic media services are tightly coupled with other sectors of the industry such as robots, drones, vehicles, health-care, personal assistance and security [7].

It is expected that big data analytics will create new opportunities in various areas because the value of data can be extracted through data gathering, processing, predictive analysis, inference, etc. The potential of big data analysis, especially in the area of knowledge services and artificial intelligence, is maximized by employing cloud computing technology, e.g., machine learning, deep learning, inference and recognition of IBM Watson [8,9].

3. 5G Services and Technical Requirements of Other Groups

In this section, we examine the diverse 5G services, categorization of services and their technical requirements defined by other groups, such as ITU-R, 3GPP services and markets technology enablers (SMARTER) and NGMN. In addition to the Introduction, more details and the relation between groups are discussed. As shown in Figure 1, ITU-R classifies 5G services as three categories, such as eMBB, mMTC and URLLC. Furthermore, NGMN proposes 14 service categories and 24 use-cases, and 3GPP suggests five service categories and 97 use-cases for 5G mobile services. Figure 1 shows the relationship between service categories proposed in ITU-R [1], NGMN [10] and 3GPP [11]. This relationship is made between service categories with commonalities to core technical requirements.

In most eMBB service scenarios in ITU-R, peak data rate, user experienced data rate, spectrum efficiency, mobility, network energy efficiency and area traffic efficiency all have high importance, as shown in Table 1 [1]. Furthermore, low latency and mobility are most important in some URLLC service scenarios. In mMTC service scenarios, the tremendous number of devices that occasionally transmit their packets should be reliably and seamlessly supported in 5G networks.

As mentioned before, NGMN has 14 service categories, and their technical requirements (user experienced data rate, end-to-end latency, mobility, device autonomy, connection density, traffic density) corresponding to each category are specified in Table 2 [10,12]. For each category, the denoted requirement values are representatives of the extreme use cases in the category. Therefore, if the requirements of each category are satisfied, those of all the use cases in each category can be met.

Recently, 3GPP service and System Aspects 1 (SA1) completed its study item of feasibility on new services and markets technology enablers (SMARTER). 3GPP SMARTER has developed a number of use cases covering five service categories such as eMBB, critical communications (CriC), massive IoT (mIoT), network operation (NEO) and eV2X [11]. Furthermore, 3GPP SMARTER identifies the high-level potential requirements (data rate, latency, reliability, communication efficiency, traffic density, connection density, mobility, position accuracy) for each service categories. Here, the communication efficiency includes spectrum efficiency, energy efficiency and network resource efficiency. Table 3

shows the summary of potential requirements for each vertical group of use cases related to vertical industries.

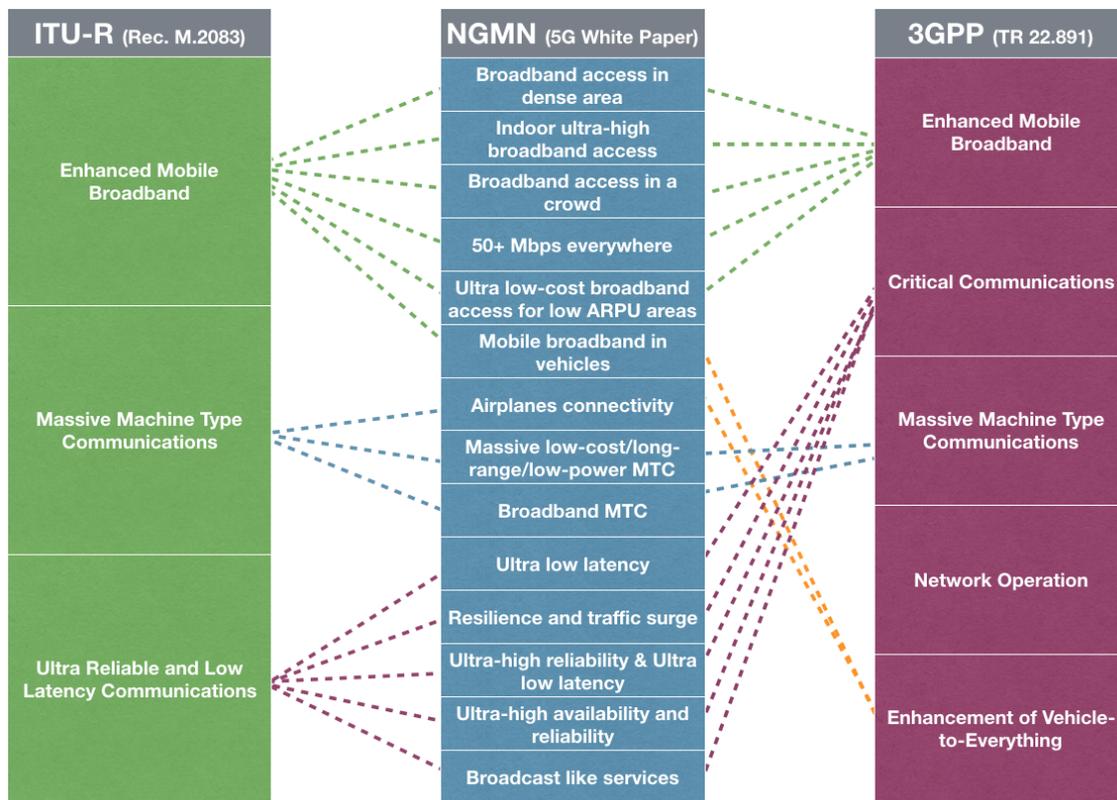


Figure 1. Comparisons of diverse 5G services in International Telecommunication Union-Radiocommunication Sector (ITU-R), Next Generation Mobile Networks (NGMN) and 3GPP [1,10,11].

Table 1. Technical requirements for 5G services in ITU-R [1]. eMBB, enhanced mobile broadband; mMTC, massive machine-type communications; URLLC, ultra-reliable and low-latency communications.

Service Category	Peak Data Rate	User Experienced Data Rate	Spectrum Efficiency	Mobility	Latency	Connection Density	Network Energy Efficiency	Area Traffic Capacity
eMBB	High	High	High	High	Medium	Medium	High	High
mMTC	Low	Low	Low	Low	Low	High	Medium	Low
URLLC	Low	Low	Low	High	High	Low	Low	Low

Table 2. Technical requirements for 5G services in NGMN [10]. ARPU, average revenue per user.

	User Experienced Data Rate	End-to-end Latency	Mobility	Device Autonomy	Connection Density	Traffic Density
Broadband access in dense area	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 100 km/h	>3 days	2500/km ² (Activity factor: 10%)	DL: 750 Gbps/km ² UL: 125 Gbps/km ²
Indoor ultra-high broadband access	DL: 1 Gbps UL: 500 Mbps	10 ms	Pedestrian	>3 days	75,000/km ² (Activity factor: 30%)	DL: 15 Tbps/km ² UL: 2 Tbps/km ²
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian	>3 days	150,000/km ² (Activity factor: 30%)	DL: 3.75 Tbps/km ² UL: 7.5 Tbps/km ²
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	120 km/h	>3 days	400/km ² in suburban 100/km ² in rural	DL: 20/5 Gbps/km ² (suburban/rural) UL: 10/2.5 Gbps/km ² (suburban/rural)
Ultra low-cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	On demand, 50 km/h	>3 days	16/km ² (Activity factor: 10%)	DL: 16 Mbps/km ² UL: 16 Mbps/km ²
Mobile broadband in vehicles	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h	>3 days	2000/km ² (Activity factor: 10%)	DL: 100 Gbps/km ² UL: 50 Gbps/km ²
Airplanes connectivity	DL: 15 Mbps UL: 7.5 Mbps	10 ms	Up to 1000 km	N/A	80 per plane 60 planes/18,000 km ²	DL: 1.2 Gbps/plane UL: 600 Mbps/plane
Massive low-cost long-range/low-power MTC	Low (typically 100 kbps)	Seconds to hours	On demand, 500 km/h	Up to 15 years	Up to 200,000/km ²	Not critical
Broadband MTC	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 100 km/h	>3 days	2500/km ² (Activity factor: 10%)	DL: 750 Gbps/km ² UL: 125 Gbps/km ²
Ultra low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian	>3 days	Not critical	Potentially high
Resilience and traffic surge	DL: 1 Mbps UL: 1 Mbps	Not critical	120 km/h	>2 weeks	10,000/km ²	Potentially high
Ultra-high reliability & Ultra low latency	DL: 10 Mbps UL: 10 Mbps	1 ms	On demand, 500km/h	Not critical	Not critical	Potentially high
Ultra-high availability and reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 500km/h	>3 days	Not critical	Potentially high
Broadcast like services	DL: Up to 200 Mbps UL: Modest	<100 ms	On demand, 500 km/h	From days to years	Not relevant	Not relevant

Table 3. Technical requirements for 5G services in 3GPP services and markets technology enablers (SMARTER) [11]. CriC, critical communications; mIoT, massive Internet of things; eV2X, enhanced vehicle-to-everything.

	Data Rate	Latency	Reliability	Communication Efficiency	Traffic Density	Connection Density	Mobility	Position Accuracy
Group eMBB	Very high data rate (e.g., peak rate 10 Gbps)	Very low latency, Low latency for high speed, Reliable low-latency connectivity between aerial objects	-	-	High traffic density	High density for UE (e.g., 2500/km ² , 50 active UEs simultaneously)	500 km/h	-
Group CriC	-	Real-time low latency (e.g., as low as 1 ms end-to-end)	Ultra high reliability, High availability	-	High density distribution (e.g., 10,000 sensors/10 km ²)	-	-	Precise position within 10 cm in densely populated areas
Group mIoT	-	-	-	Coverage enhancement, Efficient resource and signaling to support low power, Support devices with limited communications requirements and capabilities	High density massive connections (e.g., 1 million connections /km ²)	Low mobility	-	High positioning accuracy in both outdoor and indoor scenarios (e.g., 0.5 m)
Group eV2X	Medium rate (10 of Mbps per device)	Low latency (e.g., 1 ms end-to-end latency)	High reliability (nearly 100%)	-	Medium traffic density	Medium connection density	High mobility (e.g., up to 500 km/h)	High positioning accuracy (e.g., 0.1 m)

4. 5G Mobile Services

In this section, various 5G services are categorized into five groups based on their characteristics in terms not of technology, but of end-users' experience. Additionally, 5G mobile service scenarios and the requirements of each service category are investigated. Before looking into the 5G mobile service scenario, we have to explore its necessity, that is why 5G mobile services are required from the viewpoint of end-users as shown in Figure 2.

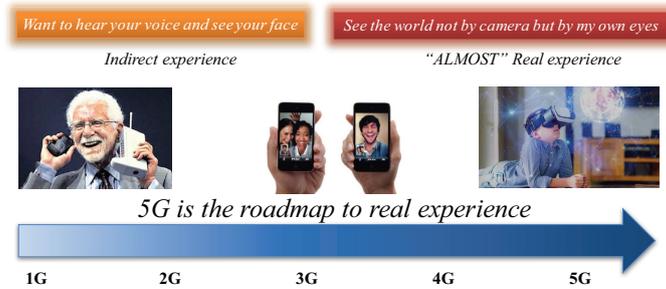


Figure 2. Concepts and necessity of 5G mobile service.

By examining the megatrend of 5G mobile services in the previous section, ideas and concepts on new 5G services can be developed. As shown in Figure 3, the new service scenarios can be grouped into five categories.

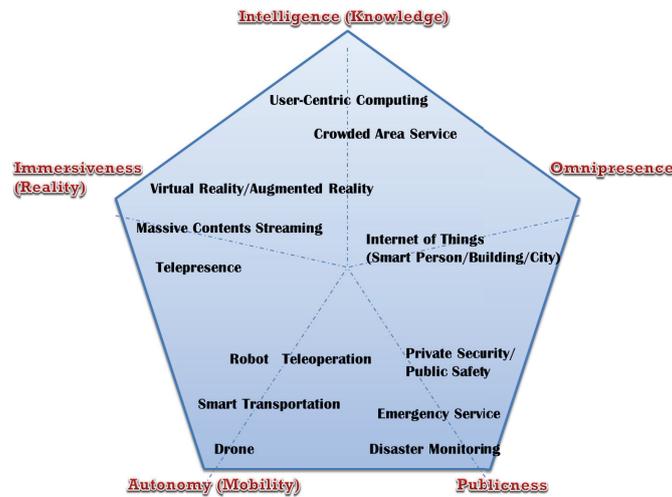


Figure 3. Categorization of 5G mobile service scenarios [13].

The suggested categorization is not far from that of IMT-2020 proposed by the IUT-R and other organizations. We can examine the similarities between IMT-2020 services and the proposed ones for exemplifying purposes. The immersive and intelligent 5G services, which require high-speed transmission, can be considered as eMBB in IMT-2020. Autonomous and public 5G services are related to URLLC. Finally, omnipresent 5G services correspond to mMTC. Then, we can conclude that the difference between the conventional and the proposed categorization of 5G is based on the point of view. The existing approach to grouping is based on a technical perspective, while the proposed one is based on the perspective of the end-users' experience.

4.1. Immersive 5G Services

4.1.1. Virtual Reality and Augmented Reality

VR and AR are the essential contents of future communications [14] as shown in Figure 4. The availability of low-cost head-mounted display (HMD) demands real-time and bandwidth-intensive services. However, long time usage of VR/AR results in dizziness and motion sickness. A possible solution to such a problem is to increase the refresh rate to at least 100 Hz and decrease motion-to-photon latency (the time required to fully reflect the motion of a user on the display screen) to 20 ms or less [15]. Furthermore, the service technology needs to cater to problems regarding insufficient image quality, viewing angle, input interface and information display methods. Future VR/AR requires offering a replica of the real site to the user. Hence, future service technology should handle a wide variety of entertainment content. Moreover, it should provide telepresence services and give the user the experience that he/she is in the same place as a remote user. Telepresence services need to be more realistic by offering the user the capability to use the five senses. Thus, VR and 3D holograms can be used together to make this a reality. Future 5G services will have to handle 4-K or 8-K resolutions to solve the image quality problem. The current VR technology provides a 110 degree viewing angle, and it needs to be extended to 200 degrees to meet the minimum level of user satisfaction. The user's equipment or HMD is limited in resources, such as memory, storage capacity, heat management and battery. This is a major obstacle in providing high definition video and 3D graphics in mobile environments. Cloud processing is one of the solutions to overcome this problem, and thus, 5G networks require supporting high bandwidth with low latency. Real-time AR/VR services cannot be achieved without higher transmission rate and low latency. In terms of a core network, network slicing can be one of the key technologies to realize low latency high throughput VR/AR services with other wireless technologies [16]. To alleviate the burden of fronthaul, backhaul and backbone networks and reduce end-to-end latency of networks, local computing with fog radio access networks (FRAN) is also required to provide real-time VR/AR services [17]. Accurate localization is also required for mobile AR services. In summary, 5G requires low latency processing and telecommunication technologies with an extremely high data rate to support real-time VR/AR and telepresence services.



Figure 4. Real-time mixed reality with AR and VR services.

4.1.2. Massive Contents Streaming

The development of digital and telecommunication technologies increases the demand for multimedia content. Such demand has been rapidly expanding over the past years in the form of broadcasting, movies, Internet and personal media. The continuous development of display technologies means that 5G technologies should be able to stream 4-K and 8-K ultra-high-definition (UHD) contents. It is anticipated that 5G will support expanding multimedia

services such as multi-view interactive 3D, personal multimedia broadcasting, massive content sharing and 3D holograms as shown in Figure 5. Multidimensional realistic media offers information that can be seen, heard and felt through the five senses, and hence, it overcomes spatial and time constraints. 5G is required to support such multidimensional realistic media services. For example, the user can enjoy a big sports event through a real-time hyper-realistic mobile hologram table. Moreover, holographic short message service (SMS) information can be transferred through 5G in conjunction with hologram technology. Though the current technology offers HD video call services, user experience is still far away from face-to-face conversation. Hence, this gap in the user's experience is expected to decrease significantly with 5G massive content streaming services. To achieve realistic services for users, hologram generation and delivery is the most desirable feature of 5G technology. 4G offers a 1-Gbps transmission rate, but it is still not able to provide holographic telecommunication services. Thus, it is important to ensure that 5G wireless technology and core networks are able to provide real-time hyper-realistic mobile holographic telecommunication services. However, hologram services require a bandwidth of several terabytes per second, and it is not possible to process holograms even with the 5G bandwidth. Still, restrictive hologram services with the minimum rate are possible. Future 5G research should concentrate on improving compression efficiency and decoding algorithms.

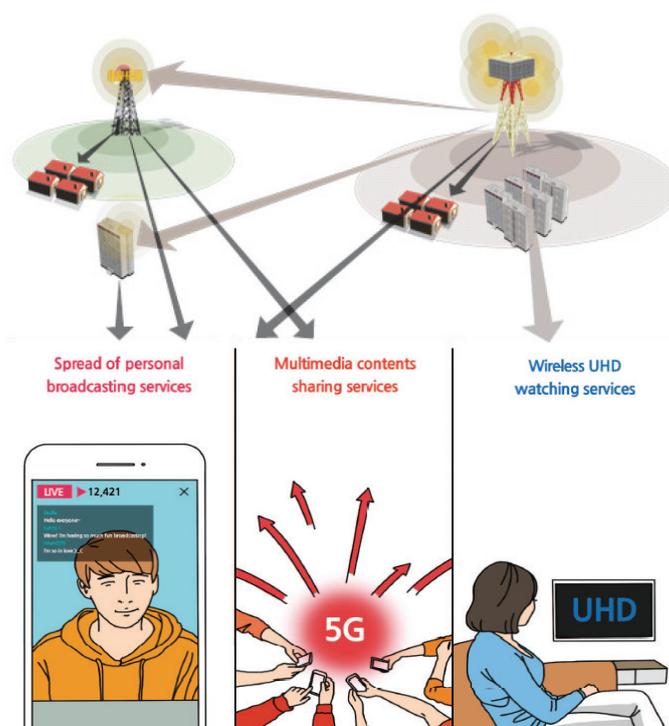


Figure 5. Massive content streaming services.

4.2. Intelligent 5G Services

4.2.1. User-Centric Computing

The user receives content after recognizing, interpreting and inferring on big data-based situational information collected through various sensors. Figure 6 shows examples of such services. Intelligent health services, such as personal health care, psychotherapy, de-stressing, business coaching, etc., are based on the big data analysis of life-logs. Future networks are expected to be more congested due to the increasing number of devices and data traffic. Consequently, this increases network delay and may hamper connectivity to cloud computing servers. The use of mobile edge computing is handy to reduce network delay and maximize efficiency when utilizing network resources [18]. Moreover, it is also useful for mobile services like smart cars, smart health care, industrial automobiles, augmented

reality and gaming. Mobile edge computing and accurate big data analysis of data coming from sensors are essential to provide prompt and timely response in the case of any disaster. They are also helpful to counteract climate change and industrial accidents. The increasing demand of data traffic requires future 5G technology to increase the data rate and decrease latency. Energy efficient actuators and sensors are necessary to support green communication. Moreover, low-power telecommunication technology is another desirable 5G feature. In short, 5G must provide efficient big data processing and rapid big data transmission with minimum latency. Additionally, accurate localization of mobile terminals is required to provide these services in a timely manner.

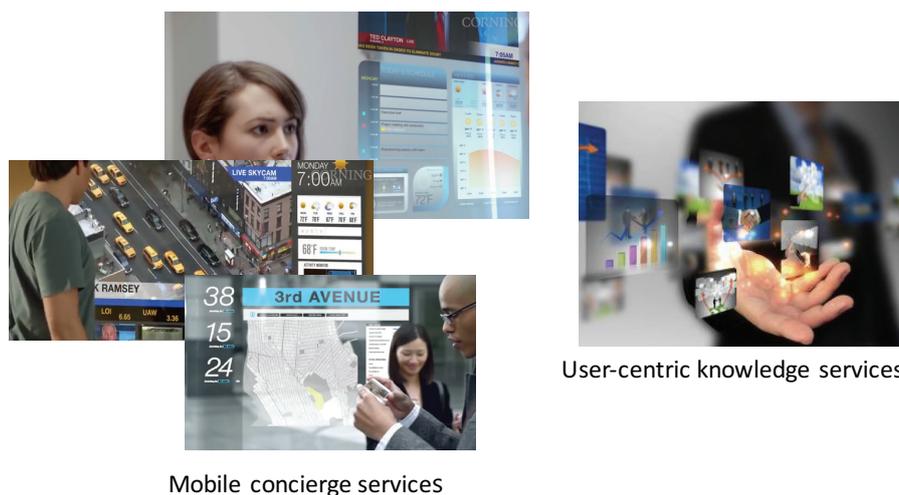


Figure 6. User-centric computing services.

4.2.2. Crowded Area Services

Crowded areas such as stadiums or concerts can be a source of massive amounts of traffic as shown in Figure 7. In these scenarios, many users are present, and they each get a different experience of service for similar and different content. Furthermore, many users upload and download UHD videos through social networks, and this eventually increases congestion. To provide wireless services efficiently in crowded areas, ultra dense networks cannot be avoided. In this scenario, placing video data at the network edge of base stations along with mobile edge computing reduces the load of the 5G core network. User location identification helps to provide location-based services in large shopping malls. The current 4G networks provide crowded area services by using many base stations and the available backbone bandwidth. Hence, 5G can provide these services effectively without any interruption by adopting the small-cell concept and mobile edge computing. However, all these services come at a certain cost; therefore, there is a trade-off between quality of service and cost. UHD and 3D multimedia contents are replacing the current low-volume contents, and the 5G network entails supporting a higher transmission rate. The ever-increasing multimedia traffic cannot be processed at the central server. Consequently, technologies such as local caching servers are essential to provide data from local servers in the 5G network.

As technical challenges for intelligent 5G services including user-centric computing and crowded area services, energy-efficient user association and power allocation, energy harvesting base stations and fronthaul technologies are considered [19,20]. To support intelligent 5G services, especially crowded area services, dense small cell networks cannot be avoided. In some cases, the small cell base station (BS) can be a moving BS, i.e., mobile BS, and then, energy efficiency can be a more significant issue. To achieve high energy efficiency, optimization of user association and power allocation, as well as an energy harvesting feature are needed. The optimal partitioning and design of fronthaul can be an issue in terms of bandwidth and latency of fronthaul.



Figure 7. Crowded area services.

4.3. Omnipresent 5G Services

4.3.1. Internet of Things

5G introduces many heterogeneous devices with different characteristics as compared to 4G. The introduction of wearable devices and network-connected home devices that often communicate with each other generates much exchange of information. These information exchanges generate huge volume of information in various dimensions that are saved in storage devices and are later processed using big data technologies. As shown in Figure 8, IoT can be categorized into smart personal networks, smart buildings and smart cities, depending on its application and network size. Smart personal networks contain smart watches, smart glasses, various healthcare devices and motion detection devices. A feature of smart personal network services is monitoring personal health conditions and suggesting exercises or medicine. The market volume of these devices is expected to increase to 162.9 million units in 2020 [21]. Smart buildings contain various sensors, light and temperature controllers, efficient energy controllers and crime prevention systems. In smart cities, efficient traffic light control systems can be deployed using various types of traffic sensors. This will eventually help to control traffic smartly while communicating with vehicles and road side units (RSUs). IoT is helpful in establishing efficient city infrastructure by using big data technologies to process information about traffic flow. Then, it is possible to inform users of the recommended transportation and the estimated arrival time according to traffic conditions. However, a network with low latency is a prerequisite or an otherwise serious problems in traffic safety might take place. The massive increase in network connected devices will soon exhaust the International Mobile Subscriber Identity (IMSI) and IPv4. In future IoT scenarios, a tremendous amount of connected devices will be present compared to current 4G network scenarios. Therefore, 5G technologies for transmission and networks have to be able to maintain multiple network connections with many devices using limited resources. Currently, the pricing policy of mobile services is applied per terminal or connection. The number of terminals is expected to increase exponentially; therefore, a new criteria of billing is required.



Figure 8. Smart personal, building and city services with IoT.

4.4. Autonomous 5G services

4.4.1. Smart transportation

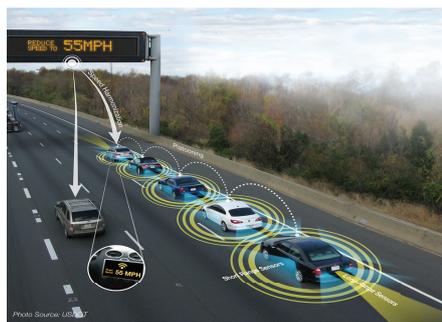
The concept of smart transportation refers to a transportation system that enables improved safety, higher productivity and efficiency with the help of a network infrastructure. 5G combined with artificial intelligence (AI) algorithms is one of the main enabling technologies for such smart transportation systems. Connected cars and RSUs will offer services of collision avoidance and route optimization under a dedicated transport network with high security, high performance and cloud computing. As shown in Figure 9, the use cases in the automotive domain that are relevant for 5G include: autonomous driving vehicles, vehicle platooning and traffic safety and control [22]. With the advent of automated driving functions, especially with the broad availability of vehicles capable of supporting higher automation levels, autonomous-driving cars are the future of smart transportation [23,24]. Autonomous-driving cars have the intelligence to recognize, decide and control accordingly. Enhanced V2X communications and autonomous functions are designed to avoid accidents caused by human error. The concept of vehicle platooning refers to vehicles traveling together by following a lead vehicle. This leads to increased safety and comfort, reduced traffic congestion and efficiency improvement. Vehicle platooning can be easily implemented through communication with 5G base stations and vehicle-to-vehicle communications. 5G base-stations can figure out the location and speed information of vehicles in real time through 5G with low latency and can support maintaining the minimum distance between cars. Traffic safety and control include all the services to ensure maximum safety in any type of situation. These applications include large-file and real-time data exchange and, in the case of passenger terminals, real-time information, entertainment systems and video advertising. V2X and some other intelligent transportation systems (ITS) applications require very low latency; much lower than the one provided by current technologies. In addition, driverless and next-generation driver-assisted cars will need real-time safety systems that can exchange data with other vehicles and a fixed infrastructure around them. These types of cars need to process at least 1 Gbps of data rate to make smart decisions. However, current technologies cannot support the simultaneous transmission and reception at such a high data rate among thousands of cars within a small area. Therefore, 5G technology is essential for providing real-time services in future vehicles, and baking low latency

into the design of 5G networks will open up the potentially large market of smart transportation for wireless operators. Localization is also one of the significant requirements for autonomous-driving vehicles to acquire the accurate information around the vehicles.

Cellular V2X (C-V2X) provides connectivity between vehicles and everything with enhanced architectures and features based on cellular technologies [25]. In 5G, C-V2X can use both below the 6-GHz band for high service reliability and above the 6-GHz band, e.g., millimeter wave, for high volume data transfer, while also providing low latency wide area network support for assisted driving. Additionally, C-V2X direct communications can operate in the 5.9-GHz ITS spectrum band, which is used by IEEE 802.11p-based WAVE technology, without cellular subscription requirement for direct safety communications. Though the coexistence of C-V2X and IEEE 802.11p-based WAVE can be considered, C-V2X may be preferred as a 3GPP standard because C-V2X can provide a direct evolution path from LTE to 5G and can support all V2X applications with the same technology.



Self driving car



Platooning



Smart traffic control

Figure 9. Smart transportation services.

4.4.2. Robots

Robots are on a high-growth trajectory within both the industrial and the consumer sectors. 5G will provide networking functions that are necessary to allow various industries to leverage the next phase of robot evolution. Moreover, the information flow between assemblies and control systems with robots is another example of 5G services. 5G will pave the way for a new generation of robots. Some robots that can freely move are controlled via wireless rather than wired communication links and exploit the vast computing and data storage resources of the cloud. Armed with these capabilities, robots can be precisely controlled dynamically in near real time and be connected to people and machines locally and globally. The use cases of 5G in robots include teleoperation and smart industrialization services. Teleoperation refers to the concept in which a robot is controlled by a person or a control center remotely. Remote surgery in Figure 10 and remote sensing are applications of teleoperation [26]. To understand the synergy between 5G and robots, healthcare is one of the best examples where robotics has immense potential. Robots may not only perform mundane functions, such as transferring things, but also perform telesurgery aided by 5G communications and cloud networks. Remote surgery services also involve transmitting 3D video data of the surgical site and medical data related to the patient in the real time. It may also involve controlling the surgery robot based on received data and delivering control information to perform surgical actions. Robot services

may also involve sending a robot in a radioactively-contaminated area and controlling it remotely based on the video and sensor data captured by the robot. Smart industrialization [27] refers to replacing human workforce with robots that can perform the same work repeatedly, such as assembly processes using robots. There are several limitations associated with the current technologies, such as latency, reliability and high throughput, for such applications of robots. Therefore, 5G for robot services provides solutions to these limitations.

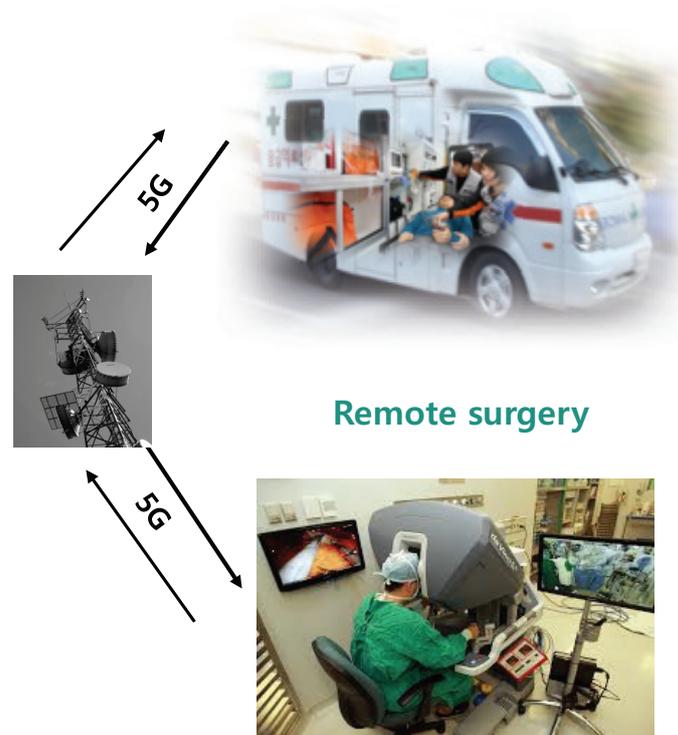


Figure 10. Remote surgery services with robots.

4.4.3. Drones

Drones can take on various tasks and bring new efficiency to a wide range of industries and enterprises. Drones can be used as flying cameras, for delivery purposes, for public safety, for disaster monitoring, for infra-structure facility management, in the military and agricultural fields, etc. With the high reliability and low latency of 5G, these tasks can be carried out by a group of unmanned vehicles (UAVs) communicating and adjusting their behavior through real-time data inputs and data sharing. For military purposes, drones can collaborate with manned aerial vehicles with or ground forces to enhance fighting efficiency. The establishment of mobile surveillance networks using drones can also be considered. To monitor disasters, inspect the status of infrastructure facilities and rescue people in emergencies, drones may communicate and share real-time data with each other, thus increasing the speed and effectiveness of search and rescue missions. Besides, drones may play an important role in intelligent transportation networks. Drones may monitor and deliver transportation status in urban areas or highways through 5G networks. Currently, there are no specific standards for communication links for drones. Hence, 900-MHz systems are used for them as an alternative, and 2.4 GHz or 5 GHz Wi-Fi is used for data transmission for videos. Thus, there exist some serious problems, such as limitations in communication range, ensuring reliability and network latency. Although the volume of data used to control drones and the data regarding their control status is not very big, the low latency and high reliability of such networks must be secured with 5G technology. In addition, 5G transmission and network technologies with high energy efficiency may be used to improve the operation time of drones. Another example of drone services with

5G connectivity is the Internet by drones [28]. Drones will help spread the Internet to areas that lack reliable connectivity. Such technology is already being tested, and connectivity through 5G will make it more reliable.

4.5. Public 5G Services

4.5.1. Disaster Monitoring

Multiple sensors can be used to monitor mountains, seas and radioactively-contaminated places, as well as to minimize damage under disaster situations by providing a quick response through interworking with public safety networks. Sensors may also monitor forest fires and landscape changes by sensing temperatures, vibrations, wind speeds and wind direction. Radioactivity detection sensors can be used to monitor changes in the radioactivity index at radioactively-contaminated areas. It is possible to monitor radioactive contamination in real time and to utilize that information for access control or disaster notification services. Moreover, sensors can be installed in infrastructure facilities, such as dams, bridges and expressways, and can be utilized for the maintenance of facilities along with monitoring the risk of collapse. As of now, such monitoring networks use existing communication standards, such as Wi-Fi or ZigBee. However, these networks are unable to provide the desired quality of service (QoS) in terms of coverage, energy efficiency, network reliability and cost efficiency. On the other hand, 5G networks may play a role in public safety networks using the highest-priority protocol when an event of emergency occurs. The integration of satellites in future 5G networks will be seen as an essential part of the terrestrial infrastructure to provide strategic solutions for critical and lifesaving services. Satellites will be able to supply critical and emergency services and keep the network alive in cases of disaster. In terms of the sensors' battery lifetime, energy efficiency is one of the most significant features for 5G. Disaster monitoring networks require extreme levels of reliability in their network connections. Hence, hyper-energy-efficiency and hyper-reliability are mandatory features for 5G networks. At the same time, the main requirements of sensor networks, such as coverage and cost effectiveness, shall also be considered in 5G networks.

4.5.2. Private Security and Public Safety

In disaster situations, networks may be reconstructed as quickly as possible with mobile base stations and wireless core networks, as first-aid activities are carried out. In such situations, infrastructureless networks should be established only with mobile devices to provide the minimal telecommunication services needed. In addition, network-connected CCTVs can monitor city safety. These examples are shown in Figure 11. The spatial limitations can be overcome by using drones and unmanned robots in cases where the rescuers cannot easily access the disaster area. These robots will be able to inform about field status to the rescue workers and the command center and also rescue and restore the site remotely. Moreover, a service to inform about the location of people to rescue can be provided by using relay transmissions between public safety-enabled (PS-enabled) terminals even without a network infrastructure [29]. In addition, 5G can provide advanced security mechanisms. The most important feature of 5G to facilitate such security and safety services is to classify public safety service data according to priority. Additionally, public safety services may be provided with PS-enabled terminals that can broadcast the message and perform direct relay communication via their terminals. For public safety networks or military strategy networks, features regarding higher security and reliability may be provided. Energy efficiency of PS-enabled terminals shall be secured for longer operating times in emergency situations. Furthermore, mission critical services requiring very high reliability and global coverage will be supported by the 5G infrastructure.

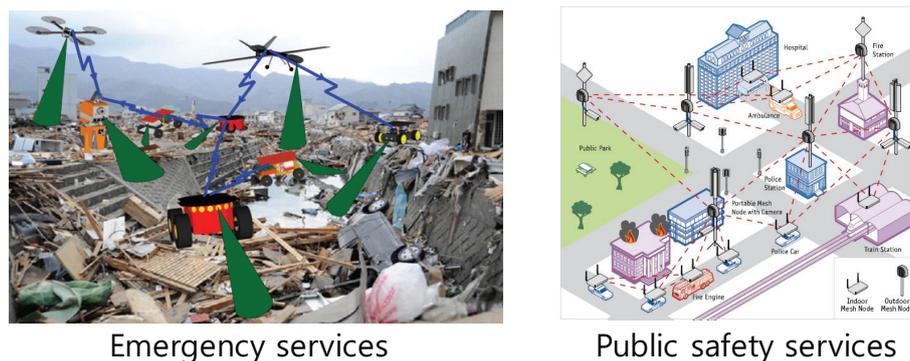


Figure 11. Private security and public safety services.

4.5.3. Emergency Services

In an emergency situation, responsiveness to the emergency can be improved by providing the data of a patient in an ambulance and getting remote medical care. In detail, when an accident occurs in a remote place and emergency actions are required, medical treatment can be provided through first-aid robots. The limitations of current technologies for these types of services include reliability and the requirement of low latency. The delivery of medical data obtained from emergency situations and the information on remote medical treatment and surgery should be delivered with the highest level of reliability and the lowest latency. In addition, high-quality videos regarding the emergency area and the medical data on the patients need to be sent with high speed and wider network coverage. Hence, 5G will be suitable for such types of emergency services, with its ultra-reliable wireless transmission and latency within 1 ms.

5. 5G Wireless Network Requirements

In the previous section, the limitations on 4G networks to provide for each service scenario were examined, and the new technical requirements were suggested to overcome these limitations. Based on this analysis, the requirements of 5G networks in terms of wireless technologies to provide for each service are summarized in Table 4. In this table, seven required wireless technologies are included along with a detailed description. These are closely related with the KPIs of 5G. Additionally, Table 5 (⊙: first-tier requirement, ⊖: second-tier requirement, ○: third-tier requirement, MCS: massive contents streaming, UCC: user-centric computing, CA: crowded area, ST: smart transportation, DM: disaster monitoring, PS/PS: private security/public safety, ES: emergency services) shows the relationship between 5G services in different categories and the required wireless technologies. For example, the requirements of IoT services can be explained as follows. Technology for massive connections are required to support the huge number of sensors in a single cell. Because most of these sensors can operate for at most several years with the battery that is initially equipped, energy efficiency in wireless transmissions is a significant requirement. Furthermore, the implementation cost of such sensors should be minimized. In addition, some of the data delivered through the smart grid networks and intelligent transportation networks in smart cities should be transmitted with high reliability and low latency. Thus, as the first three requirements mentioned are needed in every IoT scenario, they are placed in the first tier. The remaining two are in the second and third tiers because they are limited to certain scenarios.

Table 4. Technical requirements for 5G wireless networks.

Technical Requirements	Description
W1: Ultra high speed	Provide tens of Gbps peak data rate Provide up to 1 Gbps user experienced data rate Provide areal capacity of 10 Mbps per square meter
W2: Massive connection	Identify all devices (maximum of one trillion devices) over the world Provide services to a million terminals per square kilometer
W3: High reliability	Provide 99.999% service availability even in an extreme situation Guarantee a single packet transmission failure per 10,000 or 100,000 transmissions
W4: Ultra-low latency	Provide less than 1ms latency over radio interface
W5: High mobility	Guarantee seamless connectivity to moving terminal at speed of 500 km/h
W6: High energy efficiency	Improvement of 100 times energy efficiency per bit, in both network and device sides Energy harvesting capabilities can be applied to sensors
W7: High cost effectiveness	Improve cost effectiveness in network side even handling huge volume of traffic Reduction of devices' cost especially in sensors

Table 5. Requirements of 5G services in terms of wireless technology. ⊙: first-tier requirement, ⊙: second-tier requirement, ○: third-tier requirement, MCS: massive contents streaming, UCC: user-centric computing, CA: crowded area, ST: smart transportation, DM: disaster monitoring, PS/PS: private security/public safety, ES: emergency services.

•	Immersive 5G		Intelligent 5G		Omni-Present 5G	Autonomous 5G			Public 5G		
	AR/VR	MCS	UCC	CA	IoT	ST	Drone	Robot	DM	PS/PS	ES
W1: Ultra high speed	⊙	⊙		⊙			⊙	⊙			
W2: Massive connection				○	⊙				⊙		
W3: High reliability					○	⊙	⊙	⊙	⊙	⊙	⊙
W4: Ultra low latency	⊙	⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙
W5: High mobility						⊙	⊙		⊙		
W6: High energy efficiency					⊙		⊙		⊙	⊙	○
W7: High cost effectiveness			⊙	⊙	⊙				○		

6. 5G Core Network Architecture and Requirements

The technical requirements of 5G core networks are summarized in Table 6. These core network requirements are described in three aspects to support various 5G services in Section 4: functional requirements (F), architectural requirements (A) and operational requirements (O) [30]. For example, to meet the core network requirement F1, the 5G core network should support seamless mobility regardless of cell type and radio access technologies (RATs) where macro-cell base stations (BSs), small-cell BSs, personal-cell BSs, wireless local area network (WLAN) access points (APs) and relay stations are mixed and overlapped. In addition, to provide IoT-related 5G services, the 5G core network should provide the requirement, A2. In order to provide lightweight signaling, the 5G core network should have a lightweight signaling protocol to support a variety of terminals such as massive machine-type communication (MTC) terminals. In addition, fine grained location tracking is one of the

most important requirements for user-aware (or context-aware) 5G services. The 5G core network should provide the functionality to trace the mobile terminal's location with a fine granularity for advanced location based services. Table 7 shows the relationship between 5G services and 5G core network requirements. Therefore, we are herein able to check the required functionalities in the 5G core network in order to support each service addressed in Section 4. To provide 5G-based mobile virtual reality and augmented reality services, the 5G core network should provide the functionalities: F1-seamless mobility, F2-wired/wireless terminal switching, F3-context aware best connection, A4-fine grained location tracking, O1-flexible reconfiguration and upgrade and O2-network on-demand. In other words, the 5G core network needs to satisfy these essential requirements to offer an immersive and realistic user experience.

Figure 12 shows a software-centric 5G core and access network architecture designed to support various 5G mobile services. In particular, the 5G network should create optimized service environments for supporting a variety of vertical services via 5G mobile networks [14,22,26,27]. In order to efficiently manage physical and logical network resources, the 5G core network appropriately manages and orchestrates these various vertical services as virtualized network slices (1:VR/AR, 2:MCS, . . . , n:ES) as shown in Figure 12. In this figure, the fronthaul and the backhaul represent the interface between access units (AUs) and the edge cloud and the interface between the edge cloud and the core cloud, respectively. The AU-cloud unit (CU) configuration is similar to the conventional radio unit-digital unit (RU-DU) configuration of a cloud radio access network (C-RAN) in the 3GPP-LTE system. The legacy RUs are remote RF units located at cell-sites, and centralized DUs are connected with these RUs and have relatively heavy functionalities regarding the medium access control (MAC) layer, radio link control (RLC) layer and the packet data convergence protocol (PDCP) layer, compared with RUs. Because the fronthaul data overhead between RUs and DUs is predicted to increase explosively, several functionalities of DUs will be moved into RUs at cell-sites. Thus, we call this modified cell-site unit in the 5G core network the AU, and CUs can be considered as the lightweight DUs. In addition, the mobile edge computing (MEC) entity in the edge cloud provides application developers and content providers with cloud computing capabilities and a 5G service environment at the edge of the 5G mobile networks. In particular, this MEC technology is leveraged to support ultra-low latency and high-bandwidth services. In the 5G core network architecture, the separation of the control plane (CP) and the user plane (UP) is one of the most important features in order to increase operational efficiency, as well as to improve network simplicity and flexibility. Moreover, elaborated management and orchestration of a number of virtualized network resources and slices should essentially be provided in 5G core networks.

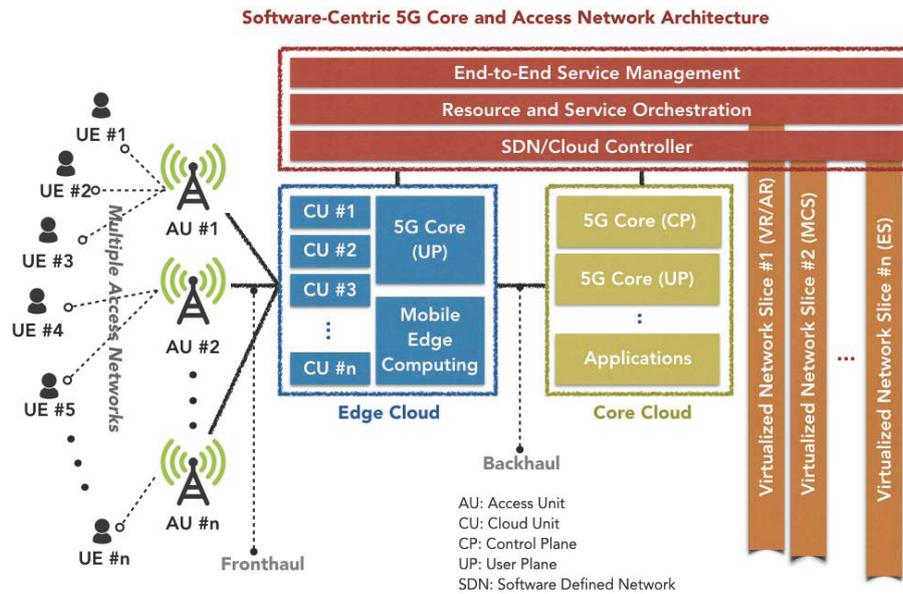


Figure 12. Software-centric 5G core and access network architecture.

Table 6. Technical requirements for 5G core networks [30]: functional requirements (F), architectural requirements (A) and operational requirements (O). RATs, radio access technologies.

Technical Requirement	Brief Description
F1 Seamless mobility	Shall support seamless mobility regardless of the cell types and RATs where the macro-cell BSs, small-cell BSs, WLAN APs, and relay stations are mixed and overlapped.
F2 Wired/wireless terminal switching	Shall support terminal and/or session mobility to provide fast handover between wireless and wired terminals
F3 Context-aware best connection	Shall utilize the various context information (device, user, environment, network) to provide always best connection/service
F4 Single ID for multiple access	Shall recognize a mobile terminal as a single entity regardless of its access network
A1 Distributed architecture	Shall support the distributed network architecture to accommodate anticipated 1000 times of traffic
A2 Lightweight signaling	Shall have lightweight signaling to support a variety of terminals such as massive MTC terminal
A3 Multiple RAT interworking	Shall have architecture to support 'Flow over Multi-RAT' to provide the high volume service with low cost and guarantee the service continuity in spite of the bandwidth deficiency in a wireless access
A4 Fine-grained location tracking	Shall have function to trace the mobile terminal location in a fine granularity in order to provide advanced location based service
O1 Flexible reconfiguration and upgrade	Shall provide virtualization environment and support to reconfigure and upgrade the core network at low cost without changing the physical network infrastructure
O2 Network on-demand	Shall be able to build the network based on the QoS/QoE, charging, and service characteristics

Table 7. Relationship between 5G services and 5G core network requirements.

Service Category		F1	F2	F3	F4	A1	A2	A3	A4	O1	O2
Immersive 5G Service	Virtual Reality and Augmented Reality	✓	✓	✓					✓	✓	✓
	Massive Contents Streaming	✓	✓			✓				✓	✓
Intelligent 5G Service	User Centric Computing		✓	✓						✓	✓
	Crowded Area Service	✓				✓				✓	✓
Omnipresent 5G Service	Internet of Things		✓	✓		✓	✓			✓	✓
	Smart Transportation	✓	✓	✓	✓				✓	✓	✓
Autonomous 5G Service	Smart Drone	✓		✓					✓	✓	✓
	Smart Robot			✓			✓			✓	✓
	Disaster Monitoring			✓				✓	✓	✓	✓
Public 5G Service	Private Safety and Public Security			✓				✓	✓	✓	✓
	Emergency Service	✓		✓				✓	✓	✓	✓

7. Conclusions

By analyzing the megatrends of future mobile services, the concept of 5G services, which emphasize the realistic experience of end-users, has been established. Immersive, intelligent, omnipresent, autonomous and public 5G service categories and detailed service scenarios have been explained from the end-users' perspective. Depending on the use case, the technical limitations of 4G, which can be technical challenges of 5G, have been analyzed. To provide the various 5G services described, innovative wireless technologies and a new network architecture should be guaranteed. The proposed requirements for both wireless technologies and core networks can be used as a guideline in the standardization, implementation and deployment of 5G networks.

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Author Contributions: Heejung Yu and Howon Lee proposed the categorization and technical requirements of 5G services. Hongbeom Jeon analyzed trends of mobile services and provided the direction of the paper.

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