SK Telecom 5G White Paper

SK Telecom's View on 5G Vision, Architecture, Technology, and Spectrum

Network Technology R&D Center

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Table of Contents

1. Introduction

While voice service was the centre of mobile telecommunications until the third generation, innovative technology and evolution of services in 4G has led a significant paradigm shift towards data-centric mobile telecommunications. Recent mobile data traffic trends show that the types of services such as multimedia and the internet-based services which were used to be available only with wired networks have now become major contents in the wireless network environment as well. This change in mobile content usage patterns is attributable to, in the process of the technological evolution from 3G to 4G, a rapid improvement of data transmission speeds and development of a range of new services by mobile service providers for differentiated customer experience. The technological evolution is moving beyond 4G and now discussions on 5G are already under way at home and abroad with an aim to commercialize it by 2020.

Currently, ITU-R is preparing to define vision for 5G-based convergence services and the Korean government has also set up the Creative 5G Mobile Strategy, under which it presented SNS, mobile stereoscopic image, intelligent service, ultra-high-speed service and UHD/hologram as the five core services. In addition, some countries including Korea, EU, China and Japan have started to establish a special organization to define the 5G concept and share views on 5G network and services around it. And initial discussions are ongoing focused on innovation of mobile telecommunication technology to deliver Giga-bit data rate and the potential 5G services that can reflect people's life styles in 2020, the year the industry is aiming to commercialize the technology.

In an effort to meet the requirement of evolution to 5G from in and out of the country, SK Telecom has also conducted research on 5G network from 2013 and is actively participating in global 5G discussions.

This document will outline how SK Telecom views and conceives 5G in general, which includes background behind the technological evolution to 5G and requirements, vision, architecture, major enabling technologies, potential frequencies and services and future direction of the telecommunications network development.

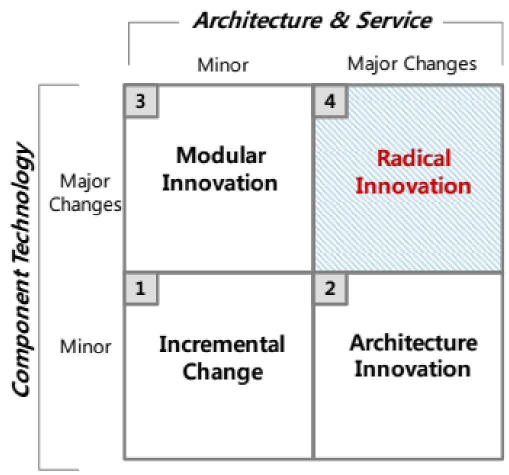
2. Direction and Key Requirements of 5G

2.1 The Direction of Evolution

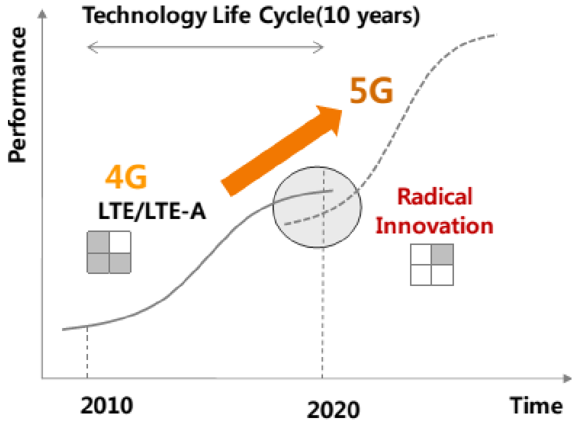
Mobile communications service operates by a different combination of diverse network component technologies, and it has developed over time with emergence of new technologies throughout the generations. Evolution of telecommunications technology can be classified by two criteria, architecture and component technology, as described in Figure 1 below. Until 4G, it was individual or gradual development of architecture and component technology that has led the evolution while, in 5G, innovation in network architecture, combined with component technologies, will become a catalyst for new value creation and another leap in mobile communications. In other words, a true evolution to 5G can be achieved by pursuing both continued technological evolution build upon the existing LTE/LTE-A and a completely new revolution of technology.

A development curve in Figure 2 is showing this pattern of technology evolution. If we consider the life cycle of one generation of network technology as 10 years, it is expected that the 5G evolution will arrive roughly in 2020 through innovation of architecture and overall component technologies. Besides, introduction of revolutionary technologies will further accelerate the drastic improvement of network performance by the time when 5G takes hold.

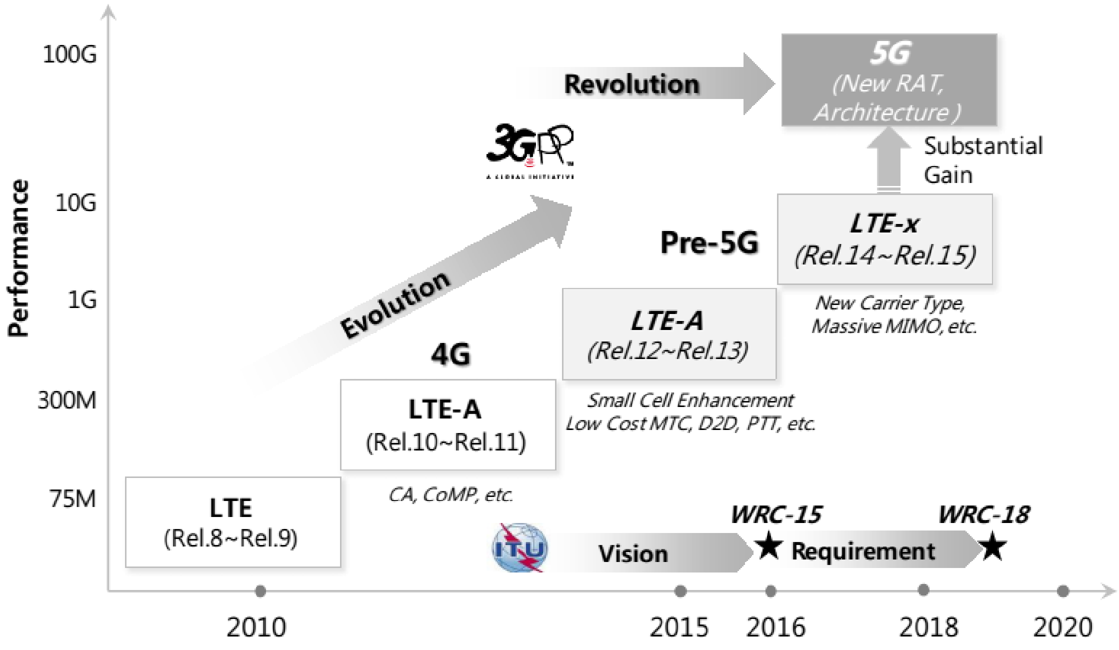
In view of the two dimensional development of 5G, evolution and revolution, the evolution can be achieved by a continued advancement of the existing LTE-A. Meanwhile, 5G standards are highly likely to be developed by 3GPP, which also published specifications for the current LTE/LTE-A, the development timeline is anticipated to be as Figure 3.



[Figure 1] Classification of technological evolution



[Figure 2] 5G evolution curve



[Figure 3] Direction and expected timeline of evolution to 5G

2.2 Key Requirements

Although no requirements or technical specifications of 5G have been agreed upon yet, 5G is widely conceived by its global ecosystem to be a set of telecommunications technologies and services that support a 1000 times more data capacity as LTE and 1Gbps per user through super-dense networking.

Requirements for 5G should be defined in multiple dimensions encompassing perspectives of user, network and service. This document suggests the below five conditions as key requirements for 5G.

① User Perspective: **"Ultra High Speed & Low Latency"**

- Achieve 1000x fast data transfer speeds as LTE, ultra-low latency response time of less than a few milliseconds and realistic contents

② Performance Perspective: **"Massive Connectivity"**

- Accommodate 1000x more devices and traffic and secure seamless connectivity (4A Connectivity – Anytime, Anywhere, Anyone, Anything)

③ Architecture Perspective: **"Flexible/Intelligent Network"**

- Provide S/W-based structure, analyse data in real time and provide intelligent/personalized services

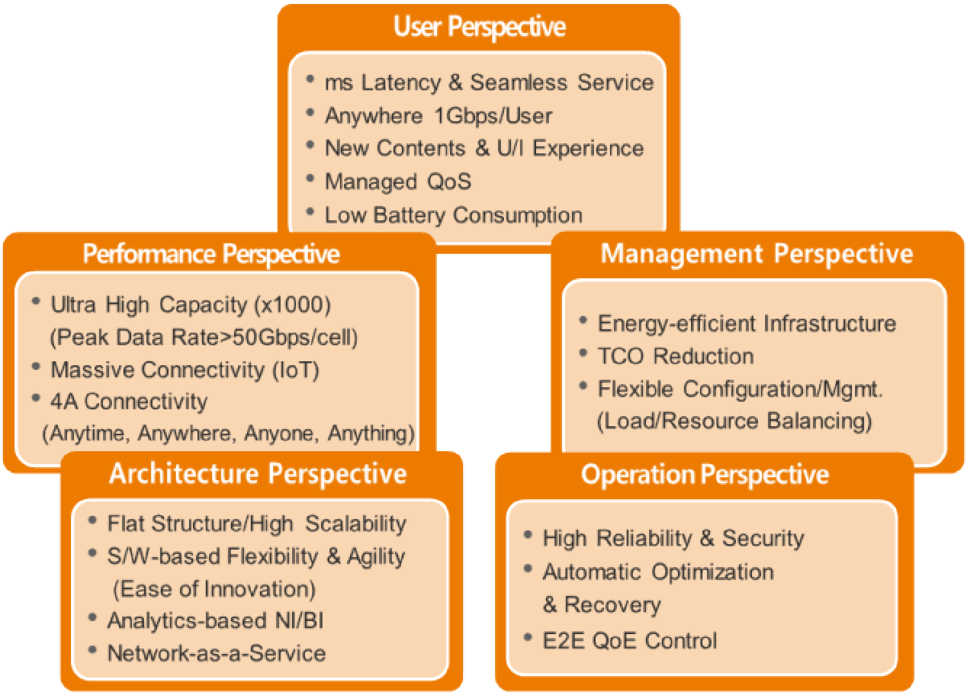
④ Operation Perspective: **"Reliable/Secure Operation"**

- Secure more than 99% of network availability and reliability as well as self-healing/reconfiguration

⑤ Management Perspective: **"Energy/Cost-Efficient Infra"**

- Achieve a 50-100x higher energy efficiency as LTE and low-cost infrastructure/devices

Figure 4 describes the key requirements with a diagram. In order to satisfy the five requirements, quantitative KPIs (Key Performance Indicator) as well as more detailed requirements for such indicators have to be defined and, currently, discussions with such goals are taking place around the globe. As a reference, this paper adds detailed quantitative requirements that have been agreed in the 5G Forum, which SK Telecom is participating as a chair company, in Table 1. Looking into major requirements, 5G networks should provide a capacity of more than 50Gbps per cell and guarantee more than 1Gbps speed per user anywhere while supporting ultra-low latency response of less than 1ms in data plane. Such technical requirements are subject to change according to an evolutionary direction of the technology and are to be amended reflecting radio frequency status or technological maturity in the process of standardization.



[Figure 4] 5G key requirements

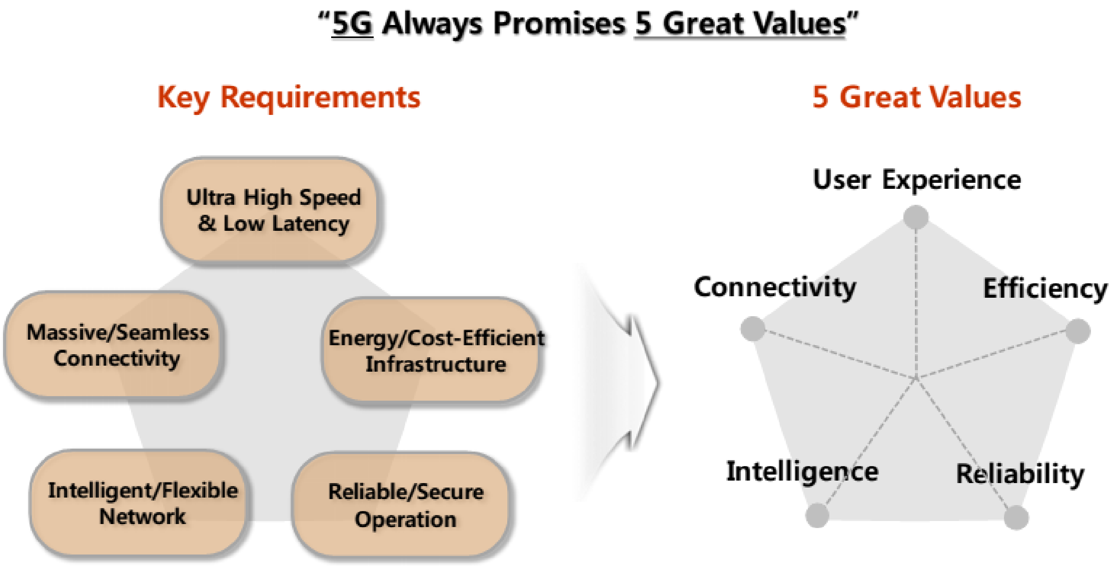
[Table 1] Technical requirements (5G Forum)

Area	Requirements
Cell Spectral Efficiency	DL : 10 bit/Hz/cell (@10/30 Km/h)
	UL : 5 bit/Hz/cell (@10/30 Km/h)
Peak Data Rate	DL : 50 Gbps
	UL : 25 Gbps
Cell Edge Data Rate	DL : 1 Gbps (@10/30 Km/h)
	UL : 0.5 Gbps (@10/30 Km/h)
Latency	Control Plane : 50 ms
	User Data Plane : 1 ms
Handover Interruption Time	10 ms
Areal Capacity	FFS
Energy Efficiency	FFS

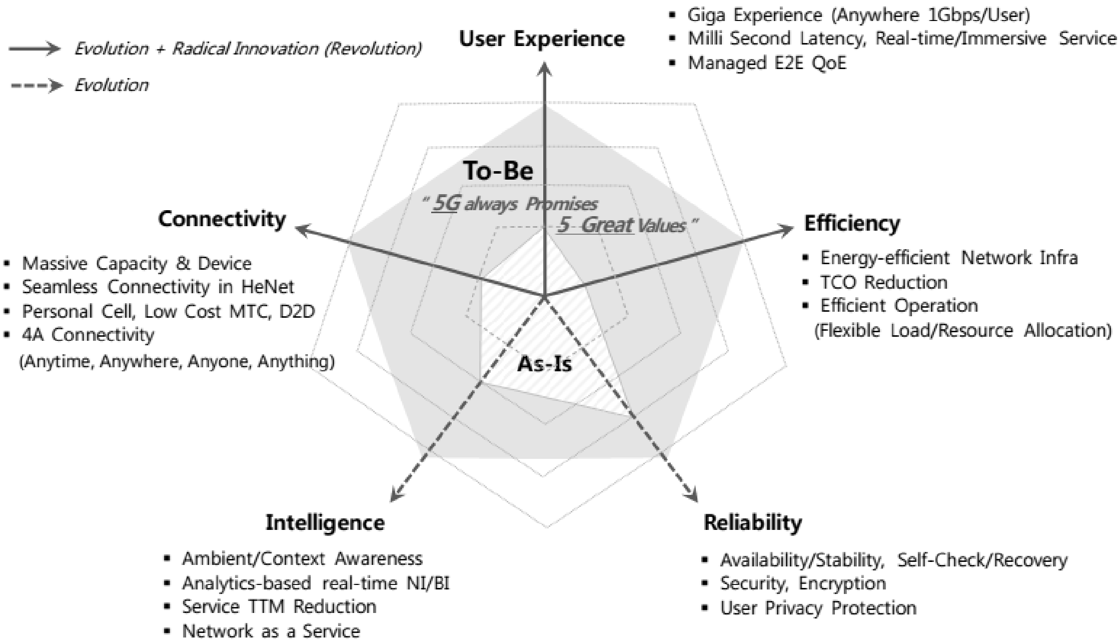
3. Vision

Before diving to details of 5G technology, vision and values of the 5G mobile networks need to be defined. Based on the five key requirements for the technology evolution mentioned in chapter 2, SK Telecom drew values and presents 5 Great Values of 5G. This paper suggests User Experience, Connectivity, Intelligence, Reliability and Efficiency as five differentiated values of 5G in Figure 5. Each value can be mapped back to individual requirement, and each of the five components should add value from both end user and MNO's perspectives. These 5G requirements and 5 Great Values well define SK Telecom's vision for 5G, which is 5G systems should become value-creating networks that always guarantee 5 Great Values while bringing innovation to mobile life in our society and creating value with ICT by achieving "5G Connected Society".

Figure 6 in the below explains 5 Great Values more in detail and analyses status quo of each value. Among the great values, according to the diagram, the gap between the current status and a level required for 5G is noticeably wide in User Experience, Connectivity and Efficiency, which means these areas need substantial improvement through both continuous evolution over 4G and new revolution in parallel.



[Figure 5] 5G Key requirements and 5 Great Values

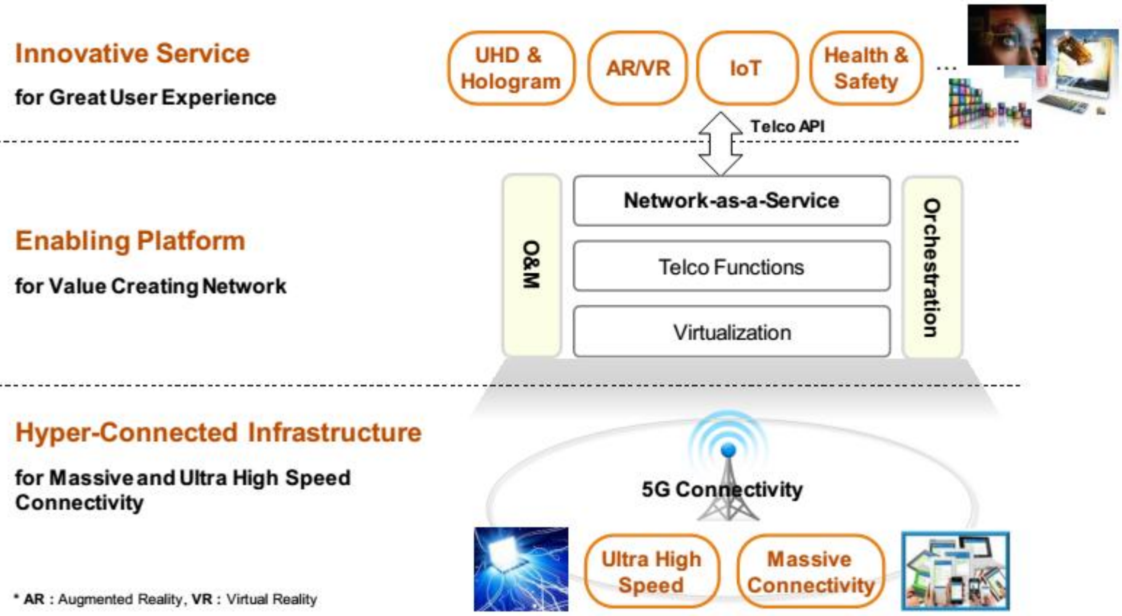


[Figure 6] Description and gap analysis of 5 Great Values

4. Concept and Architecture

In order to achieve 5 Great Values, the ultimate goal of 5G, 5G system needs; 1) innovative 5G services, 2) a software platform to implement the innovative services and 3) ultra-high speed infrastructure. Based on this analysis, 5G system will consist of three layers of Innovative Service, Enabling Platform and Hyper-connected Infrastructure in high level architecture as in Figure 7.

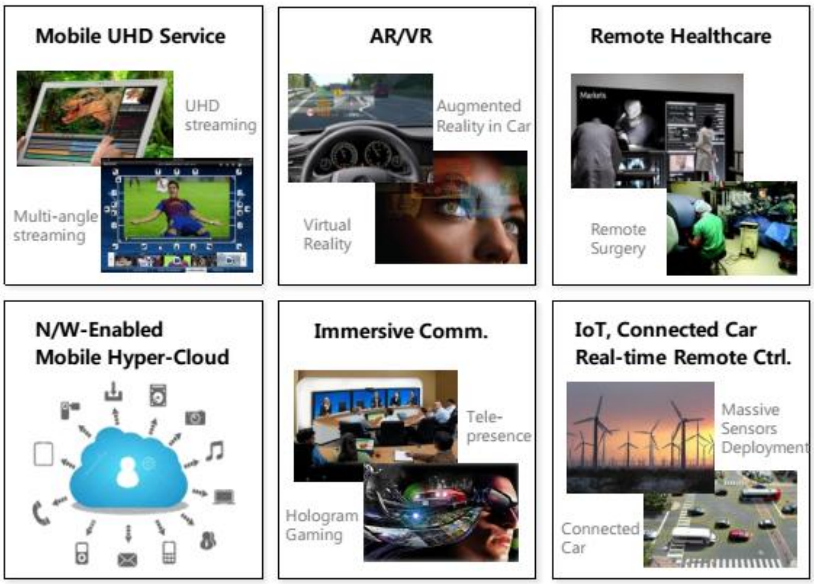
On the top layer is service, namely Innovative Service, which accommodates 5G requirements and provides new user experience. Beneath that is Enabling Platform, a software platform, on which a range of complex telecommunications network functions can be efficiently implemented and an intelligent engine can be mounted. On the bottom is Hyper-Connected Infrastructure, a hardware infrastructure of telecommunications networks, that act as a data pipe supporting the massive and ultra-high speed connectivity over densely connected network coverage. (Refer to appendix for detailed 5G system architecture with network topology.)



[Figure 7] 5G system structure

4.1 Innovative Service

In terms of network service, 5G sets itself apart from the previous generations of telecommunications technology most noticeably for its immersive customer experience available beyond limitation of time and place, which will be enabled by ultra-high speed data transfer and innovative UI. For example, as Giga-bit data rates

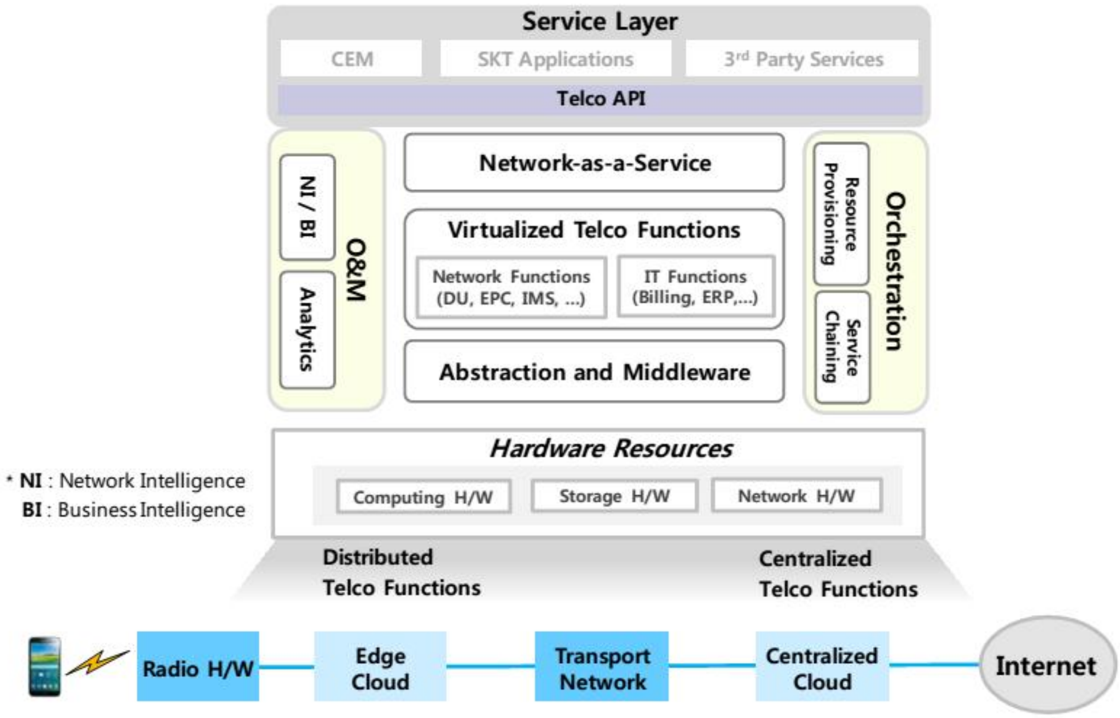


[Figure 8] Examples of 5G services

will be available anytime and anywhere on high-definition multimedia including UHD and 4K, 5G technology will allow the users to enjoy realistic services, such as augmented/virtual reality and holograms, and hyper-connected network services including Tele-presence and IoT (Internet of Things).

4.2 Enabling Platform

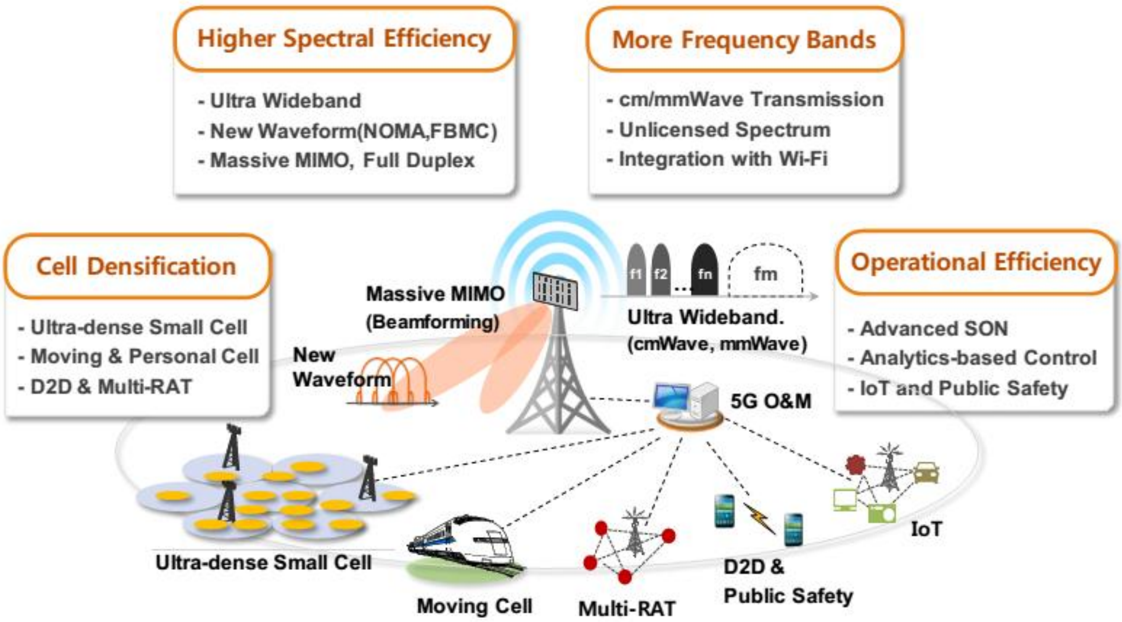
5G Enabling Platform provides the software-oriented framework and Telco asset-based interface to create differentiated value through a range of innovative services. A core function of 5G Enabling Platform is to provide Network-as-a-Service platform, which allows configuration and change of all telecommunications and service functions, with virtualized software on the programmable hardware. Also, the platform provides API for service utilization and enables implementation of various analytics-based services. The platform is efficiently operated through intelligently integrated control and orchestration.



[Figure 9] Software-based 5G Enabling Platform

4.3 Hyper-Connected Infrastructure

In order to accommodate a 1000x more data traffic and support massive connectivity, new network technologies that are currently under discussion as potential 5G technologies should be combined to configure hyper-connected infrastructure. This needs development of a range of 5G component technologies to enhance cell split, improve spectral efficiency, expand frequency bandwidth and increase the efficiency of network operation. Enhancement of cell split, in particular, is to maximize areal capacity through different types of cell configuration including ultra-dense small cell, moving cell, personalized cell and D2D, which is the core technology area to meet the requirement of a 1000x increase in data capacity. Also, capacity of 5G systems can be increased by applying various technologies to enhance spectral efficiency such as new modulation/multiple access, massive MIMO and interference coordination while expanding bandwidth in higher frequency bands (cm/mm wave, for example). Lastly, diverse technologies to improve efficiency of network operation including advanced SON and cellular-based IoT will help the system reliability of 5G networks and save TCO and energy.

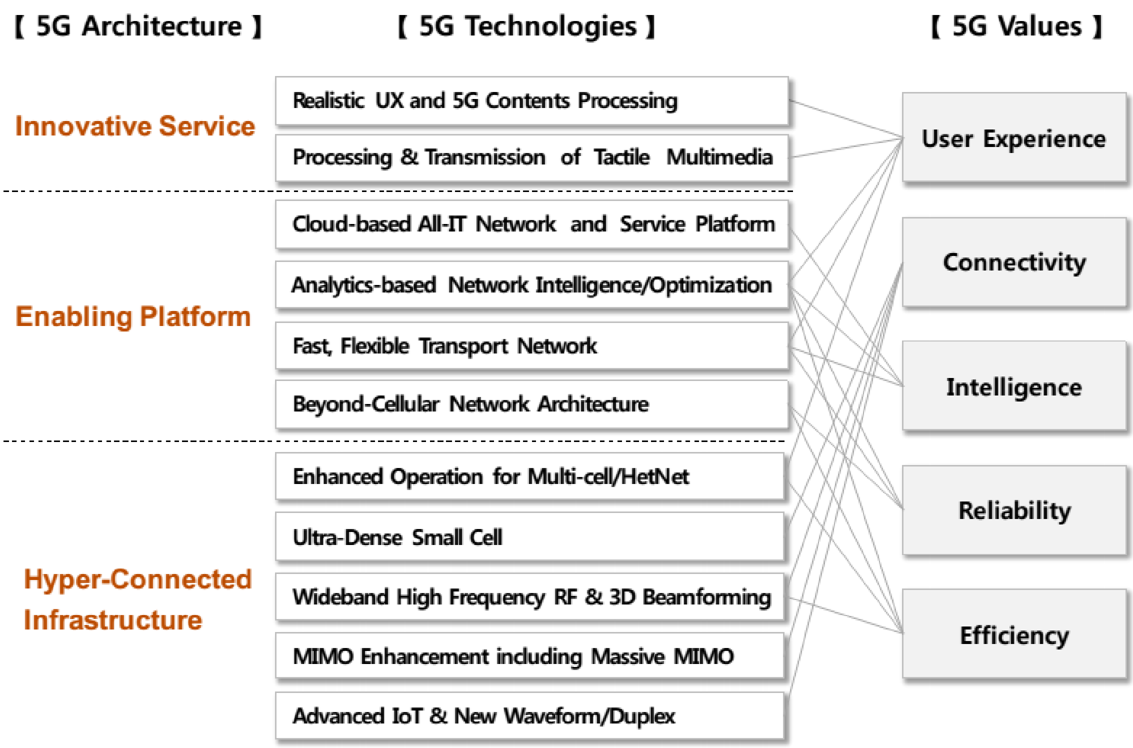


[Figure 10] 5G Infrastructure to support ultra-high data rate and massive connectivity

5. Enabling Technologies

5.1 5G Technology Classification

As explained in Chapter 4, Innovative Service, Enabling Platform and Hyper-Connected Infrastructure are the three layers that constitute high-level architecture of 5G technology and will become the ground to achieve 5 Great Values. Looking into technical details of the concepts, a total of eleven major technologies can be drawn from the high-level architecture and each category is linked to 5 Great Values respectively as in Figure 11.



[Figure 11] Major technology categories from 5G architecture/values

For User Experience, the core technologies include content processing and multimedia transmission for immersive service, analytics-based optimization and CE enhancement technologies and they are usually concentrated on Enabling Platform and Innovative Service, the upper layers of the architecture. Major technologies linked to Connectivity including ultra-dense small cell, wideband high frequency/MIMO and enhanced schemes for the spectral efficiency are mostly placed on the Infrastructure layer. Core technologies for Intelligence and Reliability are mostly on Enabling

Platform Layer and include technologies that are intelligently operated and controlled on All-IT, flat and flexible platform by virtualized S/W and analytics. Lastly, diverse technologies to enhance operation efficiency on Enabling Platform and Infrastructure Layer are linked to Efficiency. Details on each of the eleven core technologies are described in 5.2.

5.2 Enabling Technologies

5.2.1 Realistic UX and 5G Contents Processing

- Object/space recognition: Advanced technologies to fast recognize a range of surrounding objects and spaces inputted by a camera/sensor of the user's device
- Real-time rendering and display technology: Rendering technology to display quality information related to an object recognized in real time and immersive display technologies including glass and HMD
- Real-time hologram processing: Technologies to reconstruct a real image of an object with 360 degree field of view in 3D space

To provide differentiated user experience with 5G services, realistic contents processing technologies including AR/VR and holograms are greatly important. The existing AR technology is not sufficiently advanced to provide differentiated immersive experience with realistic contents to users in terms of network speeds, data processing performance of devices, recognition/tracking technologies and etc. In particular, to make immersive experience available in diverse user environment, an object the user views should be recognized without limitation of time and place, and related AR content should be processed and provided in real time. In this aspect, real-time response and sufficient bandwidth of 5G are expected to provide the technological basis for this large-volume AR/VR service and, in parallel, technologies of recognition/tracking and rendering need to be further enhanced as well.

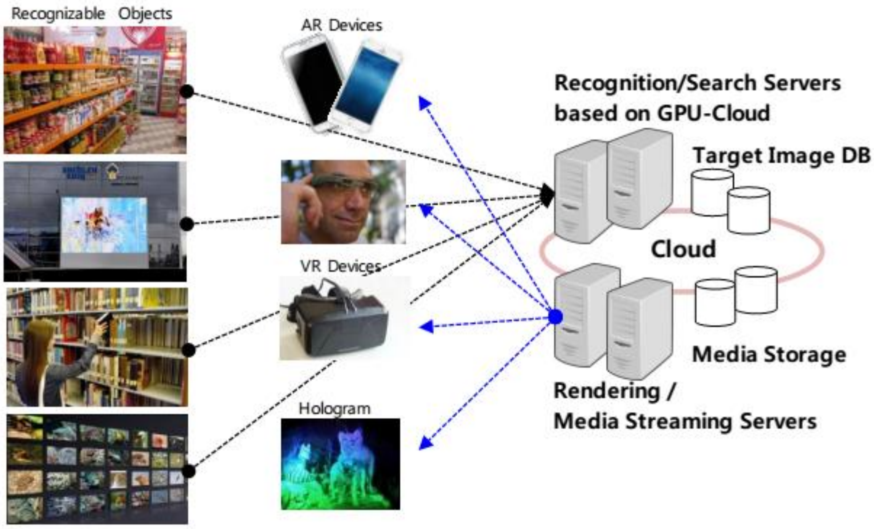
Processing of large-scale AR requires a highly advanced recognition technology to recognize all objects and information including 2D image, 3D objects in different forms, 3D space, the user's face, expression and voice inputted from a sensor without limitation. The existing technology recognizes different objects through different algorithms due to unique features of each object, which is bound to fall behind the level of recognition by human senses. However, for certain objects(face, in particular), recognition technology is exceptionally performing as accurately as human senses, based on deep-learning technology for example, and development of the relevant technologies is expected to continue.

In addition, such service requires a technology that enables distributed/parallel processing of recognized large-volume data in a cloud environment and GPU cloud system and large-volume DB optimization technologies to run a range of recognition algorithms, feature extraction for example, at high speeds.

While a camera on a device is now the main tool of image input, devices mounted with other sensors such as Lytro camera and 3D depth sensor, which will enable easy acquisition of 3D depth information from an object and space, are expected to prevail in the next generation technology. In fact, companies including Google, Intel and Apple are already in development of 3D depth sensors and supportive devices, and therefore once the number of such devices increases, so will the AR/VR-based services. Continued improvement of computing power will lead to more sophisticated functions including pre-processing of high-volume data contents, real-time tracking of an object, image processing and rendering, beyond simple transmission of image information to a server and display of information coming from a server.

Real-time responsiveness in 5G will also change rendering technology, an important factor for AR service, in many aspects. Already being applied in certain areas including games, the cloud-based rendering technology enables rendering of all necessary information from a cloud environment and then transfers it to a device as a video stream. In particular, it is critical to have a technology to accurately render high quality media and information such as (U)HD Audio/Video and 3D to video stream according to the device tracking results and sensor information and converts and transfers the video in real time in a format suitable to display on each device, for instance glass, HMD or smartphone.

Holography, another much-expected technology to provide new user experience, requires ultra-high volume data transmission. Therefore, 5G needs a ultra-high-speed real-time data processing technology on its infrastructure and a user-friendly hologram-based I/O equipment technology to efficiently create and naturally display hologram contents.



[Figure 12] Realistic UX and 5G contents processing technologies

5.2.2 Efficient Processing & Transmission of Tactile Multimedia

- MMT (MPEG Media Transport) technology: A standard digital image container processing technology defined by MPEG to minimize latency in media transmission on All-IP network
- High efficiency multimedia coding: Multimedia coding technologies, MVC (Multi-view Video Encoding) for example, for efficient creation/transmission of realistic 3-dimensional multimedia content including multi-view video
- Cloud-based computing, caching and orchestration: A technology for dynamic allocation and orchestration of cloud resource and caching to process realistic high-volume multimedia

While the current multimedia transport technologies generate a longer latency of a few or even tens of seconds compared to terrestrial broadcasting, the network technology in the era of 5G should be able to deliver True Real-time UHD Streaming Service (TRSS), which means such content as UHD (Ultra High Definition) can be transferred in true real time without latency. To achieve seamless streaming service of realistic/high volume multimedia, development of a new media streaming protocol and optimization of wired/wireless data transfer technology should come first.

To this end, latency in multimedia content transfer should be minimized while data transfer speeds within network and resource utilization efficiency need to be maximized, with the support of sophisticated MMT(MPEG Media Transport) streaming protocol and Edge Multicast technology for efficient group communications. Network operation efficiency needs improvement as well through CDN virtualization and optimized service distribution.

Super multi-view display service, much mentioned as an example of 5G realistic service, enables a user to view the video from the angle the person wants. The service requires technologies such as; 1) an encoding method to integrate multiple high-resolution images recorded from different angles into a single stream, 2) a technology to transfer and store high-volume data into a cloud server in real time, and lastly 3) a technology to dynamically create a streaming image using information from a view point the user wants. The multi-view display service, in fact, can be implemented in a limited manner even with the current 4G systems and wired networks, but, with 5G network systems, high-quality realistic image will be available in real time based on the 5G infrastructure that supports high-speed and high-volume data transfer.

Here, encoding techniques including MVC (Multiview Video Coding) and MPEG 3D Video Coding are important to minimize duplicated information by binding multi-view image streams into a single stream. Examples of such techniques will be 1) an image data processing technology to efficiently create 3D images using multiple 2D images, depth-information and metadata, 2) a technology to process bulk image data (e.g., creation of a 360 degree view image from image streams recorded from multiple views) that usually is not supported by devices for reasons like discharged batteries, and 3) technologies including NFV, SDN and integrated orchestration to support network operation on the cloud in a dynamic, flexible and scalable way. Latency generated by communications between a device and a network has to be unnoticeable and, therefore, to deliver the service through optimized network path, development of high-speed network communications technologies and diverse intelligent analytics-based service optimization technologies is much needed.

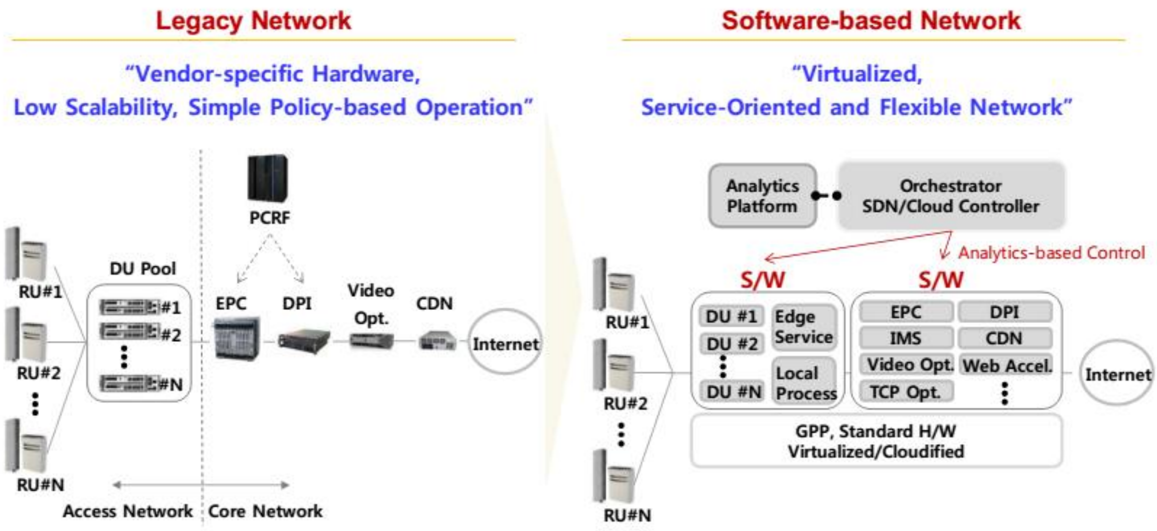
5.2.3 Cloud-based All-IT Network and Service Platform

- NFV-based virtualized core network operation: A technology to build the cloud by virtualizing a standard hardware and operate a range of network/service functions on the software-based network
- Virtualized RAN: A technology to centralize and virtualize DU(Digital Unit) of a base station into a standard H/W-based cloud and process RAN signals in real time
- SDN and integrated orchestration: Effective control and lifecycle management of the software-based network services from a centralized & unified network service orchestrator

In order to efficiently process a massive traffic and meet the requirement of low latency in the era of 5G, infrastructure should evolve to become a cloud-based All-IT infrastructure with flat architecture optimized to accommodate 5G services. A range of H/W-based network functions needed for 5G are to be distributed and operated by S/W and the properly allocated functions should be efficiently linked and managed through intelligent and automated control and orchestration.

This can be enabled by NFV (Network Functions Virtualization)/SDN (Software Defined Networking). Alongside the technologies, network analytics-based orchestration is another important technology to support dynamic link and LCM (Life Cycle Management to support steps of creation, update, scaling, restoring and closing) of different IT S/W functions required for 5G services together with network functions.

Also, the 5G network architecture is expected to become flat to satisfy the requirements of flexibility, scalability, efficient traffic processing and millisecond level latency and etc. Such architecture will need Edge Cloud in the form of Micro Data Center and the network functions and services distributed to the Edge Cloud are to be efficiently managed by an end-to-end integrated orchestration method. In convergence with big data and analytics technologies, orchestration will provide a basis for NI (Network Intelligence)/BI (Business Intelligence) services.



[Figure 13] Evolution of software-based network by NFV/SDN

5.2.4 Analytics-based Network Intelligence & Optimization

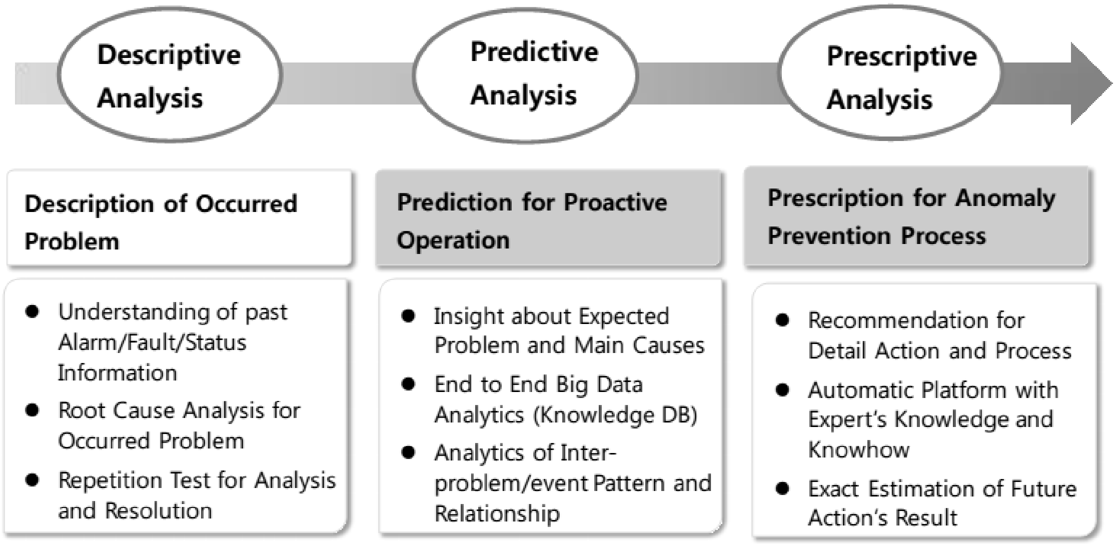
- Big data analysis: A technology to provide insight on a specific phenomenon or data by swiftly comparing in multi-dimensional space, analyzing and inferring large volume of multi-dimensional/unstructured data
- Network intelligence & analytics: A technology to optimize operation and performance of networks using information on performance, log, traffic and etc. collected from different network equipment
- Analytics-based SON (Self Organizing Network): A network operation technology to automatically detect abnormality, optimize and take necessary measures by analyzing big data generated from wireless network in real time

Recently telecommunications networks have become intelligent and converged with other IT technologies such as analytics/big data at a faster speed, and such trends are expected to continue in 5G network systems. Thus, it will be possible to optimize the overall network management including operation, performance and security with real-time analysis of data gathered from networks, users and objects.

From the previous OAM (Operation and Management)-based data analysis where statistics and failures were analysed afterwards, the data analysis method has evolved to "Big Data Analysis" which uses system log and data gathered from the device together to diagnose an exact cause, and, converged with other IT technologies, now the technology is moving onto a new paradigm of fast data analysis for real-time analysis. In addition, beyond simple descriptive results, the platform will support prescriptive results based on an automated process.

Analytics-based SON and ITM (Intelligent Traffic Management) would be prime examples. Such technologies will evolve to enable automatic fault recovery and prediction as well as examination and optimization of 5G systems, and provide users with optimized service in a complex network environment through traffic management and path optimization.

With the increased need for Telco asset-based personalized/customized services, real-time intellectual recognition technology became ever more important as it will provide customized information by recognizing surroundings including face, object, conversation, sound with Context-Aware technology (Deep Learning, for example) and accurately inferring the user's needs. In addition, technologies such as service orchestration and open API will open the door to a new kind of platforms and ecosystem that allow open/cooperative service development and an end-to-end automation.



[Figure 14] Evolution of data analysis for telecommunications network

5.2.5 Fast, Flexible Transport Network

- POTN (Packet Optical Transport Network): All-IP/All-Optical transport technology that converges multiple layers to increase simplicity and efficiency of network
- Transport SDN: Integrated networking technology to efficiently use and automatically control network resources in multi-layer, multi-vendor, multi-domain networking environments

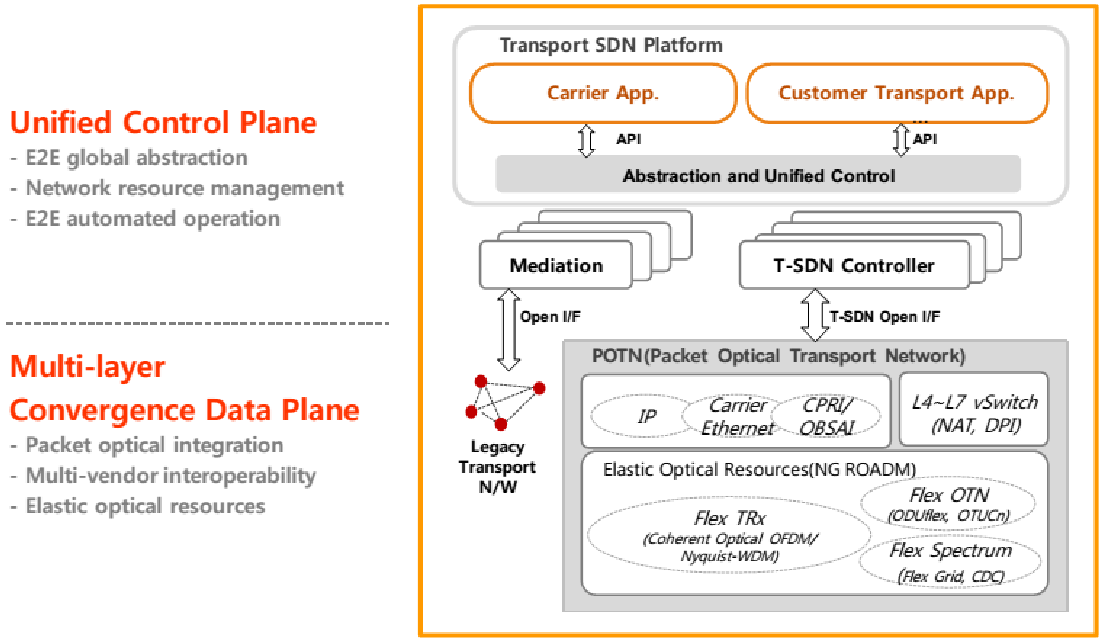
To process large-volume data traffic in 5G, transport network needs significant improvement in its capacity through "the next generation technology of optical transmission at beyond 100Gbps" and the 5G transport network can be built by enhancing such technologies as coherent optical OFDM and flexible grid

While the 100Gbps optical transmission uses a single carrier, coherent optical OFDM or Nyquist-WDM will employ multiple sub-carriers, enabling the optical transmission beyond 100Gbps. Based on such technologies, standardization for optical transmission signal interface is underway in ITU-T to raise the speeds beyond 100Gbps. Also, IEEE 802.3bs, a task force, was formed in March, 2014 with an aim to standardize 400Gbps Ethernet by March, 2017.

Depending on the technology used to aggregate sub-carriers, a bandwidth of optical transmission signals differs and, to efficiently use and switch such variable bandwidths, flexible spectrum switching is necessary.

To maximize efficiency of transport network on top of such physical transmission technologies, Lambda switching-based flexible optical and packet integration technologies including optimized path and dynamic wavelength allocation are required. Furthermore, applying these technologies, transport network technology has to evolve into POTN-centric transport technology that can integrate multiple layers. Also, transport SDN is essential to comprehensively control the network in a multi-layer and multi-vendor environment. And at the same time it enables smooth migration to the new infrastructure while accommodating the legacy.

By establishing 5G uCTN (Unified Converged Transport Network) based on POTN and transport SDN platform, low latency and flexibility of network, the key requirements for 5G, can be achieved.



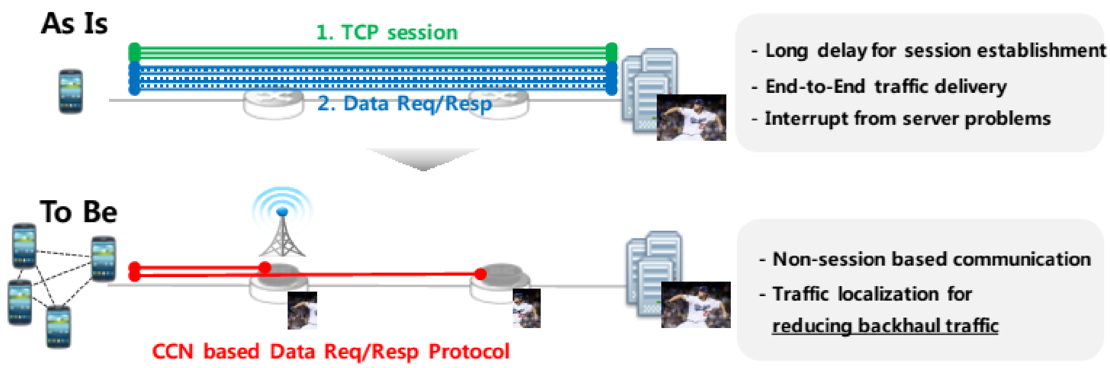
[Figure 15] Next generation transport network uCTN architecture

5.2.6 Beyond-Cellular Network Architecture

- ❍ Direct D2D (Device-to-Device) communications: A technology to directly share diverse types of contents information and data between devices
- ❍ Contents Centric Networking (CCN): A network architecture that stores content in a transport equipment on the network path and provides it by a mapped name of content

The cellular communications method (a single cell-to-device network) of the current cellular systems is expected to evolve into a multi-link network. In the evolution, direct device-to-device communications will emerge as a key factor and underlying technologies including discovery/direct transmission and PTT/proximity technologies will enable a variety of services.

Plus, with the support of ICN (Information-Centric Network) and CCN that store content on network nodes and deliver data on the shortest path based on the content's name rather than the previous IP address. And also, network operation will be optimized for contents and information delivery rather than acting as a simple data pipe.



[Figure 16] Device-to-Device communication and content centric networking

5.2.7 Enhanced Operation for Multi-cell/HetNet

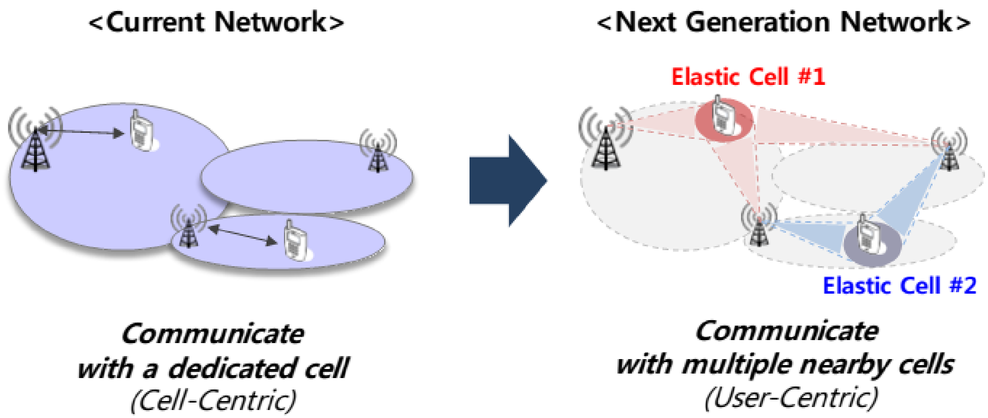
- Elastic cell: A technology to dynamically select and communicate with a cell best for the user's current channel environment in real time
- Aggregation of heterogeneous networks: A technology to improve data rate by combining cellular network with different networks such as WiFi or with LTE leveraging unlicensed band

In 5G network systems, different networks, that were separately used for different purposes in 4G networks, will be combined or selectively utilized when necessary thereby increasing data rate of a device and minimizing impact of nearby networks. For small cells, as a single device becomes able to communicate with multiple cells based on strengthened coordination of cells, it can work as if each device has its own cell. Here, dynamic cell association/clustering and coordinated interference control techniques suitable for the environment of the user and the network operation are critical. Also, it is important to secure a technology to receive feedback on channel quality of the multiple cells from the user's device.

In 5G networks, as shown in Figure 17 below, different cells can be selected each time to provide the most optimal speeds for the device in that particular transmission thereby creating a user-centric environment, , compared to the current cell-centric one where each handset communicates with only one specific cell. This mechanism will deliver improved user experience of 5G services for each user's environment.

Also, data rates can be raised through technologies for aggregation and interoperation among different networks including WiFi. In an area where both WiFi and cellular network are serviced, data will be divided and transferred by the two networks and therefore the data will be transmitted at a faster speed. Plus, if the current techniques to aggregate or split data at IP or TCP level continues to develop, it may be possible to aggregate or split data at RLC level by interfacing cellular network with WiFi after assessing WiFi environment.

Meanwhile, network bandwidth is also set to expand in 5G by deploying cellular network technology on unlicensed band just as in Licensed-Assisted LTE (LA-LTE) where the unlicensed band of WiFi is utilized for LTE.



[Figure 17] User-centric cell association and network operation

5.2.8 Ultra-Dense Small Cell

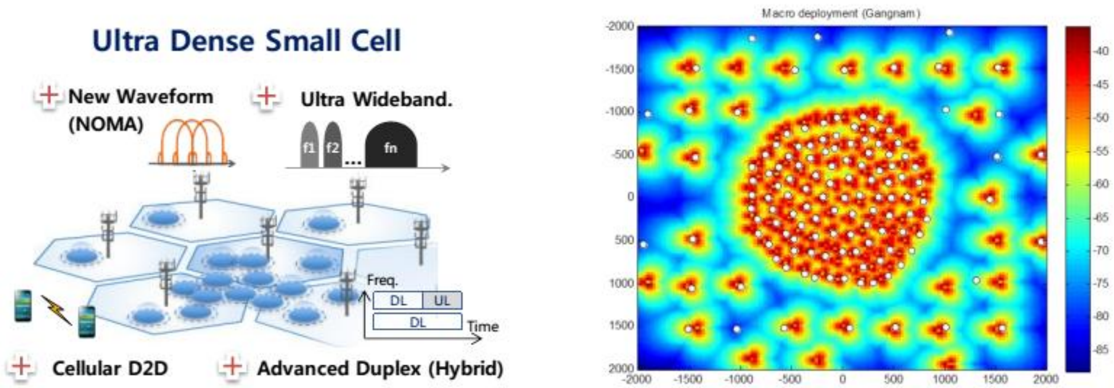
- ❍ Dynamic interference control and coordination: A technology to improve signal quality at cell edges by enabling nearby cells to cooperate in real time
- ❍ HetNet SON: A technology to automatically optimize wireless network operation in diverse cell environment thereby improving QoS

In order to support a 1000 times more traffic than LTE, it is essential to increase network capacity through significantly improved cell spilt as expansion of the current limited frequency resources will not be sufficient. This means 5G systems need ultra-dense small cell network of which the cell density is more than the level discussed in LTE-A HetNet.

Enhanced interference coordination and resource management technologies such as cell breathing, dynamic clustering/selecting/blanking will be the central part of such networks, and interference coordination performance and application of the technologies on the commercial network will determine the network capacity in the ultra-density small cell environment. Accordingly, 5G network needs to secure differentiated small cell O&M technologies and expand relevant ecosystem with high-performance/low-cost small cell, cost-effective backhaul/relay technologies.

In an ultra-dense small cell environment, different combinations of different potential 5G technologies of NOMA, D2D, hybrid duplex and ultra wideband will result in different performances of cell throughput, and thus, establishment of 5G network needs exhaustive scenario-based assessment to seek the most optimal combination.

Therefore, it is expected that there will be active performance analysis of diverse potential 5G technologies under ultra-dense small cell networks, and development of relevant technologies is likely to start with concept validation through end-to-end simulator and tool-based proof-of-concept and eventually lead to establishment of a prototype commercial network.



[Figure 18] Ultra-dense small cell-based 5G network scenario and simulation snapshot

5.2.9 Wideband High Frequency RF & 3D Beamforming

- 3D beamforming: A technique that provides RF environment for high-speed transmission by controlling electromagnetic waves or forming multiple beams in the vertical and horizontal directions
- Beam switching/tracking: A technique that provides an optimal link by selecting an optimal beam out of many or changing the direction of the antenna beam according to the location of the user

The traditional cellular frequency bands below 6 GHz, for mobile cellular communications, are close to saturation owning to the mobile communications as well as other uses, and their varied and fragmented uses make it especially difficult to secure continuous wideband of over at least 500 ㎒ required for high-capacity transmission. Hence higher frequency bands above 6 ㎓ whereby securing continuous wideband spectrum is relatively easy is emerging as a potentially viable solution for high capacity communication in 5G. In particular, the higher frequency bands have an advantage from the RF system implementation standpoint as the higher the center frequency, the wider the operating bandwidth.

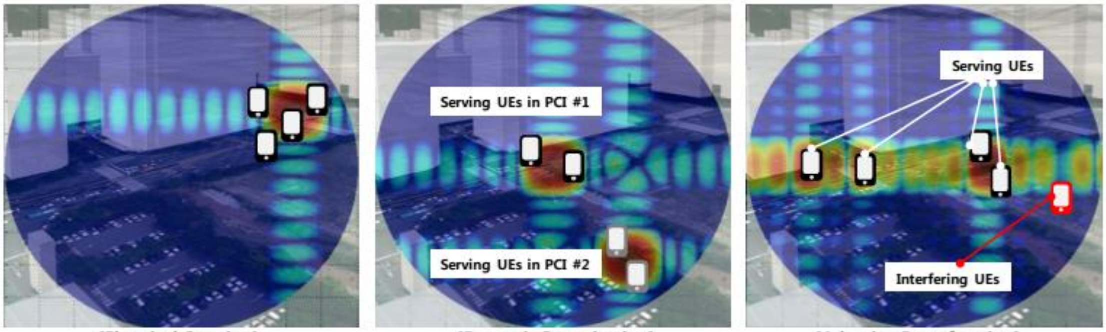
Also, densification of antenna is possible in high-frequency spectrum. In higher frequency bands, more radiators can be integrated in array antenna of the same physical aperture size. Those can serve as the H/W basis for implementing 3D beamforming and Massive MIMO, which provides a variety of antenna beam patterns by controlling RF amplitude and phase on each radiator. Figure 19 shows distribution of electromagnetic radiation within coverage area by 3D beamforming method including: electrical steering, which steers antenna beam according to the subscriber distribution; dynamic sectorization, which increases capacity through multi-beam transmission/reception; and adaptive beamforming, which minimizes interference to the direction of terminal belonging to other cells by antenna nulling.

While millimeter band has a big advantage over current cellular band in that it can use wideband frequency, overcoming increased path loss and the relatively higher straightness and low diffraction resulting from using the high frequency band remains a huge challenge. To address this, high-gain pencil beams are formed (since the gain of an antenna increases with frequency) to overcome the increased path loss.

In high frequency band, beam width narrows considerably and straightness of radio wave becomes stronger while diffraction effect is weakened. Therefore, communication fails unless base station/terminal each selects appropriate transmission/reception beam according to the terminal's movement. As such, beam switching technique whereby base station/terminal selects a suitable beam from many pre-designed candidate beams for optimal link or beam tracking technique which enables to estimation of reflection path between base station and terminal or track user's movement needs to be developed.

The 3D beamforming enables multiple beams to be transmitted or received in the horizontal and vertical directions to increase network capacity by SDMA (Spatial

Division Multiple Access) and can enhance SINR (Signal to Interference plus Noise Ratio) of subscribers inside the cell by increasing the strength of the transmitted and received signal to the served terminal and suppressing interfering signals. This, in turn, allows cost-effective cell division according to changes in traffic and implementation of subscriber-oriented cell (user-centric cell).



[Electrical Steering] [Dynamic Sectorization] [Adaptive Beamforming]

[Figure 19] Receiving electric field distribution for various 3D beamforming methods

5.2.10 Enhancement of Multiple Antenna Technology including Massive MIMO

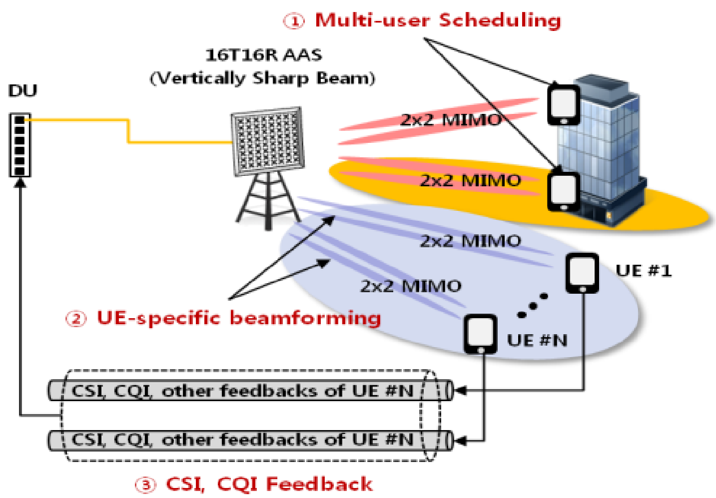
- UE-specific beamforming: A technique that suppresses mutual interference between multiple terminals by utilizing independent and sharp beams
- CSI/CQI feedback: A technique that enhances accuracy of CSI (channel state information) and CQI (channel quality indicator) which can be obtained from base station while minimizing uplink signaling overhead

As high frequencies are used in 5G, densification of base station and terminal antenna, even at the same size, becomes possible and this enables utilization of the enhanced MIMO technology. However, it should be noted that despite the increased number of base station antennas, wireless channel rank between terminal and base station may not increase by much. In particular, when the base station antennas are mounted on high altitude places (a roof of a building), there is a lack of scattering around the base station antenna and thus distinguishing the two antennas at the terminal with high probability requires a large distance of about 3~4 λ per antenna.

Notwithstanding the above, the downlink 2 layer transmission became widely used in the current LTE because base station antennas employ +45/-45˚ polarization. In a nutshell, apart from polarization, there exists a trade-off between the possible number of antenna elements in the same area (density) and wireless channel rank and thus even if the number of antennas in the terminal increases, capacity enhancement using SU-MIMO (single-user MIMO) in 5G is likely to be limited. Therefore, to achieve capacity boost via MIMO in 5G, it is essential to apply MU-MIMO (multi-user MIMO) method where multiple terminals spaced far apart are scheduled simultaneously and reuse the same time-frequency resources.

A key element of the MU-MIMO method is scheduling of terminal that can suppress mutual interference via beamforming at the base station. For this, base station needs to know the precise downlink wireless channel conditions of each terminal and perform UE-specific beamforming by terminal accordingly. As such, accuracy of each terminal's CSI and CQI is very important and related standardization work is currently underway in 3GPP from a 'LTE's sustainable evolution' point of view.

In case of CSI, reducing the amount of uplink CSI feedback and at the same time, increasing accuracy of CSI obtainable from base station is needed. One option is to utilize channel reciprocity in TDD and perform two-stage precoding in FDD. In case of the current LTE CQI feedback scheme, the terminal reports its channel condition assuming it is scheduled alone within a PRB. Therefore, when MU-MIMO which involves multiple users in the same time & frequency block is applied, estimation of the terminal's true channel condition is needed at the base station. Such CQI mismatch results in degradation of performance. Also as the number of antennas at the base station increases, orthogonal pilot sequences become insufficient which is called pilot contamination issue. Addressing these issues is required to successfully commercialize MIMO transmission technology.



[Figure 20] MU-MIMO (UE-specific beamforming) operation mode

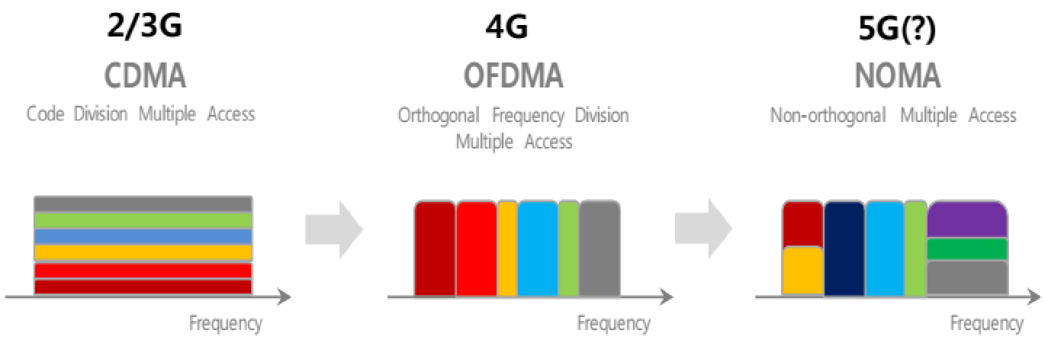
5.2.11 Advanced IoT & New Waveform/Duplex

- Cellular-based MTC (Machine-Type Comm.): High-capacity multiple access & machine data processing technology to support IoT service on mobile communication network
- New waveform (NOMA, FBMC): Transmit and receive technology that increases efficiency of accommodating multiple users and data through receiver interference cancellation and filter-based interference suppression
- Hybrid duplex & full duplex communication: Flexible allocation scheme for DL/UL resources and simultaneous transmit and receive technology based on self-interference cancellation

Until 4G, conventional wireless network technology has evolved to provide higher speed to more users. But with the emergence of the IoT era in which objects along with people are connected to the internet, 5G – as key communications infrastructure – needs to provide massive connectivity and low latency in addition to faster speed.

Providing connectivity to multiple sensors and high transmission efficiency albeit at lower transmission speeds are required in environmental field such as weather observation and water quality monitoring for which IoT technology has been mostly deployed as well as for sensor/meter application including smart farm. Revision of LTE standard for such MTC is under discussion in 3GPP and technological standardization to support low-cost IoT terminals including half-duplex support, efficient signaling for small data, massive UE handling, and extended DRX is underway. Moreover, with high-capacity/real-time IoT services such as connected car and remote control/telemedicine gaining attention as the main services of 5G, ultra-low latency has become all the more important. But existing LTE has limitations in that it cannot be decreased below TTI (Transmit Time Interval) of 1ms.

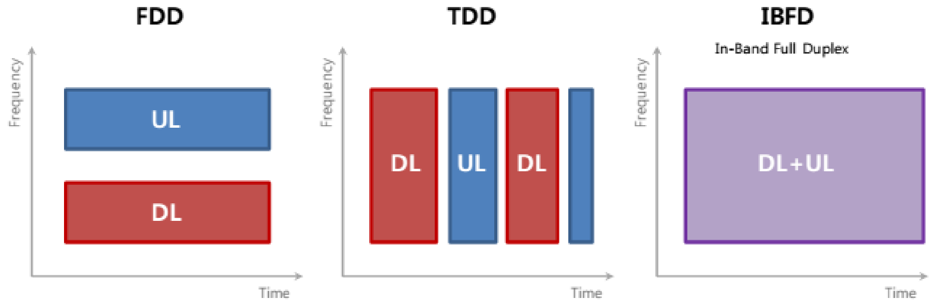
Likewise, wireless network for IoT has to meet various demands from sensor/meter which generate sporadic traffic at a very low data rate to connected car and remote healthcare which require high data rate for sending high-resolution images and real-time control. Hence a 'new scalable radio access' structure different from the conventional LTE is necessary.



[Figure 21] Evolution of mobile communication's multiple access technology

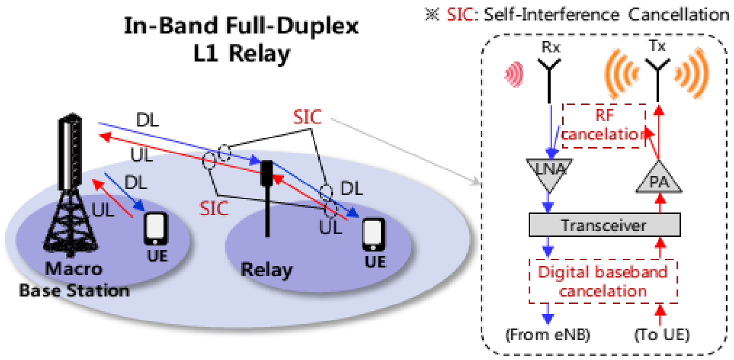
To accommodate ever greater number of terminals and increase capacity in cellular network, new multiple access technology is gaining attention, such as NOMA (Non-Orthogonal Multiple Access). While 4G used OFDMA (Orthogonal Frequency Division Multiple Access) which allows multiple access among several terminals while preserving frequency orthogonality, NOMA provides multiple access utilizing power control in the frequency domain. As shown in Figure 21, receiver can eliminate interference between terminals utilizing SIC (Successive Interference Cancellation) technique with varying transmission power of several terminals' signals even at the same time/frequency. Since several terminals' signals can be sent at the same time on the same frequency, higher number of terminals can be accommodated as well as increasing the overall cellular network capacity. In addition, UFMC (Universal Filtered Multi-Carrier) and FBMC (Filtered Bank Multi-Carrier) are among those being discussed for the 5G candidate technologies as the new radio access technology which can overcome disadvantages of the conventional OFDMA.

Downlink and uplink of the existing communication system are separated by frequency (Frequency-Division Duplex, FDD) or in time (Time-Division Duplex, TDD)



[Figure 22] Frequency duplex method of mobile communication

In order to minimize mutual interference. But in 5G, In-Band Full Duplex (IBFD) is expected to be possible where uplink/downlink transmissions can occur simultaneously at the same time on the same frequency. To realize this, it is crucial to develop self-interference cancellation technology whereby interfering signal that leaks into the receiver while transmitting is removed. In fact, it was recently shown that over 100 dB of suppression was achieved by combining analog and digital cancellation techniques. As shown in Figure 23, IBFD is likely to be the primary choice for In-Band L1 Relay and others since standards of existing networks based on FDD/TDD need to be changed and additional validation is required for multi-cell environment. However, increased complexity of RF chain and the need for digital cancellation considering multipath fading are some of the areas that require continued technological development when implementing multiple antennas going forward.



[Figure 23] In-band full duplex communications

6. Services

So far, we've reviewed the requirements, architecture and major technologies in relation to the evolution of 5G communications. In this chapter, we will discuss various 5G services and their applications that will be created based on such evolution.

6.1 Hologram & Multimedia-based Immersive Service

Currently, high definition (HD) video calling and higher quality sound VoLTE services are widely used in 4G. However, video calling and VoLTE still have some way to go from a user experience perspective compared with people talking in person. Future 5G will see great strides in the development of 5 senses, especially the sense of sight, to provide immersive communication experience to users which allow them to feel as if the other person is right next to them.

As such, on 5G network, where ultrahigh-capacity communication is possible, ultra-high resolution images such as 4K-UHD which offers four times the resolution of Full HD and 8K-UHD which delivers 16 times the definition will become common and, over time, expand to 3D imaging or hologram services. Figure 24 shows data capacity by image resolution. Along with the improved image quality, customized real-time interactive services which support five senses in the form of immersive media are projected to become possible.

[Figure 24] Required data volume according to image types

Hologram display using smart phone accessary

Hologram-based I/O interface

Concert performance using Hologram

[Figure 25] Real-time interactive hologram service

The 3D hologram, in its true sense, requires terabyte-level bandwidth which is challenging even for 5G bandwidth to process. Hence hologram-like services such as super multi-view stereoscopic image, and computer-generated hologram are being proposed instead. And development of key technologies including improvement of 3D image compression efficiency, decoding algorithm for real-time playback, high-capacity parallel processing and free-space display is required. Also 3D holographic communication will become feasible with the adoption of optical memory and parallel processing computer whereby recording in three-dimensional space is possible.

In the case of high-definition streaming services, real-time UHD multi-view contents streaming service which meet the need for watching concerts and sporting events from various viewpoints will become mainstream.

High Quality Multi-View Contents

UHD Camera Accessary

[Figure 26] High-definition multi-view steaming service

6.2 Large-Scale Immersive AR/VR Service

Current smartphone-based mobile augmented reality systems focus on providing various contents with augmented interface based on the information acquired and processed by high-definition camera, GPS and other sensors. Granted, while some of the recognition functions of the AR technology were executed on server, there was a limit to real-time performance due to the NW's limitation. Moreover, device's performance constraints for tracking and rendering led to limitations in making a service that delivers optimal user experience.

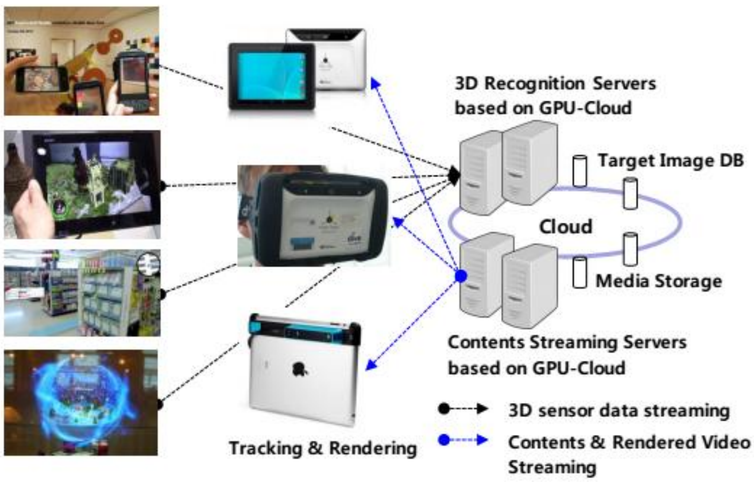
However future 5G network can collect various sensor information including images, 3D depth data, gyroscope, etc. in real time from various devices such as smartphone, cars, CCTV, etc. driven by super-high capacity, real-time and super connectivity. By recognizing these in real time via big data analysis and cloud system and presenting such information processed and optimized according to purpose of their usage and user preference through various displays, a novel user experience merged with reality in real time can be provided.

Looking at the latest research trends by automotive companies, BMW Group is collecting environmental and road condition data as well as providing information to drivers to help them find the optimal path for driving and promote safe driving while GM is developing augmented reality car windows for entertainment purposes. Also, there is an ongoing research on augmented reality system which enables surgeons to operate with more precision in the operating room by recognizing people's organs such as vocal cords with MRI. These will soon be commercialized in phases with the arrival of 5G era along with technological progress in each area.

5G network will provide a basis for a variety of augmented reality services to be applied to users' daily lives at high speed and in real-time. Ordinary users will be able to experience augmented reality services provided at all times using not just smartphones but also various devices including Glass and HMD through 'mobile recognition and augmentation' service without expending additional effort of searching information related to reality such as things or space around their environment. For example, in the case of cars, augmented reality in the HUD allows drivers to receive useful information in a comprehensive way based on various road condition, camera fitted to cars and sensor while, in the field of medicine, it would be used for performing diagnosis and surgery at a distance using surgical robot and transmitting and augmenting information necessary for the surgery in real time by analysing images acquired via camera and MRI equipment from the remote site.

Large-scale AR service involves recognizing various objects such as landmark/building, products, posters in the environment surrounding the user based on cloud in real time as well as processing relevant high-quality media and information including (U)HD audio/video 3D according to user and transmitting them to device to provide augmented reality. Such large-scale AR service can maximize user's immersive experience through 3D Sensing-based AR services which combine 3D depth sensor data with 3D object/space recognition technology and display information and media providing a reflection of reality and optimized for wearable devices such as Glass and HMD.

5G-based AR technology is expected to enable 'immersive exhibition service' whereby virtual art of work/picture/media/artefact are exhibited in the empty space of the real world such as living room walls; 'AR high-quality service' whereby high quality media including UHD is provided; and 'everyday life AR service' whereby the amount and type of food in the refrigerator and its shelf life are displayed at all times.



[Figure 27] 3D Sensing-based AR service

6.3 Ultra-Low Latency Service

In many ways, mobile communications network is beginning to surpass wired network fuelled by rapid development of mobile communication technology up to 4G. In 5G era, services requiring low-latency response are expected to emerge and hence overall network structure is expected to change to minimize end-to-end delay of network. For example, various element technologies mentioned in chapter 5 such as cloud-based infra (section 5.2.3), transport network technology (section 5.2.5) and next-generation radio transmission technology (section 5.2.11) will be dynamically and flexibly placed and combined in the network based on intelligent analytics-based end-to-end network analysis and optimization technology (section. 5.2.4). Consequently, end-to-end delay will be reduced from current several seconds to several milliseconds.

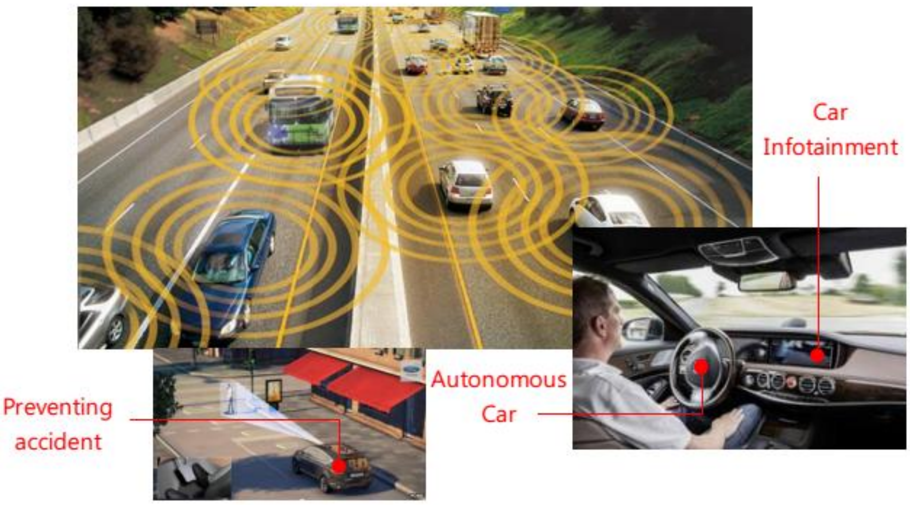
Therefore, in 5G era, it will be possible to deploy network services hitherto implemented only for wired network for reasons of speed and reliability. Furthermore, services which were impossible to implement in wired network due to space and price constraints will newly emerge based on the 5G infrastructure. For instance, remote rescue robot control service will be possible whereby robots are deployed in dangerous construction sites to replace human enabling wireless remote control as well as prompt response to a change in the environment based on real-time high resolution images and information. Here, D2D (Device-to-Device) communication where terminals in proximity to each other including termination (robot and remote controller in the given scenario) under network management/control can communicate directly is also expected to be possible. As such, various technologies including D2D communications will minimize unnecessary intermediate interaction with network or equipment to reduce end-to-end latency and enable efficient use of the radio resources in the 5G era.

[Figure 28] Example of life-saving robot and remote control

A similar scenario is treating patients in remote places where the doctors can't easily visit themselves using robots. Many low-latency remote control services including the telemedicine services will be actively used. In addition, communication services between devices such as super-precision automation system in factories which require high reliability and real time operation at the same time as well as self-driving cars which require interfaces between sensor, power train system, steering system, and brake system will also feature prominently.

[Figure 29] Telemedicine services requiring low-latency control

"Connected Car" service is a classic example which capitalizes on the 5G's low latency to enable autonomous driving based on image recognition and V2V (Vehicle-to-Vehicle)/V2I (Vehicle-to-Infrastructure) communication. Also it is possible to send accident alarms and road condition information as well as building intelligent transportation safety infrastructure which supports near field communication between terminals in the event of network failure. Lastly, enhancements will be made in automotive infotainment services such as virtual reality and cloud-based 3D games in cars.

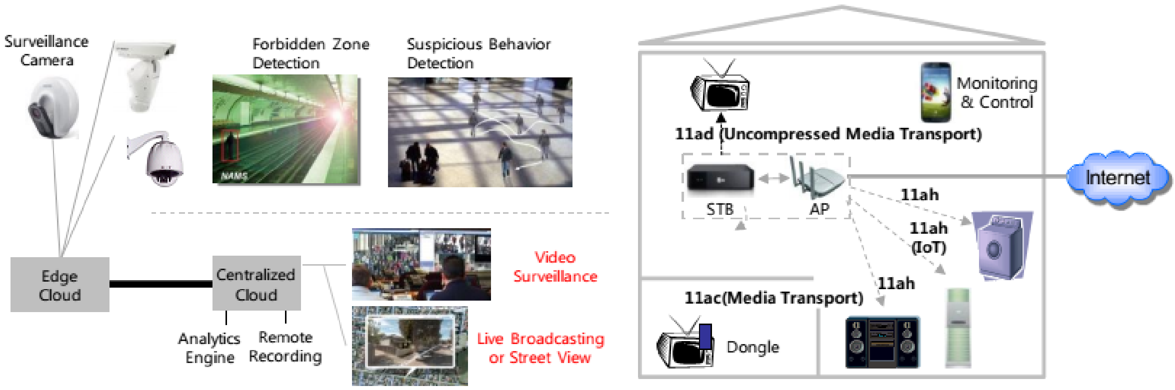


[Figure 30] Connected car services

6.4 Massive Connectivity-based IoT (Internet of Things) Service

In the 5G era, as the current Internet of Things services spread widely across society, massive connectivity based IoT services, where all the objects are connected, will emerge. At present, the IoT can merely recognize the conditions of objects and thus its usage is limited to logistics management services using RFID (Radio Frequency Identification) chips or location-based fleets (buses, taxis, trucks, etc.) management services. In the future 5G where super-connected communications become a reality, new technologies will be implemented including: remote monitoring which collects objects' condition or environmental data with objects connected to the network on a large scale; remote control with which facilities or equipments are remotely controlled; remote tracking based on location information of moving objects; and information exchange via wireless network. Through these, a variety of IoT services are expected to materialize in: Connected Car service which enables autonomous driving & maintenance system, linking to insurance products and traffic control; factory/building/facility management system which enables automation of saving energy, curbing carbon emissions and preventing leakage of hazardous materials; smart home services which let people control home appliances remotely or automate housework via communications between home devices; and in the areas related to quality of life such as water/air quality and noise.

When IoT technology is applied to video surveillance area, precise detection and alarming upon occurrence of events via quick storage and analysis of high definition images based on 5G's real-time response as well as provision of managed QoS regarding video traffic are possible. Also, if IoT N/W is formed by holistically harnessing advanced WiFi technology (11ad, 11ah, etc.) that delivers high-capacity



[Figure 31] IoT-based video surveillance services & smart home service media transmission and massive connectivity, remotely monitoring conditions and controlling smart devices at home (TV, refrigerator, air conditioner, etc.) as well as effectively delivering mutual connectivity between hundreds or even thousands of smart devices becomes feasible down the road.

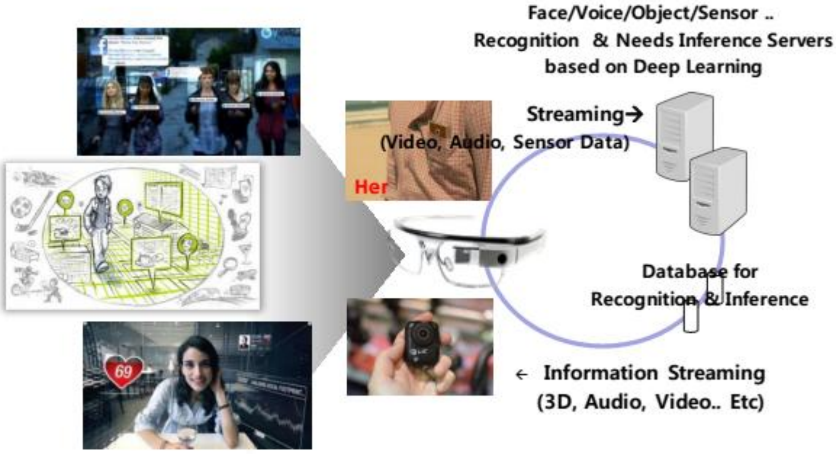
6.5 Big Data-based Intelligent Service

In the 5G era, advancement of big data technology based on a wide variety of information collected will come to the fore and this will give rise to various intelligent services. Previous intelligent services were mainly used for reporting purposes by obtaining a few low-dimensional/structured statistical data. However, big data technology which is seeing rapid growth in recent years is evolving in such a way that analysing past & present information or predicting future information – which proved difficult with existing analysis technology – is feasible by comparing, analysing and inferring high-dimensional/non-structured data in multi-dimensional space. At present, big data technology is mostly used for improving efficiency in business as well as overall network operation and management and the technology is rapidly advancing under the name of business intelligence (BI) and network intelligence (NI).

Data mining, analysis, inference, and prediction methods which are key technologies of BI/NI driven by big data analytics will combine with the rise of IoT (Internet of Things) in 5G to evolve into service intelligence (SI) technology along with explosion of various high-dimensional/non-structured data. The SI technology in 5G era will be of great help in discovering novel services that even existing mobile carriers or users weren't aware of. Furthermore, by providing Telco asset-based personalized service, the SI will serve as a platform for a future-oriented lifestyle in which "it knows me better than I know myself". For instance, existing intelligent services merely provide information for weather, shopping, restaurant, etc. by identifying user's location using simple situational awareness technology and terminal's GPS. However, future big data-based SI technologies will evolve such that not only individual user's three-dimensional situation awareness but also overall user's propensity, public opinion from SNS and user's surrounding information from web, etc. will be comprehensively analysed in real time with the format customized to suit user's specific needs and circumstances to provide an optimal service.

The combination of 5G and big data technology will go beyond simply providing information such as navigation services, a guide to the best places to eat & travel, and provide recommendations on products and services, etc. to make everyday life more convenient and comfortable. Also, it would be integrated into people's lives via personalized service for a smart life that saves time and cost.

Also big data technology in 5G era will evolve into an artificial intelligence service which provides services involving not only awareness of current situation but also prediction of future with high probability as well as appropriate preventive measures for user's convenience and safety. For example, combining big data and context-aware technologies and applying them to 5G system enables AI (artificial intelligence) real-time situational awareness service whereby customized information is provided via awareness of the surrounding environment including face, object, conversation, sound, etc. using cognition technology such as deep learning and accurately inferring user's current situation and needs. More specifically, a variety of wearable terminals (things) such as Smart Glass, Badge Camera, etc. which fall into the category of IoT will collect vast amounts of data in real time. Various data including high-resolution images will be sent to high-capacity cloud storage in the network. Then, through the big data/deep learning techniques of artificial intelligence in the cloud, information about user's surroundings such as face, conversation, sound, object, location, etc. become available in real time based on which contexts are inferred. These contexts, in turn, serve as a basis for inferring user's needs, enabling provision of customized information for each user (e.g., AR, audio, video, etc.) in real time, and without delay.

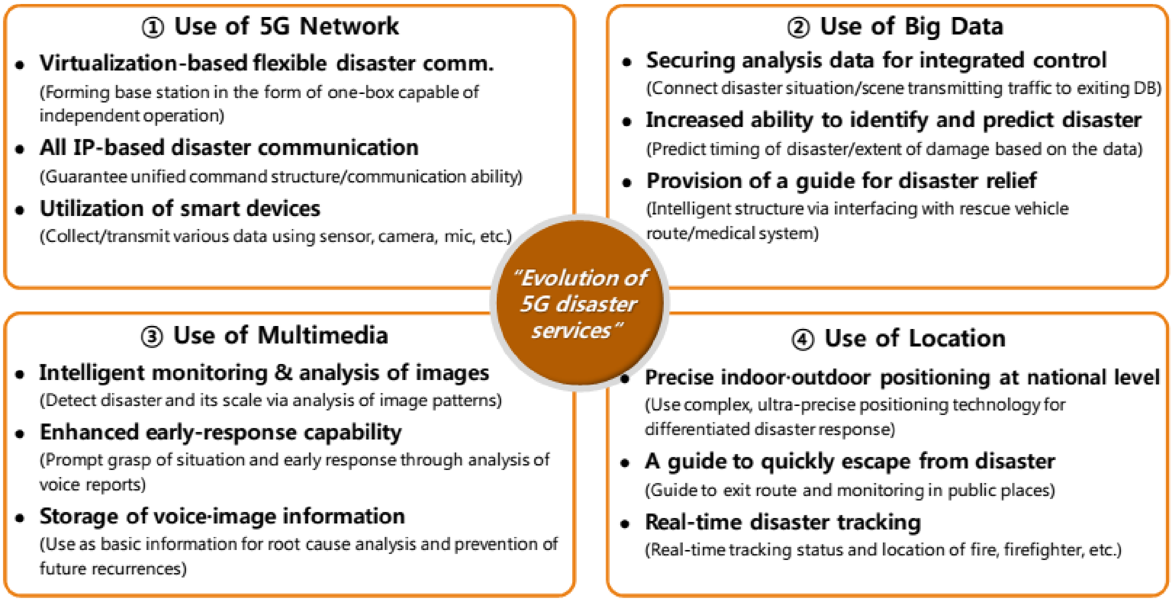


[Figure 32] Artificial intelligence real-time context-aware service

6.6 Public Safety & Disaster Relief Service

Future 5G network can be utilized as disaster safety communication network which is expected to evolve from providing simple voice and text into one tapping into ICT convergence such as big data-driven intelligence, multimedia based on faster wireless network and more-precise location, etc. to provide disaster relief services.

5G networks, like LTE networks, are allowing interfaces between service nodes and thus delivering unified command structure and communication capability as well as making it easier to collect and send various data on accidents/disasters scenes using smartphone sensor, camera and microphone. Also, precise analysis information such as disaster identification and predictive ability can be gained via big data analysis by connecting incident scenes transmitting traffic with database held by existing carriers or governments. And, by linking to location measuring technology, differentiated services can be provided such as disaster situations tracking and escape guide service.



[Figure 33] Evolution of 5G disaster relief services

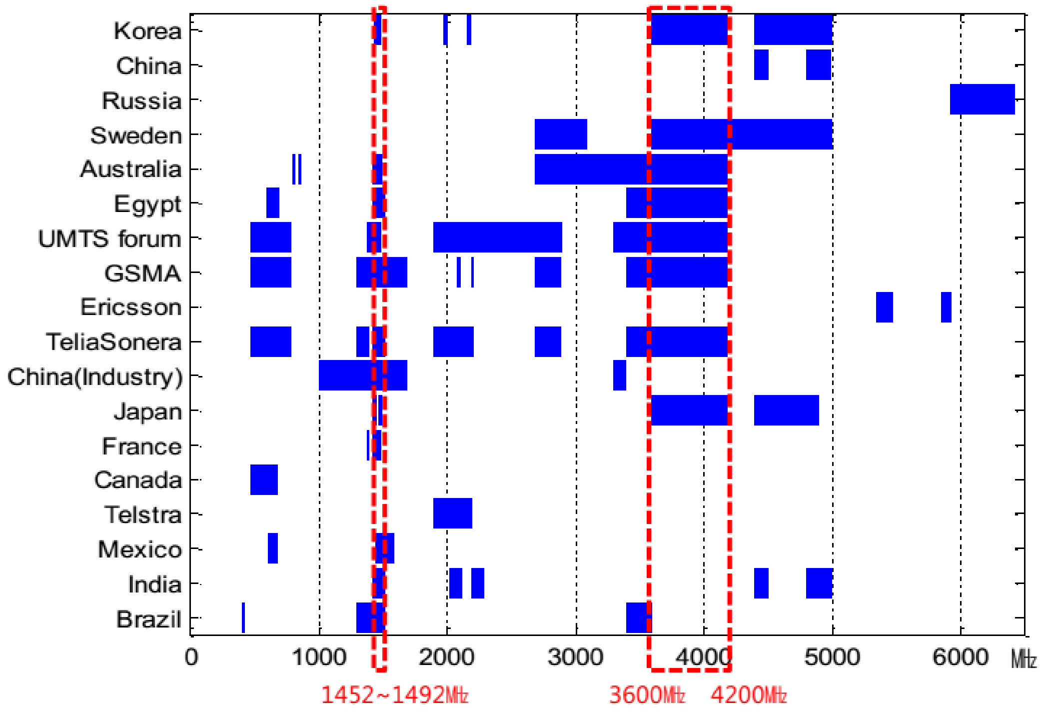
7. Spectrum

7.1 5G Candidate Frequency Bands

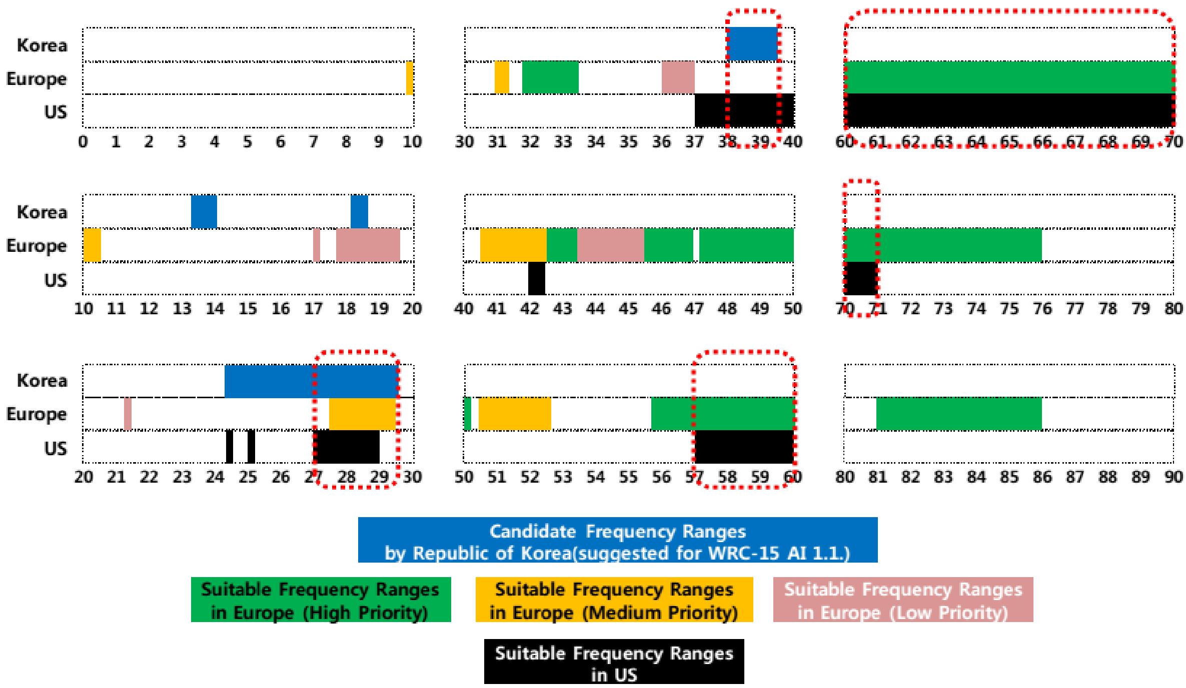
Analysis of expected frequency requirements resulting from increased traffic in the 5G era shows a bandwidth of up to 1960 MHz is required and, as such, reviewing various frequency bands including super-high frequency band above 6GHz is in order for 5G communication.

ITU-R is reviewing spectrum both below and above 6GHz as potential candidate frequency bands for 5G and each country and company has proposed IMT spectrum below 6 GHz at ITU-R WP5D (Working Party 5D) to propose 5G candidate frequency band at WRC-15 (World Radio Conference) which will be held at the end of 2015. Korea has proposed frequency bands 1452~1492 MHz, 1980~2010 MHz, 2170~2200 MHz, 3.6~4.2 GHz, and 4.4~5.0 GHz to the ITU-R and the band 1.5 GHz & 3.6~4.2 GHz appear to be the strongest candidates when considering present frequency requirement, 5G requirements and global harmonization.

The super-high frequency band above 6GHz is in the early stages of being reviewed and is expected to be discussed in earnest at WRC-18. Korea has proposed bands 13.25~14 GHz, 18.1~18.6 GHz, 24.25~29.5 GHz, and 38~39.5 GHz to the ITU-R but an agreement has yet to be reached. Bands 27~29 GHz & 70~80 GHz seem promising when considering candidate spectrums in METIS, FCC.



[Figure 34] IMT frequency bands below 6GHz proposed to ITU-R WP5D



[Figure 35] Candidate frequency band above 6GHz for mobile communication

7.2 Forecasting Future Demands for 5G Radio Spectrum

It is predicted that by the year 2020, the total spectrum requirement resulting from traffic growth in 5G era is between 1340 ㎒ and 1960 ㎒ based on analysis of user density taking into account market demand, technological advancement, approaches to building a network, etc. [1] Also, around 1000 ㎒ of additional bandwidth is projected to be needed in super-high frequency band but this may vary depending on the actual increase in traffic [2].

The ITU-R forecasts that between 1340 and 1960 ㎒ of spectrum will be needed by 2020 based on analysis of RATG (Radio Access Technique Group) 1 (IMT-2000) & RATG 2 (IMT-Advanced)'s requirements - as shown in Table 2 - considering market demand, technological progress and building of networks.

An extra 1000 ㎒ of spectrum is forecast to be needed for super-high frequency band (cmWave, mmWave) above 6 ㎓ assuming 30% offloading of WLAN and etc. based on the analysis of spectrum requirement for existing bands below 6 ㎓.

[Table 2] ITU-R spectrum requirement forecast (2020)

Classification	RATG 1 spectrum req.	RATG 2 spectrum req.	Total spectrum req.
Lower user density settings	440 ㎒	900 ㎒	1,340 ㎒
Higher user density settings	540 ㎒	1,420 ㎒	1,960 ㎒

[1] Spectrum Requirement for IMT Related to WRC-15 Agenda Item 1.1, ITU-R WP5D, Jul. 13, 2013.

[2] Spectrum Requirement for Performance Above 6GHz Regarding WRC-15 Agenda Item 1.1, ITU-R WP5D, Jan 23, 2013

[Appendix] Summary of 5G Enabling Technologies

Category	Technology	Description
Realistic UX and 5G Contents Processing	Object/space recognition	Advanced technologies to fast recognize a range of surrounding objects and spaces inputted by a camera/ sensor of the user's device
	Real-time rendering and display technology	Rendering technology to display quality information related to an object recognized in real time and immersive display technologies including glass and HMD
	Real-time hologram processing	Technologies to reconstruct a real image of an object with 360 degree field of view in 3D space
Processing & Transmission of Tactile Multimedia	MMT (MPEG Media Transport) technology	A standard digital image container processing technology defined by MPEG to minimize latency in media transmission on All-IP network
	High efficiency multimedia coding	Multimedia coding technologies for efficient creation/ transmission of realistic 3-dimensional multimedia content including multi-view video
	Cloud-based computing, caching and orchestration	A technology for dynamic allocation and orchestration of cloud resource and caching to process realistic high-volume multimedia
Cloud-based All-IT Network and Service Platform	NFV-based virtualized core network	A technology to build the cloud by virtualizing a standard hardware and operate a range of network/service functions on the software-based network
	Virtualized RAN	A technology to centralize and virtualize DU(Digital Unit) of a base station into a standard H/W-based cloud and process RAN signals in real time
	SDN and integrated orchestration	Effective control and lifecycle management of the software-based network services from a centralized & unified network service orchestrator
Analytics-based Network Intelligence/ Optimization	Big data analysis	A technology to provide insight on a specific phenomenon or data by comparing, analyzing and inferring large volume of multi-dimensional/unstructured data
	Network intelligence & analytics	A technology to optimize operation and performance of networks using information on performance, log, traffic and etc. collected from different network equipment
	Analytics-based SON	A network operation technology to automatically detect abnormality, optimize and take necessary measures by analysing big data generated from the network in real time
Fast, Flexible Transport N/W	POTN (Packet Optical Transport N/W)	All-IP/All-Optical transport technology that converges multiple layers to increase simplicity and efficiency of N/W

	Transport SDN	Integrated networking technology to efficiently use and automatically control network resources in multi-layer, multi-vendor, multi-domain networking environments
Beyond-Cellular N/W Architecture	Direct D2D (Device-to-Device) communications	A technology to directly share diverse types of contents information and data between devices
	Contents centric networking (CCN)	A network architecture that stores content in a transport equipment on the network path and provides it by a mapped name of content
Enhanced Operation for Multi-cell /HetNet	Elastic cell	A technology to dynamically select and communicate with a cell best for the user's current channel environment in real time
	Aggregation of heterogeneous networks	A technology to improve data rate by combining cellular network with different networks such as WiFi or with LTE leveraging unlicensed band
Ultra-Dense Small Cell	Dynamic interference control and coordination	A technology to improve signal quality at cell edges by enabling nearby cells to cooperate in real time
	HetNet SON	A technology to automatically optimize wireless network operation in diverse cell environment
Wideband High Freq. RF & 3D Beamforming	3D beamforming	A technique that provides RF environment for high-speed transmission by controlling and forming multiple beams in the vertical and horizontal directions
	Beam switching /tracking	A technique that provides an optimal link by selecting an optimal beam out of many or changing the direction of the antenna beam according to the location of the user
MIMO Enhancement including Massive MIMO	UE-specific beamforming	A technique that suppresses mutual interference between multiple terminals scheduled at the same time using independent and sharp beams
	Enhanced CSI/CQI Feedback	A technique that enhances accuracy of CSI and CQI which can be obtained from base station while minimizing uplink signaling overhead
Advanced IoT & New Waveform/ Duplex	Cellular-based MTC (Machine-Type Comm.)	High-capacity multiple access & machine data processing technology to support IoT service on mobile communication network
	New Waveform (NOMA, FBMC)	Transmit and receive technology that increases efficiency of accommodating multiple users and data through interference cancellation and suppression
	Hybrid duplex & full duplex comm.	Flexible allocation scheme for DL/UL resources and simultaneous transmit and receive technology based on self-interference cancellation

[Appendix] 5G Network Architecture