SK Telecom 6G White Paper

5G Lesson Learned, 6G Key Requirements,
6G Network Evolution, and 6G Spectrum

ICT Infra

Version 1.0 (August 2023)

SK telecom

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[Executive Summary]

[Definition]

- 6G refers to communications and services at the time of convergence of service·terminal evolution and mobile communication evolution, which will arrive around 2030, based on the lessons learned from the world's first 5G commercialization.

[5G Lessons Learned]

- 6G requires setting achievable goals and continuous communication with the market and consumers.
- Efforts of all participants in the new 6G ecosystem are required, such as expanding of 6G usage scenarios, selecting candidate spectrums, vitalizing open interfaces, e.g., Open RAN, and simple architecture options, etc.

[2030 Promising Service Outlook and Technology Trends]

- Based on 6G communication · AI · sensing technologies, services such as autonomous driving · UAM · XR · hologram · digital twin are being discussed, it is essential to discover 6G killer services and devices.
- 6G is in its early stage, but major countries and companies have already started 6G R&D, presenting 6G visions and research results through technical forums and white papers.

[6G Key Requirements]

- 6G Framework Recommendation includes and proposes usage scenarios and capabilities, and some KPIs such as peak data rate are to be discussed in detail in the technical performance requirements (TPR) phase.
- It is essential to identify 6G products and services, to define simple architecture options, and to develop technologies for coverage expansion and for UE heat and power consumption to improve user experience.

[6G Network Evolution]

- The outlook for 6G network technology evolution is as follows: ▲AI-Native ▲Green-Native ▲Quantum Security Network ▲Wireless Evolution Technology ▲Open RAN ▲Core Network ▲Transport Network ▲Aerial Network

[6G Spectrum]

- For 6G, identifying new spectrums and researching on spectrum refarming of existing spectrums should be conducted in parallel.
- Through the research on 6G candidate frequencies, coverage/capacity characteristics for each band should be identified.

[6G Timeline]

- ITU completed the 6G Framework Recommendation in 2023 and plans to approve the 6G standard specification in 2030.
- 3GPP is expected to submit 6G standard specifications to ITU that meet 6G technical performance requirements in 2028, and 6G commercialization is expected around 2030.

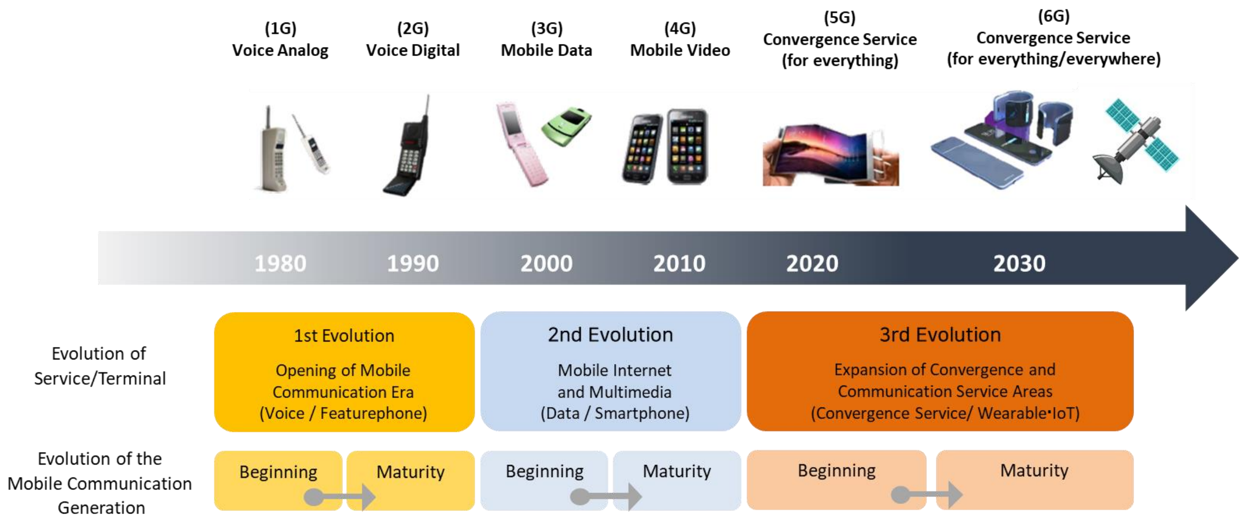
[Conclusion]

- SK Telecom plans to take the lead in developing 6G technology through collaboration with 6G partners in industry, academia and research, and aims to contribute to Korea becoming a leading global ICT country.

1. Preface

Looking back on the past, when the demand for new services and the development of various industries to support them progressed in tandem, the development of mobile communications became a catalyst that further accelerated the development of services and industries, which led to a new generation of mobile communications. The history of mobile communications, which continues to evolve into a new generation every 10 years, shows this virtuous cycle well.

CDMA, which was commercialized for the first time in the world by Korea, became the starting point of explosive growth while meeting the needs of the times for popularization of mobile communications. Since then, the growth of wired internet has become a driving force for longing for internet service in the palm of a hand anywhere in the world, and the evolution of mobile communications to 3G could continue naturally. The development of smartphone form factors such as cameras and application processors, and the rapid growth of the multimedia market that meets the prosumer trend have attracted numerous OTT services. This has become the basis for 4G(LTE) to lead mobile communication to maturity, naturally requiring broadband mobile services.



[Figure 1] Evolutionary connection between service/terminal and mobile communication

Since the commercialization of the world's first 5G services in 2019, standardization of 5G-Advanced technology is already in progress to further enhance 5G services. Compared to LTE, 5G is expected to support new services based on wider bandwidth and lower latency, but it is also true that there are some areas that fall short of the service innovation experienced during the evolution of the last generation of mobile communications. This may indicate that the mobile communications industry is also experiencing a slowing growth rate as seen in other mature industries, but it may also be due to factors such as the lack of industrial development to support new services, which were the drivers of the evolution of LTE.

In this white paper, after reviewing the various lessons experienced from the world's first commercialization of 5G, namely *5G Lessons Learned*, we present scenarios and services for 6G that we are currently interested in, which will be provided around 2030. We present our views on the major requirements of 6G and future network evolution, considering *5G Lessons Learned*, so that these services have a virtuous cycle in a complementary manner with 6G mobile communication. In addition, by presenting the standardization trend and our opinion on 6G spectrum, a core asset of mobile communication, we expect to gather consensus among stakeholders including mobile communication standardization organizations.

2. 5G Lessons Learned

The 5G Vision Recommendation[1], published in September 2015 by ITU-R, an international standardization organization under the United Nations, triggered the commercialization of 5G services in 2019. Although various goals have been achieved, we need to prepare for 6G services by checking tasks that have not yet been achieved at this point.

A variety of visionary services expected, but there was a lack of killer service

When 5G was being prepared, services such as autonomous driving, UAM, XR, hologram, and digital twin were expected. So far, there have been some cases that have not actually led to service activation compared to expectations. A more objective view regarding the future prospects of 5G as well as the readiness of its surrounding environment could have been helpful in managing the level of expectations for 5G.

3D video, UHD streaming, AR/VR, autonomous driving, and remote surgery are representative examples of 5G use cases that were stated in the 5G Vision Recommendation but have not yet become mainstream. Most of them are the result of a combination of factors such as device form factor constraints, immaturity of device and service technology, low or absent market demand, and policy/regulation issues, rather than a single factor of the lack of 5G performance.

Therefore, to successfully settle innovative services in the 6G era, all participants in the ecosystem should work together to prepare the environment along with 6G technology.

Gap between 5G Vision Recommendations and customer expectations

Although the usage scenarios and capability goals presented in the 5G Vision Recommendation are future goals to be achieved in the long term, misunderstandings have been created that can lead to excessive expectations of 5G performance and innovative services based on it from the beginning of commercialization. To prevent this misunderstanding from recurring in 6G, it is necessary to consider various usage scenarios of 6G, set achievable goals, and fully communicate with the public.

In particular, there were issues raised about the maximum transmission speed of 20Gbps, which was considered an icon of 5G key performance indicators. As 3G evolved into LTE, the radio access technology also evolved from WCDMA to OFDMA, and with the introduction of CA and multi-antenna technology, it became possible to use a much wider bandwidth than 3G. This can be seen as a 'revolutionary' improvement. On the other hand, 5G is considered as an 'evolutionary' improvement that supplements the performance of LTE based on the same radio access technology, CA, and multi-antenna system technology. Due to this, it was difficult to implement a dramatic increase in transmission speed shown in LTE in 5G at once.

Moreover, the difference in technology perception was further revealed in the initial stage of 5G commercialization. Early commercialization was promoted for 5G, however, 5G required more base station compared to LTE to build a nationwide network due to its frequency characteristics, requiring more efforts in terms of cost and time. SK Telecom has made significant efforts to expedite 5G nationwide rollout, but customers wanted the same level of coverage as LTE in a brief period.

Even though there are negative views of 5G as mentioned above, there are certainly positive aspects of 5G as well. With the spread of smartphones and the explosive growth of mobile video service, customers' wireless data usage has exploded, and the estimated timing of LTE frequency saturation point has accelerated. Nevertheless, SK Telecom was able to provide stable services by preemptively securing new 5G frequencies and establishing nationwide networks. Currently, costs per GB on 5G are more than 70% cheaper than on LTE, so 5G customers tend to use more than 50% more data than LTE customers. In addition, SK Telecom is making significant efforts to solve technical and economic problems from *5G Lessons Learned* and to provide stable quality of services to consumers.

Need to consider various frequency bands and technology maturity

6G is exploring more usage scenarios than 5G's three usage scenarios: eMBB, URLLC, and mMTC, and it is expected that more diverse frequency bands, including upper mid-band and Sub-㎔ band, will be allocated to support them. Radio technologies that compensate for poor radio wave characteristics must be prepared first, and overall technological innovation is required, from components to system units, that reduce high power consumption and heat generation of network systems and UE due to the use of wide bandwidths.

In addition, the mobile communication network is changing in line with the trend of virtualization and openness, and in the core network, a massive portion of the transition to a cloud-based virtualization and open structure has already been made. However, the RAN, which accounts for a high proportion of CAPEX and OPEX of mobile communication networks, is at a standstill in this technological change. Open RAN, which advocates virtualization and openness, enables agile development and application of new radio technologies and services. Breaking away from the existing walled-garden-type equipment ecosystem, Open RAN will enable participation by chipset companies, server companies, ISVs, and small and medium-sized radio unit manufacturers. This will be possible only when the open interfaces are defined in the 6G standards.

On the other hand, 3GPP, a de-facto standards developing organization for mobile communication technical specifications, has defined 7 network architecture options in Rel-15, the first 5G standard. The reason so many options were defined was to satisfy the requirements of various mobile operators, such as 5G deployment relying on existing LTE networks for coverage or 5G standalone deployment. Later, as derivative options were created for each option, the problem of fragmentation of standard specifications occurred, which also raised the possibility of delaying the system development schedule.

As more FRs are expected to be adopted in 6G, the requirements from mobile operators can be more diversified. In order not to repeat the fragmentation of architecture options, it is necessary to focus on the core options expected with the high demands. To this end, prior coordination and agreements in organizations such as GSMA and NGMN are required.

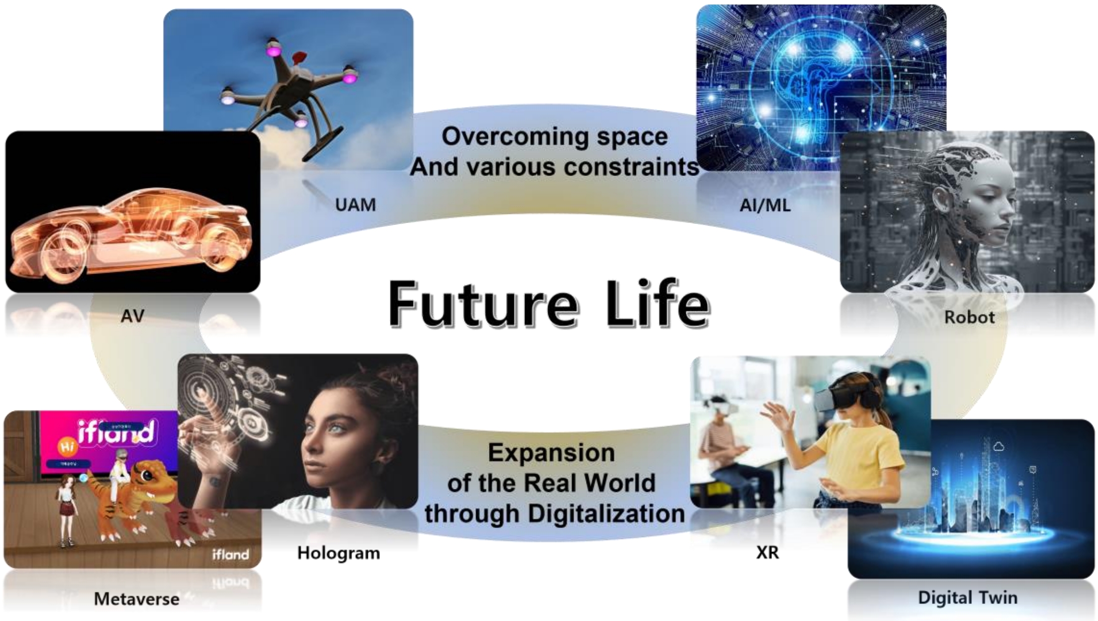
3. 2030 Promising Service Prospects and Technology Trends

In the 6G era, 5G's eMBB, URLLC, and mMTC technology characteristics will be further evolved, while AI and sensor convergence technologies will be applied to communications. At the same time, services that were difficult to fully implement with 5G technology will become feasible thanks to advanced device performance, innovative form factors, and service technology development, and more diverse new 6G services are expected to emerge.

Smart-City/Factory/Office that emerged with the advent of 5G will be enhanced along with the completeness of the service. Although it was not introduced due to technical limitations, services that already have concepts and goals will be provided in earnest. Among these services, we are watching with interest those that are expected to bring about innovation in lifestyle. In particular, AI/ML-based intelligence and sensor fusion-based digitization will alleviate the constraints of time and space encountered in daily life. We are interested in these services that can simultaneously increase the quality of life for individuals and the productivity of society, which have been difficult to coexist with so far.

Lifestyle innovating services breaking the constraints of time and space

Autonomous driving, UAM, XR, hologram, digital twin, etc. are being discussed as representative services that will alleviate the constraints of space and time to bring about innovation in lifestyle. The development of AI and sensing technology combined with the aforementioned 6G communication technology will be the basis for driving the success of these services. Each service is expected to provide customers with the experience of a successful lifestyle innovation when accompanied by the development of various industries and other related technologies.



[Figure 2] 2030 promising services

Autonomous driving requires AI-based autonomous driving algorithms, such as processing and analyzing large-scale sensor data collected during movement and optimizing routes. In addition, fully autonomous driving, called Level 4, requires 6G communication that provides high transmission speed and low latency. The Level 4 autonomous driving will provide occupants with the freedom of time and space, including safe driving experiences and provision of work, rest, and infotainment while driving.

UAM is a field that is attracting attention as a next-generation transportation system in urban spaces. Along with the characteristics of sensing, AI, and 6G ultra-high transmission speed and low latency required for autonomous driving, the UAM service is possible only when all technologies are combined including airborne network and NTN for network connection required for air vehicle control, inter-vehicle communication, and platooning in the city. When UAM service spreads in earnest, it is expected to greatly alleviate the time and space constraints of passengers.

XR is a concept that includes VR, AR, and MR. In the 6G era, it is expected to introduce XR device technology with a form factor that enhances wearability and ease of use. High-definition, high-resolution, 360-degree video and 3D image transmission will be possible due to the ultra-high transmission speed and low latency of 6G. This will make it possible to provide a realistic working environment without site visits or direct contact with the real thing.

Holograms and digital twins transmit and process high-definition, high-resolution 3D holograms in real time based on 6G technology. It is expected that the physical product or system will be transferred to a digital environment in real time through sensor convergence technology, thereby minimizing the time and space costs for constructing an actual working environment or producing and modifying a physical mock-up.

In addition, NTN, an aerial network through satellites and various aircraft, is organically linked with the terrestrial network, making it possible to secure more dense network coverage, thereby providing 6G services stably anytime, anywhere.

These services are expected to contribute to enhancing ESG effects and reducing overall social costs by creating a virtuous cycle of development and development of the overall industrial ecosystem as well as innovation of individual and social lifestyles.

4. 6G Trends

6G is pursuing a differentiated vision through convergence with disruptive innovative technologies such as AI, sensing, and NTN, going beyond the categories of ultra-high speed, ultra-low latency, and massive connectivity, which are the key performance indicators of 5G. In the case of AI, many investments and discussions are actively underway in various stakeholders such as governments, manufacturers, businesses, and academia with the goal of building next-generation AI networks and services such as OpenAI's ChatGPT and SKT's A. (A dot)[2]. Although 6G standardization has not yet begun, major advanced countries and companies have already started 6G research and development and are presenting 6G visions and early research results through technical forums and white paper publications[3]. Accordingly, this chapter aims to analyze the global 6G policy and technology trends as of June 2023[4].

4.1 Global Trends

U.S.: Form a coalition of economy/security 'allies' to secure 6G leadership

In the US, ATIS established NGA, a 6G research alliance, in February 2022 to secure leadership in 6G[5]. This private consultative body for the next generation of telecommunications includes universities and mobile network operators (Verizon, AT&T, T-Mobile, etc.), BS and UE equipment manufacturers (Qualcomm, Samsung, Nokia, Apple, etc.), and Open RAN equipment manufacturers (HPE, Dell, etc.), software and platform companies (Microsoft, Google), and other global companies in the US. They are participating in the US-led 6G technology leadership, vision, and roadmap establishment, and as part of that, NGA announced the 2022 6G vision white paper 'Next G Alliance: Roadmap to 6G'[6]. In addition, a 6G symposium was formed under the leadership of the US, and the event is held every spring and fall to expand its size and partnership. Also, it signed MOUs with Japan's B5GPC, EU's 6G-IA, and domestic 6G forum to solidify its technological leadership in the early 6G ecosystem.

China: Government-led massive investment for 6G mobile & satellite R&D

China has started 6G-related research since 2017 and has been conducting large-scale and aggressive national research under the leadership of the Ministry of Science and Technology[7]. For example, the ministry is promoting a 6G research project worth about KRW 580 billion from 2019 to 2027. The China Academy of Information and Communication Technology, a part of the Ministry of Science and Technology, established the 6G promotion team, 'IMT-2030', and started research on core technologies for 6G communication infrastructure with the goal of commercializing 6G by 2030. With rapid and aggressive government-led investment, it ranks first(40%) in 6G patent share by country, beating the United States(35%) and Japan(10%), which ranked second and third.

Huawei, which started 6G research in 2017, announced that it would launch 6G products for businesses and consumers in 2030 and define 5.5G and 6G simultaneously within the next few years. It emphasized its 6G infrastructure vision through the Smart World 2030 Forum hosted in April 2022. In addition, Huawei is also working on 6G satellite communication research by launching a total of three low-orbit research satellites for communication experiments.

Japan: Establishing global B5G/6G strategies from 5G experiences

Japan announced the "Beyond 5G Promotion Strategy," a comprehensive strategy for 6G based on its technological outlook for 2030, to recover its competitiveness in the mobile telecommunications sector, which has lagged major countries such as Korea, the US, and China, in 5G and gain a competitive edge in 6G. First, while focusing on technological cooperation with other countries through the announcement of a joint investment plan with the US($4.5 billion) and the conclusion of a 6G communication technology agreement between the Ministry of Internal Affairs and Communications of Japan and the Finnish government($2 billion), the country launched 'B5GPC' and established 'Beyond 5G New Management Strategy Center' dedicated to intellectual property rights and standardization to promote speedy introduction and commercialization of 6G. In the B5GPC, major mobile communication-related companies such as the University of Tokyo, NTT DOCOMO, KDDI, Softbank, and Rakuten Mobile are all participating. It is actively in connection with the 5GMF and the Beyond 5G R&D promotion platform related to test bed configuration[8]. In addition, in a private sector, technical discussions are underway to implement a next-generation network based on the optical technology through the IOWN Global Forum, which was established with Sony and Toyota participating in the initiative and led by NTT.

EU: University-centered 6G basic R&D funded from EU

In the EU, the 6G flagship has been established since 2018 led by the University of Oulu, Finland, and the 'Wireless Summit', an international 6G conference, has been held every year. The University of Oulu, Aalto University, Finnish Technology Research Center, and Nokia formed the 6G Flagship, a collaboration chain between companies, and is conducting various 6G research and development, starting with the ㎔ band. The Hexa-X project is another EU privately led 6G mobile communications R&D group. Another EU privately-led 6G mobile communication research and development group is the Hexa-X project. The Hexa-X project is a large-scale private project involving the EU and several European telecommunications companies including Ericsson, Nokia and Orange[9]. The project aims to develop a vision for 6G technology and define key research challenges in areas such as wireless connectivity, energy efficiency and security. Hexa-X aims to develop 6G standard technology, vision, and core service model by 2030.

4.2 Domestic Trends

World first 6G commercialization through joint 6G R&D consortium

In line with the 6G strategies of the countries reviewed above, we would like to introduce domestic research trends. In August 2020, the Ministry of Science and ICT announced the future mobile communication R&D promotion strategy for the 6G era, and established a plan to develop 6G core technologies by investing KRW 200 billion over five years from 2021 to 2025. This year, the K-Network 2030 strategy was announced with the goal of 2028, which is two years earlier than the original plan for the commercialization of 6G. Currently, a preliminary feasibility study for R&D worth KRW 625.3 billion is underway, and the government plans to increase the national share of 6G standard patents to more than 30% through continuous support.

Not only the government, but also domestic industry, academia, and research institutes are preparing for early commercialization of 6G. The 5G Forum, an industry-university-research joint forum launched in 2013 to lead 5G technology, held the 10th anniversary ceremony and regular meetings on May 2023. The 5G Forum was newly launched under the name of '6G Forum' to prepare for 6G commercialization in earnest. The 6G Forum, attended by about 150 experts from 44 industry, academia, and research institutes, will become the center of 6G cooperation in Korea, while serving as a catalyst for the development of new services converged with other industries and telecommunications. In 2019, Samsung Electronics established the 6G Research Team by launching the Next-Generation Communication Research Center, sharing technical insights by publishing 6G white papers and 6G frequency white papers in 2020 and 2022, respectively. LG Electronics is concentrating on securing original technologies by establishing a R&D cooperation belt for 6G core technologies with Germany's Fraunhofer Institute, KAIST, KRISS, and Keysight. SK Telecom is preparing for the 6G era by successfully developing RIS-applied glass technology for 6G candidate frequencies. Externally, together with Japan's NTT DOCOMO, white papers '6G Common Requirements' [10] and 'Green Mobile Network: Energy Saving Efforts by SK Telecom and NTT DOCOMO' [11] were published. In addition, SK Telecom is taking the lead in creating an early 6G ecosystem by participating in the white paper '6G Requirements and Design Considerations'[12] recently released by NGMN, a global alliance led by telecom mobile operators.

5. 6G Key Requirements

Previously in Chapter 2, we briefly reviewed *5G Lessons Learned*. In this chapter, SK Telecom's key requirements for 6G will be presented to support usage scenarios and services expected in the 6G era based on lessons learned from 5G.

5.1 Evolution through 6G Killer Services

Through the publication of the 5G Vision Recommendation, ITU-R has predicted and suggested three usage scenarios for 5G: eMBB, URLLC, and mMTC. The prominent level of expectations for the expansion of broadband service, which was the success factor of LTE, led to 5G. Reflecting this, 3GPP, which defines 5G standards, focused on technology for providing ultra-broadband communication services in Rel-15, the first full set of 5G standard. Since then, from Rel-16, standards including technologies for supporting other industrial convergence services, such as ultra-low-latency communication service and large-scale machine-to-machine communication service, have been defined.

However, there were unsatisfied parts when looking at the current point, about four years after the commercialization of 5G. Most of the use cases of 5G technology focus on eMBB services, and several factors, such as form factor constraints, immaturity of device and service technology, low or non-existent market demand, and policy/regulatory issues are complexly intertwined. As a result, representative services of 5G such as URLLC and mMTC services, are not activated.

Looking back, the explosive market growth of LTE was possible because there was a killer service called mobile video. The fact that mobile video service, which was impossible in 3G, became possible with the rapid increase in wireless speed in LTE, and the emergence of a new consumer device, a smartphone represented by the iPhone, functioned as a catalyst to promote the mobile revolution.

Efforts to increase wireless speed for eMBB services continued in 5G. To maximize the speed experienced by customers, SK Telecom introduced the 5G NSA structure(option 3x) and evolved the network into a structure that can combine the speed of the existing LTE speed and the new 5G band. However, the requirements of currently activated services or services with high demand in the market are largely satisfied even in LTE, so the development and activation of new markets due to the introduction of 5G is still insignificant.

In addition, in terms of devices, wearable devices for AR/VR services have been released since smartphones, but the limitations of the device form factor itself, such as discomfort and difficulty of use, are acting as obstacles to the spread of the service.

Need to discover 6G killer services and evolve in connection

Therefore, to revitalize related industries and create synergy through 6G, we should focus on customer interests such as lifestyle innovation as well as performance improvement in terms of simple network infrastructure, and convergence with future technologies such as AI and sensing technology. All participants in the related ecosystem must think together to discover exclusive products and services that can only be experienced in 6G by seeking synergies and paradigm shifts in mobile communication services.

In addition, since the emergence of new device types such as XR, UAM, self-driving cars, and holographic watches can cause the proliferation of 6G-only products and services, it is necessary to monitor the technology development trend in related industries and prepare network infrastructure to support them.

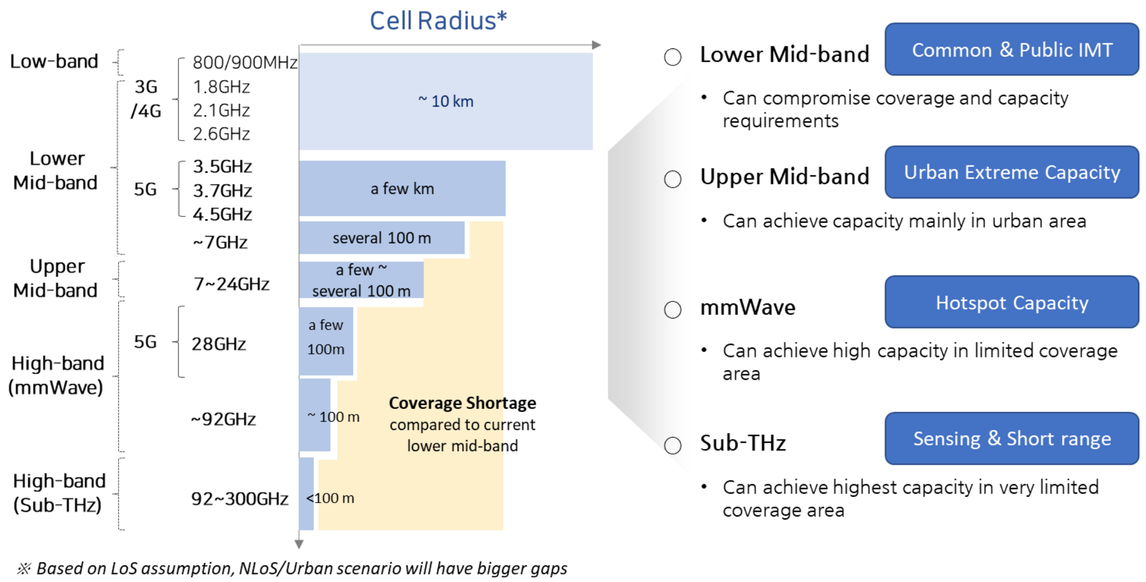
5.2 6G Vision

WP 5D, a mobile communication standardization working group under the ITU-R, is in charge of defining the vision and requirements of next-generation mobile communication when it evolves into a new mobile communication generation and approving candidate technologies that satisfy them as international standards. WP 5D presents the vision of next-generation mobile communication through the publication of recommendations and has presented a vision to reach technology maturity through usage scenarios and target capabilities of the technology.

In 6G, as in 5G, there should be no misunderstandings that can raise expectations.

First, WP 5D approved the 6G Vision Recommendation at the 44th meeting in June 2023. The document called 6G Vision Recommendation will be called 6G Framework Recommendation. It is necessary to avoid misleading the public that the goals presented in the 6G vision will be realized immediately with the introduction of 6G.

Second, the specification of the technical performance requirements will be conducted from 2024. Instead of presenting the performance target for each indicator as a single figure, which was previously presented as a fixed value, we can present it as a range considering various frequency bands and deployment scenarios. In 6G, various bands are expected to be used as existing frequency bands for IMT services become saturated, and deployment scenarios for each band are also expected to be diverse. For example, Low-band is expected to provide efficient coverage in the suburbs, Mid-band to provide capacity in downtown areas, and High-band to be used for short-range hotspot capacity and sensing. As the frequency band increases, it is easy to secure a wide bandwidth, so the maximum achievable transmission rate increases proportionally, while the coverage decreases due to the increase in path loss. In particular, in the case of an urban area with many buildings, it is more difficult to secure coverage due to diffraction characteristics of radio waves.



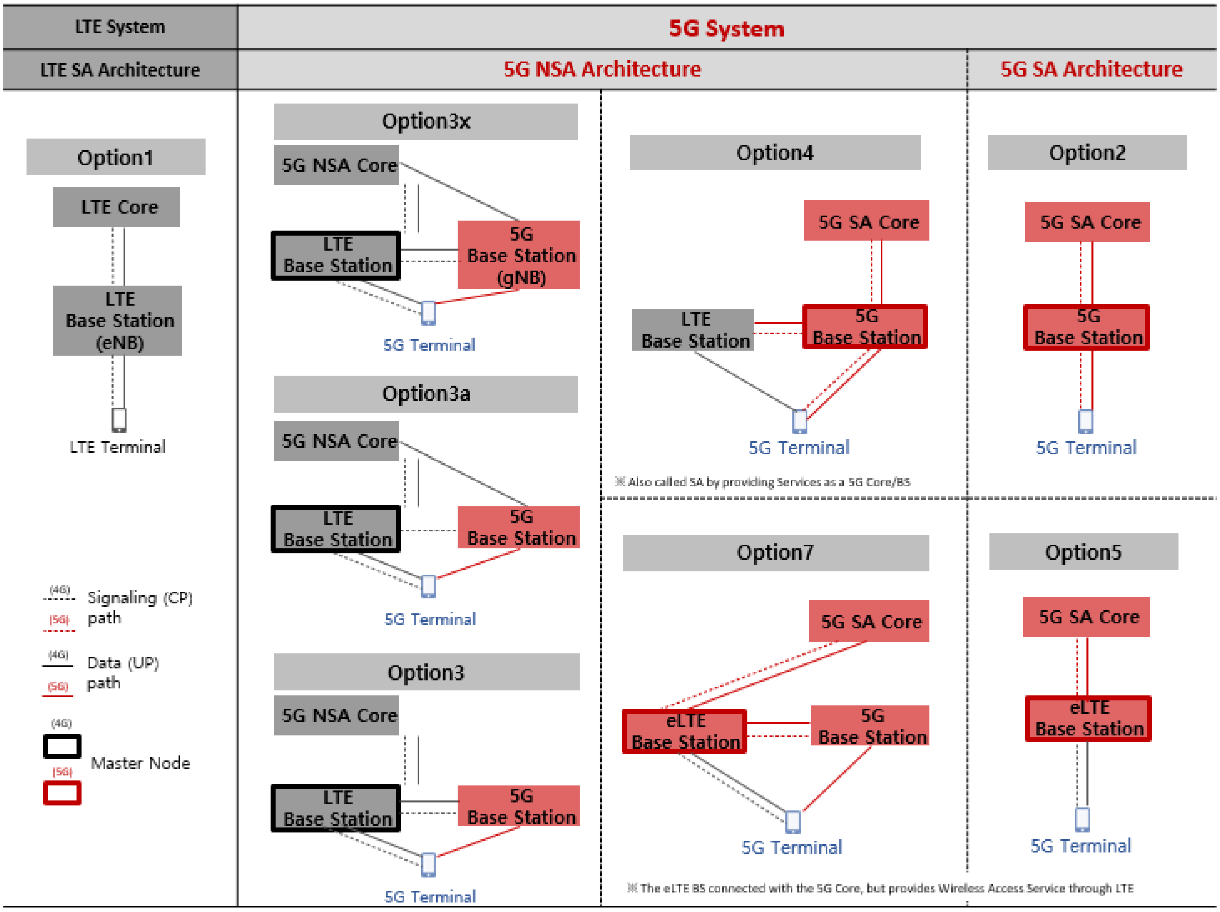
[Figure 3] Deployment scenarios by frequency bands

Lastly, even considering that the performance goal is set as the maximum achievable goal, it should be set to a realistically achievable number, not an unfounded figure. For example, when the discussion of 6G first started, a maximum transmission rate of 1Tbps was discussed along with Sub-THz technology. However, it is necessary to set a realistic target maximum speed considering the band expected to be used for actual 6G mobile communication and the available bandwidth.

SK Telecom has continuously proposed the above opinions to standardization and related forum organizations, and it was partially reflected in the 6G recommendation approved as DNR by WP 5D in June 2023. Performance targets for some key indicators, such as maximum transmission speed, will be determined in the technical performance requirements phase, which will begin in 2024.

5.3 Defining Simple Architecture Options

At the time 5G was introduced, 3GPP considered various environments and different purposes of introducing infrastructure for each mobile network operator. Various architecture options were discussed, and even derivative options for each option were defined. In 3GPP, NSA Option 3 was first standardized in December 2017 through the Early Drop, followed by SA Option 2 in June 2018, and Option 4 through the Late Drop in March 2019.



[Figure 4] 5G architecture options

SK Telecom launched 5G commercial service by adopting the 5G NSA Option 3 architecture that supports stable call connection and mobility. We adopted an option 3x architecture that facilitates future 5G infrastructure expansion and SA network evolution and can control LTE and 5G traffic. Voice service operates based on stable LTE with nationwide network coverage, and data service can increase the perceived speed by using LTE and 5G at the same time.

To additionally support URLLC and mMTC services as well as eMBB, it is necessary to evolve the network into SA. One thing to consider when evolving from the current NSA to the SA architecture is that service quality, such as stable call connection, mobility, perceived speed, and voice service, must be maintained beyond the existing level.

SK Telecom completed the development of SA Option 2 to provide call processing, data, and voice services exclusively through 5G, and developed a network slicing function to select 5G cores for each slice and differentiate/separate radio resources to provide differentiated services for each 5G service. However, SA option 2 has an issue in that the perceived speed is lowered compared to the existing NSA architecture because it cannot use 5G and LTE at the same time for data service. Therefore, among the SA options, we are considering Option 4, which can maintain the same level of perceived speed by transmitting user traffic with 5G and LTE by applying the DC operation introduced in the NSA Option 3x. However, the global ecosystem related to the SA architecture is still formed around Option 2, and the BS/UE manufacturer's development plan for Option 4 is yet to be determined.

As described above, 3GPP defined several architecture options through several drops, but this resulted in fragmentation of standard specifications and delayed system development schedule.

Simple 6G architecture options taking into account the existing networks

ITU-R is seeking new spectrum for IMT, such as Upper Mid-band (7-24 ㎓), since the existing spectrum for IMT is nearing saturation. Considering the refarming of the existing IMT spectrum for 6G, it is very likely that the diverse spectrum will be considered for 6G. In addition, when introducing 6G, coexistence and efficient interworking with existing generations must be considered, and the architecture design needs to enable efficient network evolution when existing services are terminated. Considering the service maintenance and termination plan of the previous generation, which are different for each mobile operator, it is expected that the requirements from mobile operators will become more diversified.

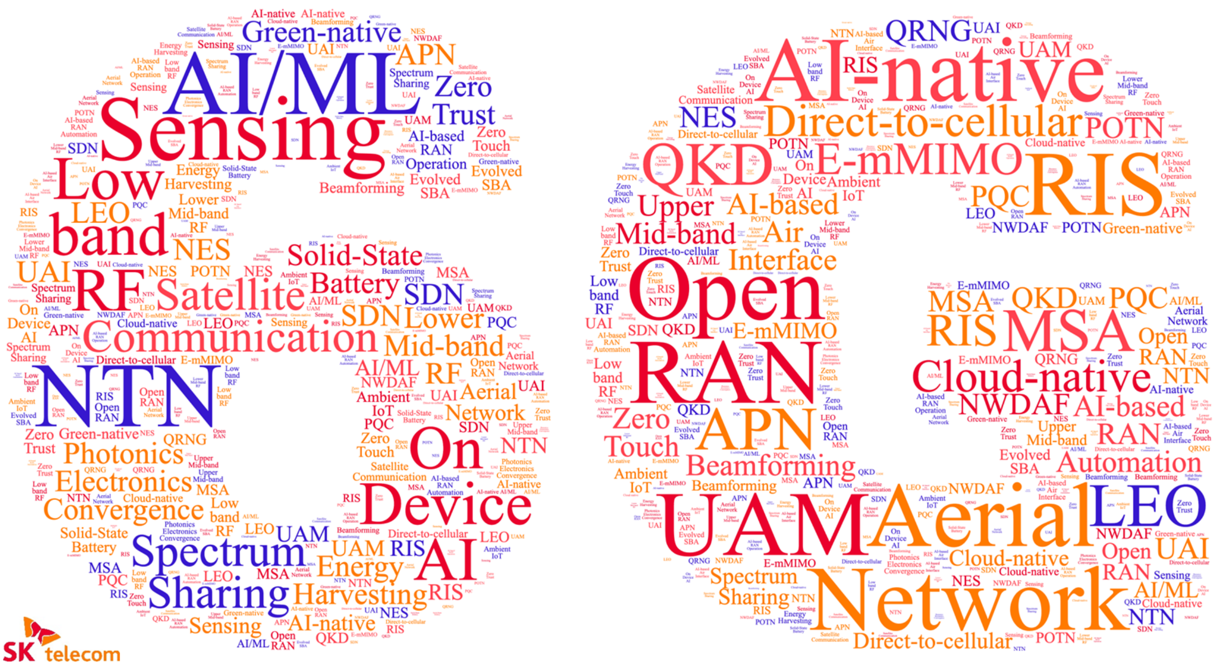
Therefore, there is a possibility that the fragmentation of 5G architecture options will be repeated even in 6G, and to prevent this, standardization work should be done by focusing on the most probable 6G architecture options. In addition, when introducing

6G, it is necessary to design an architecture that can maintain service quality, including speed experienced by customers, at a level equal to or higher than that of existing services. To this end, it is necessary to develop and standardize technologies that can maximize service quality and enable coexistence and evolution between generations, such as inter-band frequency combining technology (CA, DC) and efficient spectrum sharing technology.

6. 6G Network Evolution

6.1 Technology Evolution Prospects

AI, satellite, etc. are being discussed as technologies for all areas of the network and individual areas that are expected to be used in the 6G era, and the main keywords are summarized below.



[Figure 5] 6G keywords

[Table 1] 6G keywords

No	Keyword
1	Aerial Network
2	AI-based Air Interface
3	AI-based RAN Automation
4	AI-based RAN Operation
5	AI/ML

6	AI-native
7	All Photonics Network (APN)
8	Ambient IoT
9	Beamforming
10	Cloud-native
11	Direct-to-cellular
12	Energy Harvesting
13	Evolved Service Based Architecture (eSBA)
14	Extreme massive MIMO
15	Green-native
16	Low-band RF
17	Low Earth Orbit (LEO)
18	Lower Mid-band RF
19	Micro Service Architecture (MSA)
20	Network Energy Saving
21	Non-Terrestrial Network (NTN)
22	Network Data Analytics Function (NWDAF)
23	On-device AI
24	Open RAN
25	Packet Optical Transport Network (POTN)
26	Photonics Electronics Convergence
27	Post-Quantum Cryptography (PQC)
28	Quantum Key Distribution (QKD)
29	Quantum Random Number Generation (QRNG)
30	Reconfigurable Intelligent Surface (RIS)
31	Satellite Communication
32	Sensing
33	Software-defined Networking (SDN)
34	Solid-State Battery
35	Spectrum Sharing
36	UE Assistance Information (UAI)
37	Upper Mid-band
38	Urban Air Mobility (UAM)
39	Zero Touch
40	Zero Trust

In SK Telecom's 6G network, megatrends such as AI, power saving, and security will be widespread across all network areas, and technologies specialized for each network area, such as radio access network, core network, transport network, and aerial network, will be applied and evolved. Each technology will be explained in the following chapters.

6.2 AI-native Network

As interests in generative AI technology such as ChatGPT rapidly increase, it is expected that AI will play a vital role in leading innovations in many areas and cracking previously unresolved problems. As AI technology is being discussed as a key element in 6G, SK Telecom is conducting R&D that integrates AI technology into wireless access networks, core networks, and UEs.

RAN

AI-based RAN technology can be divided into three major parts depending on where data collection, AI training and inferences are performed.

AI/ML for	Characteristics	Use Cases
RAN Automation (OAM)	1. Data Collection: BS statistics, OAM info for other NW nodes* * unified OAM system is required for E2E optimization 2. AI Training: located in OAM (Online/Offline) 3. AI Inference: located in OAM	1. Energy Saving: cell/antenna on/off 2. Cell Shaping: beam shaping for each environments 3. And more
RAN Operation (>L1)	1. Data Collection: local BS, UE measurement*, neighboring BS* * via implementation based or standard Xn interface (for multi-vendor interoperability) 2. AI Training: located in OAM or BS (Online/Offline) 3. AI Inference: located in BS	1. Energy Saving: cell/antenna on/off 2. Load Balancing: steering UE among multi-bands 3. Mobility Mgmt.: minimizing call drops "Rel-18 AI/ML for NG-RAN WI Scope" 4. Link Adaptation: faster outer loop convergence 5. And more
Air Interface (L1, PHY)	1. Data Collection: local BS/UE 2. AI Training: OAM/BS (Offline) or BS/UE (Online) 3. AI Inference: located in BS and/or UE	1. CSI Compression 2. Beam Management 3. Positioning Accuracy Enhancement "Rel-18 AI/ML for Air Interface SI Scope" 4. And more...

[Figure 6] Classification of AI-based RAN technologies

First, AI-based RAN automation performs both AI learning and inference on the OAM server based on statistics extracted from BSs. Since data acquisition/learning/inference can all be performed on cloud servers where it is easy to secure additional computational power for any AI use cases and feature designs, implementation itself is simple. However, to obtain a substantial performance gain compared to legacy E2E monitoring and optimization by network operation experts, it is important to integrate statistics and operational data from all related network equipment, including not only BS but also core/transport network servers, and to finally manage/analyze them based on AI. SK

Telecom has implemented TANGO, which integrates more than 150 OSS systems from LTE, and is automating the operation of BS power saving features using AI.

The second technology is AI-based RAN operation that aims to maximize the desired KPI based on data such as internal information of the BS (CU/DU), UE reports, and adjacent BS information. Due to the limited BS computing power, preferred implementation method in 5G commercial network is BS only perform inference based on real-time input information and the AI model is trained offline on an external server. By applying such offline trained AI model to link adaptation operation in BSs, SK Telecom has secured a 10% throughput improvement at the cell edge. In addition, although standard support for AI-based RAN operation is not essential, 3GPP has approved Rel-18 AI/ML for NG-RAN WI, which defines necessary signaling for three target use cases (energy saving, load balancing, and mobility management) considering potential interoperability with other network node (OAM, 5GC) and other vendor's BSs (NG-RAN). In 6G networks, it is expected that online learning will also come true when BS with dedicate AI chipsets becomes widespread.

The last technology to be noted is AI-based air interface where AI technology is applied to PHY interface between BS and UE. Standard support is inevitable to realize AI-based air interface since procedures between BS and UE should be defined in the specifications. In this sense, 3GPP has approved Rel-18 AI/ML for Air Interface SI which investigates relevant procedures for three target use cases — CSI compression, beam management, and positioning accuracy enhancement). It is still initial study phase and expected to be further refined in Rel-19 and 6G.

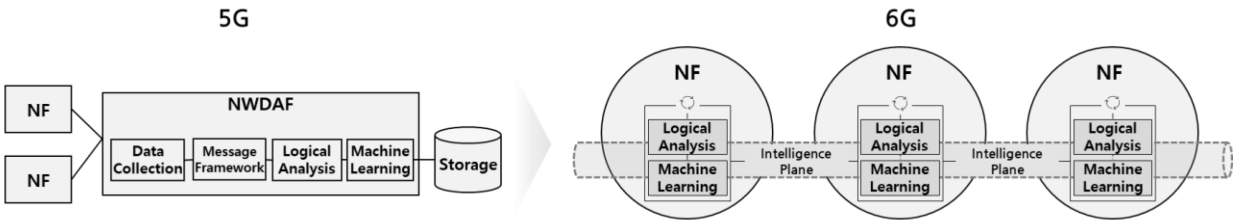
Core Network

One of the prominent differences between 5G core and LTE is the introduction of ML-based AI technology for the first time. 3GPP has defined NWDAF for 5G SA, which analyzes AI-based network data for intelligent and autonomous network operation and service management. NWDAF has five detailed components, including data collection, message framework, logical analysis, machine learning, and storage.

NWDAF provides a service that collects data in the 5G core system, analyzes trends, and performs future predictions based on machine learning. However, it is limited to collecting data from dozens or hundreds of NFs, which also limits the scope of analysis performed.

The 6G core will become a highly distributed AI structure as NWDAF service is inherent per each NF. Logical analysis and machine learning components will be essential two components for each NF, and an intelligent plane will be constructed through interconnection among NFs. Data collection, message processing, and storage functions will be performed by the NFs themselves.

In an intelligent plane, information from all network layers is collected, analyzed, and inferred, and AI-based data learning will be performed with ultra-low latency across the entire network area. Additionally, AI-based analysis and inference results are shared through the intelligent plane to ensure high reliability, and parameters and network configuration information that were previously managed statically are now dynamically auto-configured and optimized. SK Telecom has successfully developed local NWDAF technology that dynamically predicts paging areas as subscribers move, greatly reducing paging signal messages. In conjunction with this local NWDAF, we are designing a central NWDAF that performs centralized data analysis and modeling.



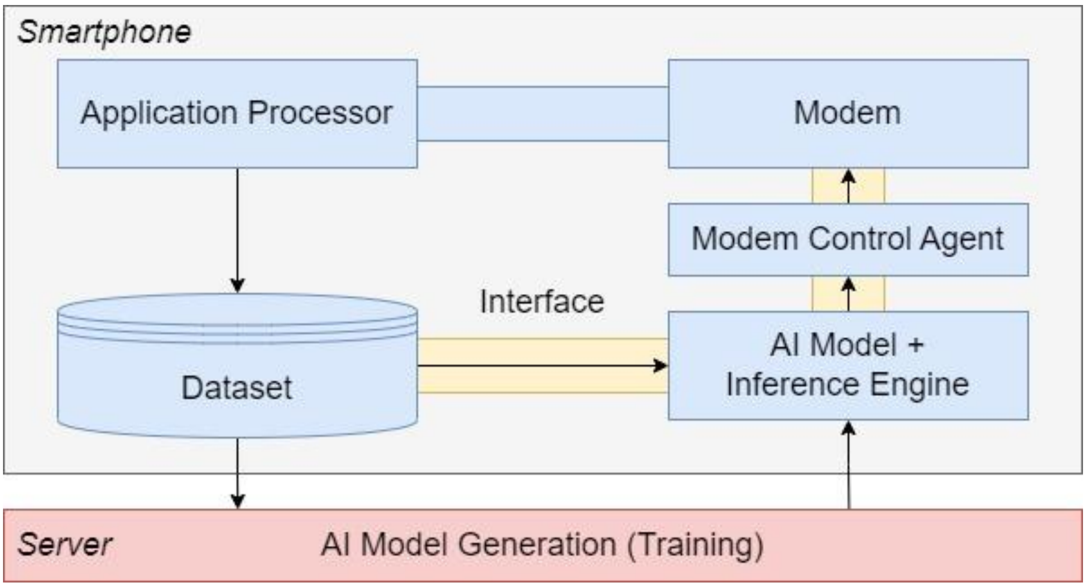
[Figure 7] NWDAF in 5G and AI-native NF structure in 6G Core

Device

As computing performance, integration, and power consumption of semiconductors supporting AI technology improve, a favorable environment is being created for applying AI to mobile devices such as smartphones. In other words, the computational power of CPU/GPU optimized for mobile devices has greatly improved, and the trend of AI-dedicated NPU being included as a basic feature in mobile devices is spreading. Furthermore, with the development of AI compression technology targeting mobile devices instead of servers, complex AI models can now be processed in real-time on smartphones.

We are currently developing on-device AI technology that utilizes various data collected from smartphones to improve customer experience. Smartphones form the point of contact with customers in mobile communication networks but at the same time they are also a source of information that BSs may find difficult to identify. Therefore, it would be useful for smartphones to predict by their own future power consumption, heat generation, usage patterns of services or applications used by customers, and request optimized device settings from BSs based on their current state.

For example, smartphones can use AI to analyze and predict traffic patterns and utilize them for power consumption optimization. Typically, a device performs data transmission and reception in a connected state and transitions to an idle state when there is no more data to transmit or receive for a predetermined inactivity timer period. If traffic occurrence and characteristics can be more accurately predicted using AI, a flexible and power-efficient idle state transition can contribute to optimizing device power consumption instead of a fixed timer-based approach. We plan to implement this in an intelligent form optimized for traffic or customer service/app usage situations, using a series of processes of data collection/analysis, learning, inference, and verification, implemented on the device, adopting newly introduced power-saving technology from standard specifications or the global manufacturers.



[Figure 8] On-device AI operation block diagram

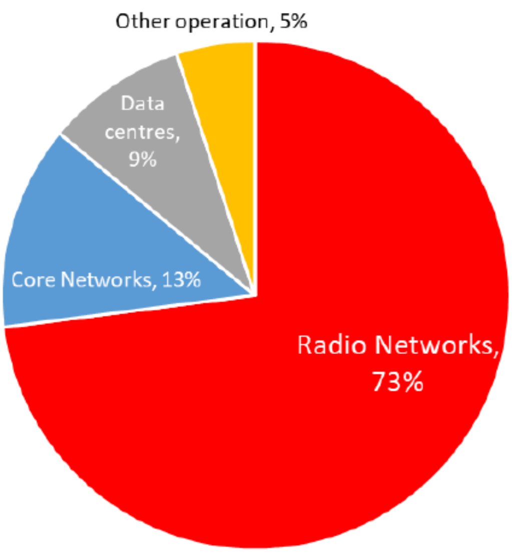
AI can also be applied to beamforming technology for performance improvement as well as power consumption reduction that directly impacts the quality of experience of customers. In the future, when utilizing high bands compared to 5G in 6G, the beam width used for communication will become narrower and the number of beams will increase. Therefore, the prediction of the accurate arrival angle and transmission/reception beam pairs of real-timely changing beams is necessary for precise beam management. Generally, sensor information such as RF, LiDAR, Radar, GPS is used for arrival angle prediction. In addition, for aerial network services such as UAM and NTN, 3D location information is also required. Therefore, AI that performs judgments based on complex data learning can be the optimal solution for intelligent service-specific beamforming operations, and we plan to continue researching relevant application technology.

6.3 Green-native Network

Climate change is a global issue, and efforts to reduce carbon emissions are everywhere in all industries, including the mobile communication industry. Mobile operators around the world are pursuing various activities to attain carbon neutrality goals, and energy efficiency is being recognized as an important consideration in mobile communication network design across all areas.

RAN

The following figure shows the analysis of power consumption by access, core, data center, and other components, revealing that power consumption by BSs accounts for 73% of total power consumption. Therefore, reducing power consumption by BSs is the most important area for improving network power efficiency.



[Figure 9] Mobile network power consumption[13]

In particular, 5G radio units show 2-4 times more power consumption over LTE RU due to 8-16 times bigger number of Tx/Rx antennas, 5-10 times higher bands and higher transmission power. Furthermore, as higher bands are used due to the shortage of available frequencies, the number of RU installed per unit area increases to overcome signal attenuation, driving power consumption reduction of RU into a KPI, so that it should be considered in the design of next-generation mobile communication technology.

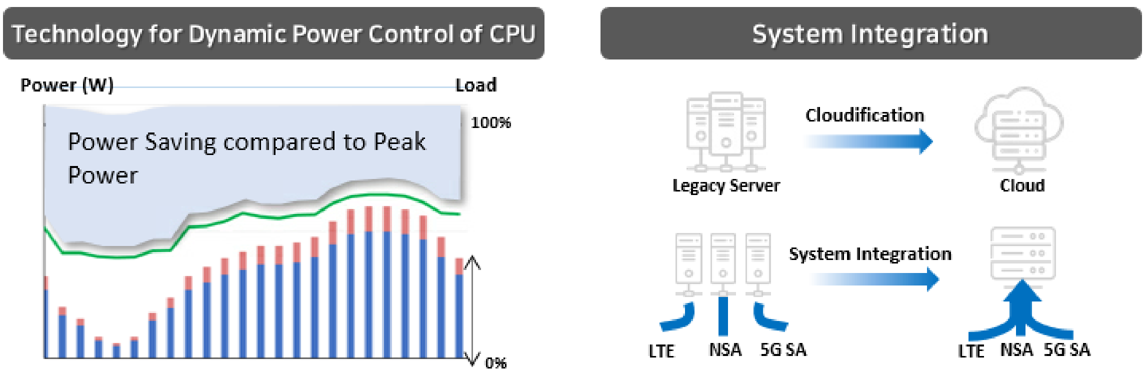
Therefore, in 3GPP Rel-18, WI for NES has been approved, and 5G standard improvements for BS power consumption reduction are underway. Specifically, to prove energy-saving benefits, energy consumption model was generated by considering the transmission and reception state of the BS, relative power consumption values, and the time and energy required for state transitions[14]. Based on this modeling, various techniques are being discussed to optimize performance in the four categories of time, frequency, space, and power. Since 6G does not have compatibility issues with existing 5G, it is expected that a more energy-efficient design will be introduced from a standard perspective.

However, in addition to such standard improvements, a comprehensive approach is needed to actively reduce BS power consumption in all aspects of BS equipment design, development, and operation. It includes i) hardware aspects such as development and application of low-power components/parts, low-power design of RF frontend which should be started from the initial development stage, ii) development of software-based power consumption reduction functions such as micro/antenna/deep/cell sleep, and iii) efficient operation of software-based power consumption reduction functions that incorporate AI in the entire cycle of BS equipment design, development, and operation.

To reach this goal, SK Telecom has published a separate white paper to provide guidelines for cooperation between manufacturers and mobile operators in developing low-power BS equipment from the initial product hardware design stage[15]. In particular, as power consumption increases significantly as equipment performance improves, we have suggested a P-index that considers performance differences amongst equipment and then proposed several power consumption monitoring methods based on P-index. Currently, SK Telecom is developing equipment with the P-index as a KPI even when introducing new 5G BS equipment, and planning to continue applying and improving it in 6G.

Core Network

In 5G, since the evolution of technology was mainly focused on, environmental and ecological considerations were not fully taken into account in equipment design and manufacturing. In 6G, the direction of evolution is towards reducing power consumption without compromising customer's quality of service. It targets to apply functions that dynamically control the power resources of all software and hardware in accordance with the situation, thereby reducing power consumption without packet loss or delay. In addition, the schemes to save resources by cloudifying existing physical servers and converging LTE/NSA/SA systems will also be considered with importance. Finally, the use of low-power, high-performance hardware components (CPU, FPGA, Memory, NIC, Fan, PSU, etc.) will also be considered to reduce power consumption. SK Telecom has developed and is planning to commercialize technologies that control CPU dynamic power according to real-time traffic volume without deteriorating service quality, and is continuously upgrading various software and hardware control technologies to reduce power consumption.



[Figure 10] Examples of green-native core network

Device

Reducing device power consumption is also very important from an ESG and customer service usage time extension perspective. 5G utilizes high frequencies and wide bandwidth compared to LTE, and has several factors that can increase device power consumption, such as having a DC structure that connects to both LTE and NR simultaneously. Nontheless, device battery capacity of 5G devices is not much different from that of LTE, and there is no standing out technology yet commercialized except for DRX operation, which works similar to LTE within the context of protocols. Therefore, to satisfy a significant level of device power consumption reduction in future 6G, technology development based on pain-point analysis of current device operations is necessary.

Generally, device power consumption is wasted when data is transmitted and received in a state where excessive capability is allocated to the device. As an example, a service can be sufficient with 20 ㎒ and 2x2 MIMO but 100 ㎒ and 4x4 MIMO are exploited. To overcome this, various UAI operations have been introduced into the standards ever since Rel-16 to enable BSs to configure optimal settings considering the state of each device. That is, the device informs the BS of its preferred CA/DC, BWP, MIMO, DRX, and RRC-related settings, and the BS configures the settings accordingly that are advantageous for reducing device power consumption of its serving devices. We plan to actively utilize the UAI operation mechanism in the future to implement detailed power-saving operations.

In addition, discussions on WUS have been actively ongoing in the standard since Rel-16. WUS is a control signal that instructs the device whether it should actually wake up during a pre-determined DRX on interval or just ignore the signal and back to sleep. We plan to verify the performance gain of WUS and apply it in the future.

In IoT, discussions are underway regarding Ambient IoT (or Passive IoT) on the top of lightweight IoT technology such as RedCap. Ambient IoT communicates at the level of several kbps using a backscattering method that converts electromagnetic waves into energy within mobile communication coverage, with IoT devices without batteries at the price of barcodes as target use cases. Interest in energy harvesting technology is also increasing with Ambient IoT. This refers to a technology in which IoT devices operate by receiving power from external sources, such as wireless charging based on RF. In the movement to pursue Zero Energy for IoT devices, we plan to research and develop energy harvesting technology suitable for various types of IoT devices and smartwatches that require lightweighting, considering the feasibility of technology implementation and future business demand.

Besides, efforts to overcome the limitations of battery technology are also ongoing, and one of the representative technology is solid-state battery technology. While maintaining the foundation of existing lithium-ion battery technology, it is expected to reduce the risk of safety accidents resulting from electrolyte leakage by changing the electrolyte (liquid) to a solid. It can also promote battery shape diversification, lightweighting, expanded sustainability, and environmental friendliness through the removal of separators. Although it is still in the research stage and may take several years or decades to commercialize, we plan to continuously monitor relevant technology and clarify the requirements for next-generation batteries based on new materials optimized for mobile devices.

6.4 Quantum Security Network

With the emergence of quantum computing technology that enables ultra-fast parallel processing by utilizing the characteristics of quantum, cybercrimes are increasing that cause serious social damage such as large-scale personal information leaks. As ESG management emphasizes the importance of information security and personal information protection, SK Telecom is also putting full efforts to strengthen mobile network security.

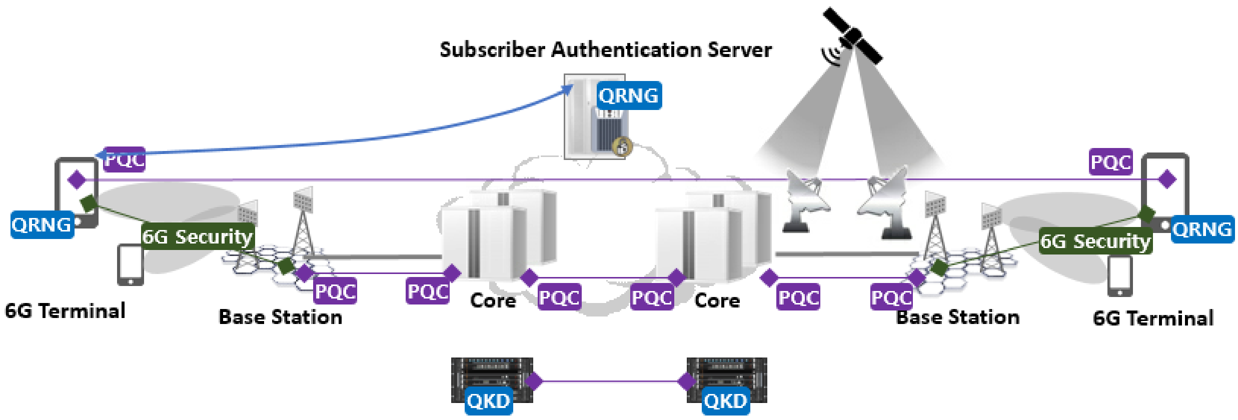
The concept of quantum security, which refers to security technology that cannot be breached even by the computing power of quantum computers, has emerged. The main technology of quantum security is QKD and PQC. QKD technology is a hardware-based technology that utilizes the sensitive nature of quantum to create an encryption key that neutralizes third-party interception attempts and distributes it to the sender and receiver simultaneously. It is based on physical phenomena rather than mathematical complexity, so it has high security, but it requires dedicated hardware equipment and is difficult to communicate over long distance due to the sensitivity of photons. On the other hand, PQC technology is an encryption method that is based on more sophisticated mathematical algorithms to prevent the risk of existing mathematical encryption systems being hacked by the fast factorization computing power of quantum computers. It provides all the necessary functions for encryption communication, including key distribution and user authentication, and is evaluated as being scalable and implementable with software alone without the need for separate equipment.

It is expected that the aspects such as network and data security and personal information protection will become even more important in the highly intelligent 6G era, and therefore 6G should be designed within a robust structure based on Zero-Trust for customer safety. SK Telecom has partially commercialized quantum security technology across transmission networks, core networks, and device areas, and plans to continue developing technology for safe 6G networks.

Transport Network

In the era of quantum computing, transport networks must provide transmission encryption functions that apply PQC to ensure high security for each optical circuit between endpoints. In addition, for essential infrastructure that must be protected from attacks by quantum computers, QKD should also be applied. To maximize security, the distribution paths through which quantum key distribution technology takes and those of PQC should be separated. More than that, the received quantum key from the QKD device and the symmetric encryption key received from the PQC module should be hybridized for encryption. QKD and PQC are complementary technology to each other, so even if PQC systems are threatened by the development of future quantum computers, security can be maintained with the help from the QKD network. In addition, in the worst event of a disaster where multiple paths of the QKD network are attacked, PQC technology can help maintain security temporarily until the QKD network is restored.

The expected evolution of the 6G transport network is shown in the figure below. When integrated with the quantum cryptography satellite network, it is composed of a global alliance QKD network. In areas where it is difficult to build a QKD network, at least end-to-end quantum cryptography security services, including wireless networks and server/cloud, should be provided through key distribution based on PQC.



[Figure 11] 6G prediction based on quantum technology

To fulfill the objectives above, we are gradually developing quantum cryptography network integration technologies such as Q-SDN and QKDN Federation to enable integrated operation and control of quantum cryptography networks between different manufacturers' equipment, between operators, and between countries. In this regard, SK Telecom's quantum cryptography network management solution proposed to the ETSI standardization organization in August 2020 was approved in December 2021, which was successfully demonstrated in a national test network in April 2023. We plan to continue promoting the development and standardization of end-to-end quantum security technologies for not only quantum cryptography networks within an operator, but also in between operators or across the borders.

Device

Next-generation device security can be divided into following four areas: 1) mobile network security, 2) hardware security, 3) firmware and software security, and 4) application and service security.

Mobile network security is an area that ensures encryption and integrity of subscriber's mobile network access and secures exchanged information within the network. PQC technology is applied to the AKA and identity privacy areas that use RSA/ECC encryption algorithms, which are vulnerable to quantum computer attacks, which has a potential to evolve in a way of including authentication procedures even in Non-3GPP networks. We plan to implement PQC algorithms in the SIM responsible for network access security.

Hardware security is an area that enhances device security by replacing ID/RNG generation/storage and security operations previously implemented in software with security hardware components. We arrange to apply quantum-security SIM, which implements quantum-based encryption and key exchange algorithms, and also QRNG and QKD components that enhance quantum key distribution and integrity to SIM cards.

Firmware and software security is an area that ensures encryption and integrity of device firmware and loaded applications to prevent falsification/tampering and hacking. We plan to utilize hardware security components and PQC technology to enhance security throughout the entire device lifecycle.

Finally, application and service security is an area that provides end-to-end data transmission security between user applications on the device and service servers or vertical B2B business servers. We map out to develop relevant technology to enable independent service security and integrated management targetting for third-party service providers through quantum technology applied to SIM and OS.

6.5 Evolution of Radio Technology

E-mMIMO

Extreme-massive MIMO(or E-mMIMO) is a next step technology followed by massive MIMO, which was a key research area in 5G. MIMO is a wireless transmission technology that uses multiple input and output antennas. By using multiple antennas on BSs and UEs, it can provide spatial diversity gain, spatial multiplexing gain, and beamforming gain. The E-mMIMO in 6G will not only mean a simple increase in the number of TRX over massive MIMO in 5G, but will also evolve in two directions: effectively increasing the number of transmission layers and solving the unresolved existing issues of MIMO. Representative unresolved issues are following: beamforming technology that guarantees seamless communications over wireless UE mobility and channel fading environments, MIMO application challenges in FDD systems, pilot contamination problems in multiple cells, reference signal and system optimization for channel estimation, hybrid beamforming, and layer control problems in wireless access stages. Although these improvements have been discussed extensively before 5G, it is expected that they will only be possible in 6G with concrete solutions and commercial applications.

In addition, with the use of millimeter-wave and terahertz bands and with the introduction of new network domain such as NTN, E-mMIMO technology that supports multi-user and 3D beamforming will be even more important.

RIS

RIS is a new wireless transmission technology that utilizes the physical characteristics of radio waves such as reflection, penetration, diffraction, scattering, and absorption in order to increase received power in NLoS areas or to increase radio wave transmittance through objects, thereby increasing outdoor-indoor coverage. In legacy communication systems, the characteristics of the communication channel of RF signals radiated into the atmosphere is passively determined by the surrounding environment and the physical location of the transmitter and receiver. RIS can actively improve the passively given channel environments in terms of mobile communication performance by adjusting the reflection coefficient, transmission coefficient, and absorption coefficient of radio waves. Therefore, instead of increasing transmission power or densifying BSs, RIS can improve the overall system's energy and cost efficiency by intelligently improving the propagation channel quality. In addition, unlike conventional system engineering that focuses on securing line-of-sight in outdoor environments, 6G needs to address new indoor scenarios such as offices, subways, concert halls, stadiums, and shopping malls where large-scale service demands are concentrated. In this case, RIS is expected to play its role as a highly valuable technology for 6G since it can provide wireless channel environment solutions in favor of 6G usage scenarios.

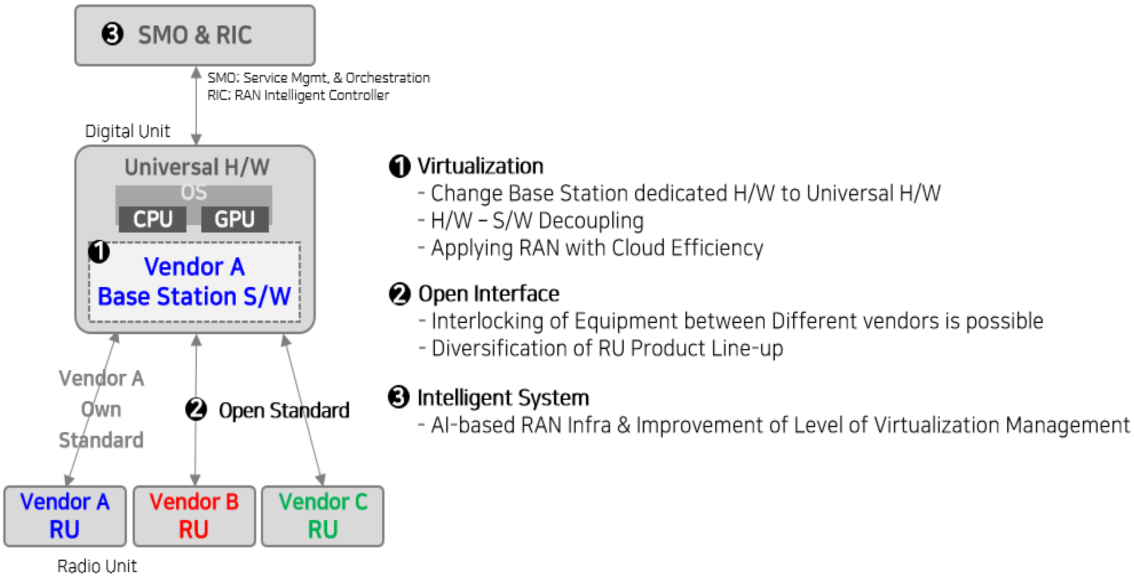
Low-/Lower Mid-band

Low-band RF or Lower Mid-band RF is a term that refers to RF technology that can increase channel capacity in the 7 ㎓ or lower band, which is not the Upper Mid-band of 7 ㎓ or higher that has recently been attracting attention as a candidate band for 6G. The reason why the already adopted Low-band RF technology needs to be re-examined in 6G can be found in the evolution of existing communication systems. The purpose of the development of communication technology and the change in communication generations is fundamentally to provide stable wireless communication services through improved channel capacity compared to the previous generation. To achieve this, brand new wireless technology has been developed for each communication generation. But still, it is the excavation of new frequencies that has been under spotlight. As can be seen in the introduction process of the 5G 28 ㎓ band, the expansion of communication bandwidth from Low-band to millimeter-wave band, as apposed to Low-band, is facing many difficulties due to the inherent characteristics of frequency utilization. On the other hand, we need to note that the remaining bands left behind after the sunset of existing 2G and 3G services can achieve higher channel capacity than before if we apply promising 6G candidate technology to them. However, Low-band utilization also confronts with many challenges. For example, the geographical limits of bands for fragmented services different for each country and region, physical antenna design with consideration of the increased wavelength of Low-band, and the exploitation of spatial multiplexing technology while avoiding severe interference are the challenges that Low-band RF needs to solve. Specifically, the RF components such as antennas, S/W, PA, LNA, Filter, Mixer, PLL need to be addressed through comprehensive architecture design. Lastly, continuous discussions between manufacturers, mobile operators, and governments are needed for further improvement of channel capacity in Low-band utilization.

6.6 Open RAN

Recently, major countries including the United States and Japan have been actively promoting government led development and adoption of Open RAN technology for reasons such as national security, supply chain diversification, and protection of domestic industry. The United States has set up a $1.5 billion fund for Open RAN technology development to revitalize its domestic industry, while the Japanese government is offering tax incentives for the implementation of Open RAN equipment and has set aside 70 billion JPY to support the 5G technology development of domestic manufacturers. The Korean government is also actively promoting the adoption of Open RAN and encouraging the activation of the domestic Open RAN ecosystem by establishing ORIA.

Open RAN is a radio access network structure that separates the hardware and software of BSs through virtualization technology and enables interoperability between equipment from different manufacturers through standardized interfaces. General-purpose servers used in data centers can be adopted in BSs, and the benefits of virtualization-specific features such as scale-in/-out can be also exploited. Standardization of the fronthaul interface between DU and RU enables diversification of RU line-ups and flexible network deployments. In addition, discussions on intelligent technology that applies AI/ML technology to optimize network management and performance are also actively taking place. Mobile operators around the world have been encouraging the adoption of Open RAN, considering the expected benefits aforementioned and the vendor lock-in by a closed RAN ecosystem.



[Figure 12]　Concept and expected benefits of Open RAN

SK Telecom has been promoting the introduction of Open RAN. In April 2019, SK Telecom commercialized the world's first 5G service using virtualized CU. SK Telecom also defined a common fronthaul interface standard for DUs and RUs from different vendors and has been providing 5G in-building services since August 2019. However, the Open RAN market was not greatly activated due to somewhat late standardization of the open fronthaul interface compared to the commercialization of 5G, performance and capacity limitations of virtualized DUs, and manufacturers' passive Open RAN policies.

Recently, hardware advancements such as improved CPU processing power and dedicated accelerator have led to a gradual reduction in performance gaps between virtualized DU and traditional DU. In addition, the vigorous standardization activity of open fronthaul interfaces and the formation of the Open RAN ecosystem sparked by the O-RAN Alliance have led to the emergence of commercialization cases. Verizon in the United States has commercialized 5G based on virtualized Open RAN, and NTT DOCOMO in Japan is providing 5G services with DU and RU equipment from different manufacturers based on open fronthaul interfaces. Vodafone in Europe is also expanding its Open RAN areas under a plan to deploy Open RAN in 30% of the European region by 2030. SK Telecom is also continuing various research and development and demonstration activities in line with the development of Open RAN technology and ecosystem growth. SK Telecom has publicly announced the results of virtualized BS tests with multiple manufacturers at MWC 2022, and has successfully demonstrated it in a real actual commercial environment for the first time in South Korea in 2023. SK Telecom is continuously exploring the commercial potential of Open RAN through various activities, including hosting the successful O-RAN PlugFest Fall 2022, demonstrating various RIC-based use cases such as traffic steering, and building Open RAN trial networks for in-building scenarios.

Following this trend, it is expected that Open RAN will be introduced from the very early stages of commercialization in 6G. In June 2022, the O-RAN Alliance, the largest standardization organization related to Open RAN, formed a nGRG to prepare for 6G Open RAN, organizing five research streams to study the requirements, structures, intelligence, security, and next-generation research platforms of 6G Open RAN.

SK Telecom considers Open RAN to be a key structure that should be ready from the preliminary stages of 6G adoption for expanding the telecommunications equipment market ecosystem, building flexible networks, enabling IT-based intelligence and cloudification, and reducing TCO. To accomplish this, it is important to reflect in standard specifications for crucial interfaces, including fronthaul, from the initial stage of 6G commercialization through cooperation between mobile operators and manufacturers. On top of that, it is also important to introduce a concrete verification process that minimizes performance loss and development time deriving from interoperability issues between equipment from different manufacturers. In addition, mature virtualization technology and corresponding hardware development are required to ensure that Open RAN BSs are equivalent to or better than existing BSs in terms of cell capacity, power consumption, as well as TCO. Furthermore, various forms of supports for activating the Open RAN ecosystem are needed to lead the 6G Open RAN era.

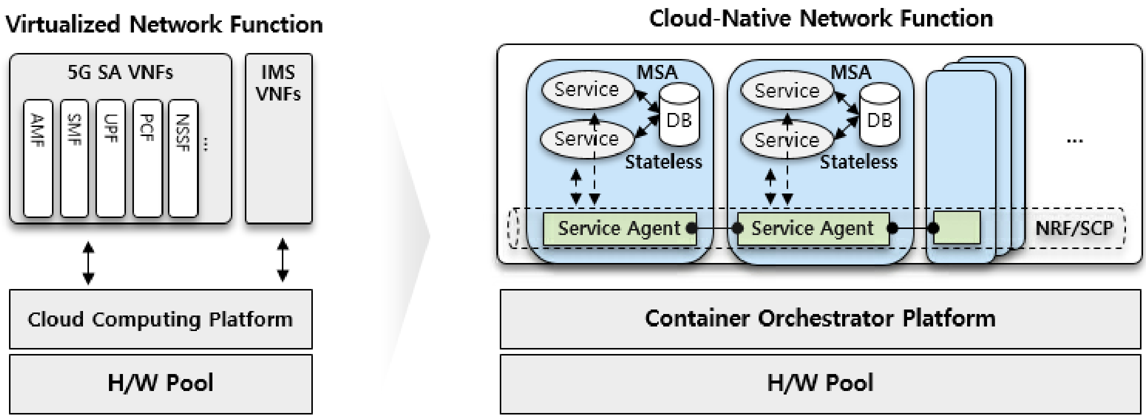
To this end, we have been closely collaborating with key players and leading the ecosystem to ensure that Open RAN is reflected as a fundamental structure of 6G. We are actively participating as co-chairs of the O-RAN Alliance nGRG requirements research stream (RS-01) to ensure that Open RAN is reflected as an essential requirement of 6G. Also, we are contributing in the NGMN's 6G white paper to emphasize the importance of timely standardization of 6G open interfaces[11], and through the joint publication of a 6G white paper with NTT DOCOMO, we have highlighted the requirements for standardization and activation of the Open RAN ecosystem in 6G. In addition, we are developing technology from a performance and TCO perspective in collaboration with manufacturers to make Open RAN reality in commercial networks. Based on our Open RAN experience in 5G, we plan to continue our collaborative research activities with various players in the ecosystem so that Open RAN can be supported from the early stages of 6G.

6.7 Core Network

The 6G core network will be designed in a cloud-native manner as well as the AI-native and Green-native methods described above and will be implemented as a robust and resilient core network that does not degrade customer experience in any case.

Cloud-native

In the 5G core network, NFs are installed and clouded in VMs that virtualize physical hardware using NFV technology, whereas in 6G core network, it will evolve into a redesigned cloud-native core network with more and more subdivided services based on CNF.

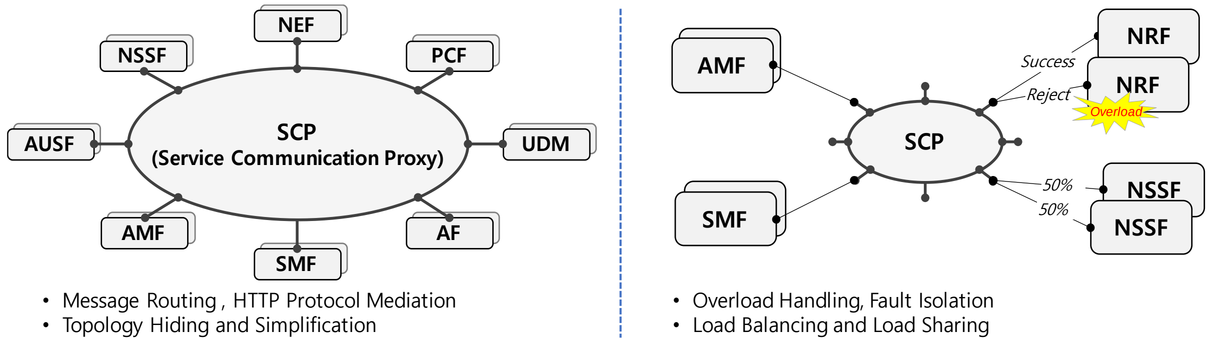


[Figure 13] 5G SA and 6G cloud-native evolution

The fundamental principle of CNF is to develop a MSA structure that decomposes software into smaller, easier-to-manage microservice units. With the MSA structure, the flexibility of managing the life cycle of services is increased, service impact and failure recovery time are reduced in case of service failure, and development and commercialization time are also shortened. However, for this, an interworking structure that can easily interoperate between microservices is necessary.

The most notable change when introducing the 5G core network is the adoption of a structure that interoperates between NFs through SBI. The SBI interworking method is further expanding, and in 6G, all interfaces from the UE to the core network and from the BS to the core network are expected to be unified with HTTPv2 or HTTPv3/QUIC, and it can evolve into 'Evolved SBA'.

In evolved SBA method, NF focuses on call processing functions inherent in mobile communication, such as authentication/authorization, mobility/session management and packet processing, which are essential functions of NF. Service mesh technology can perform roles such as multiplexing, redundancy, overload control, load balancing, and traffic routing of signal/data messages that are responsible for quality of service. These features are partly standardized as SCP in 5G, it requires redesign focusing on unified interface, MSA and QoS, and the 6G core network will become a service-centered infrastructure based on distributed mesh network architecture.

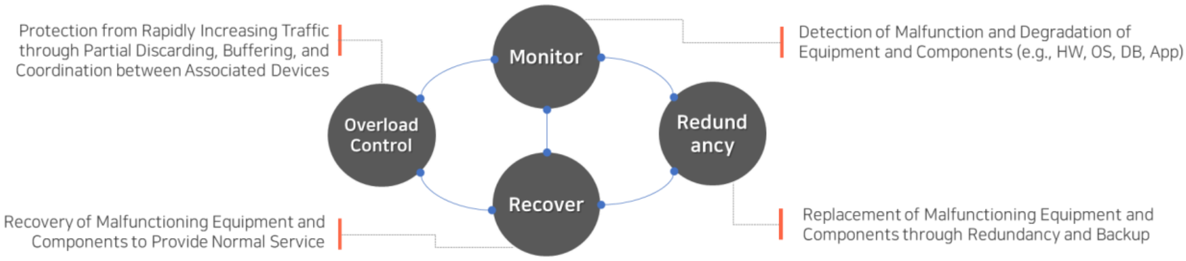


[Figure 14] Interlocking structure of evolved SBA by SCP

Robust and Resilient Core

Since main features have been designed around call processing up to 5G, there could be a problem in that the process is alive but does not actually operate properly. However, in 6G services such as smart factory and autonomous driving, even a slight degradation in quality can lead to serious accidents, so a robust and resilient core network that does not cause degradation in quality experienced by customers under any circumstances is required.

In terms of monitoring, SK Telecom not only manages success and failure of network access, but also monitors all detailed indicators that customers can experience, such as latency, jitter, and packet loss. We will evolve the 6G core network into a structure that can take immediate action and restore in case of any problem such as hang-up and overload. Specifically, the enhancement of NF set that supports uninterrupted service operation and action, function to provide the best quality by reselecting equipment according to quality change such as delay/jitter, pre-detection of failure through application of AI/ML technology will be developed.



[Figure 15] Robust and resilient core network

Automatic actions and recovery functions for failures should be equally applied to the hardware infrastructure as well as the NF. Since there are several types of NF-based hardware and vendors that provide them, it may take a lot of time to build and to take measures, and there may be operational difficulties. To solve this problem, we plan to develop technologies such as batch configuration for heterogeneous hardware, backup and restoration, isolation and network bypass in case of failure, and real-time monitoring.

In addition, operations and actions on infrastructure and NF will be mostly automated. While up to 5G, there was an improvement in the way machines automate the work done by humans, then in 6G, machines will be implemented in a way that automatically manages the work of machines from the design stage. Through this, a lot of maintenance workforce was put in for work and measures in the past, but in 6G, system operation such as rapid system construction and deployment, configuration optimization, and failure recovery automation will be possible with minimal human intervention. In addition, zero-touch operation is possible with minimal intervention by operation and maintenance personnel, and response time is minimized, which is expected to improve overall service quality for customers.

6.8 Transport Network

To handle 5G high-capacity traffic, 100/200Gbps optical transmission technology has become mainstream in commercial networks of backhaul and backbone network. Even in 6G, the trend of increasing traffic capacity is expected to continue, and 100Gbps to 3.2Tbps coherent optical transmission technology, including the fronthaul section, is expected to spread for large-capacity transmission.

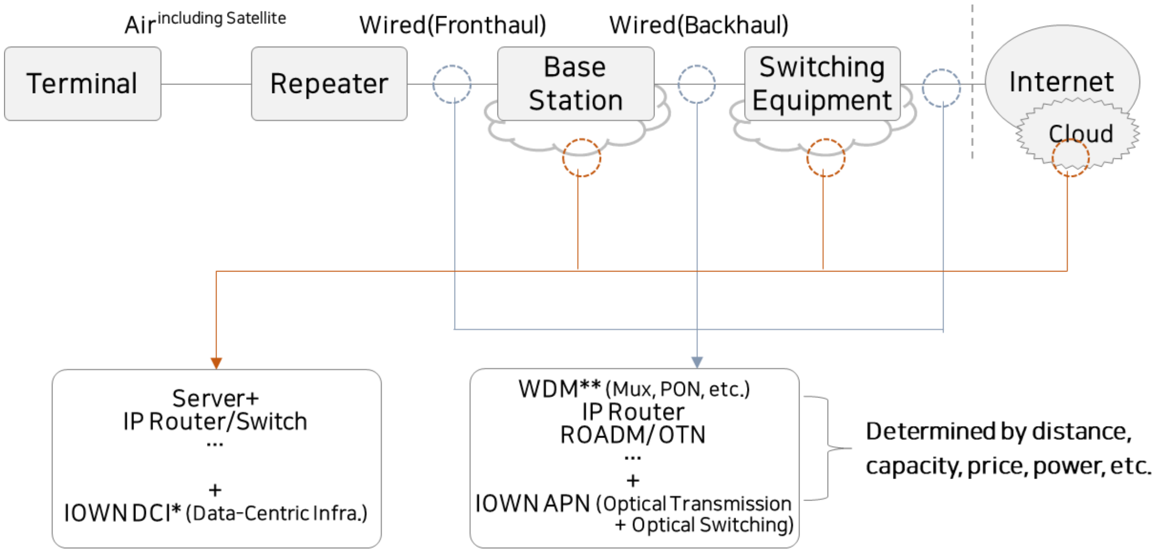
Furthermore, in addition to the existing C-band (1530-1565 nm), some network operators have started to apply WDM technology by extending it to the L-band (1565-1625 nm) to meet bandwidth requirements. In 6G, where bandwidth requirements increase, ultra-wideband WDM technology that includes not only C-band and L-band but also other bands such as O-band and S-band will be discussed as candidates.

In addition, integrated equipment according to the trend of merging optical networks and packet networks is being commercially available, and it is expected that it will continue to evolve into a layer integrated transmission technology evolved from POTN. Accordingly, the importance of an SDN-based open platform (Infrastructure Orchestration) for efficiently operating a transport network that has become complicated due to the coexistence of existing and new infrastructure is increasing. SDN platform of SKT accommodates ROADM, OTN, PTN, and IP Router, so we have POTN's common data modeling technology that integrates layers and integrated operation and control base technology.

Along with the low-latency and high-capacity requirements of the transport network, energy saving has recently become a principal factor. To maximize transport network energy efficiency, innovation of the existing transmission/wireless infrastructure is required. One of the key technologies for this is Photonics Electronics Convergence technology, which combines optical and electronic elements for ultra-high-speed, large-capacity, miniaturization, and low power consumption.

IOWN is a next-generation communication infrastructure based on these state-of-the-art photonic technology and information processing technology. At the IOWN Global Forum, the ambitious vision by IOWN(IOWN Vision 2030 [16]) was announced, which includes aims of an increase of power efficiency by 100 times, an increase of transmission capacity by 125 times, and the reduction of end-to-end delay to 1/200.

APN and DCI are the two pillars of IOWN. APN provides end-to-end optical transmission services by minimizing photoelectric conversion within the transmission network while increasing transmission capacity. DCI minimizes photoelectric conversion for distributed computing and networking between data centers.



[Figure 16] Network structure and IOWN application

In IOWN, an SDN-based open platform for automating and managing infrastructure such as APN and DCI are an essential. In IOWN, the SDN-based open platform configures infrastructure resources and automatically allocates resources according to a schedule to automatically perform resource optimization. The Open APN Controller allocates an end-to-end optical path and dynamic transmission speed within the corresponding area.

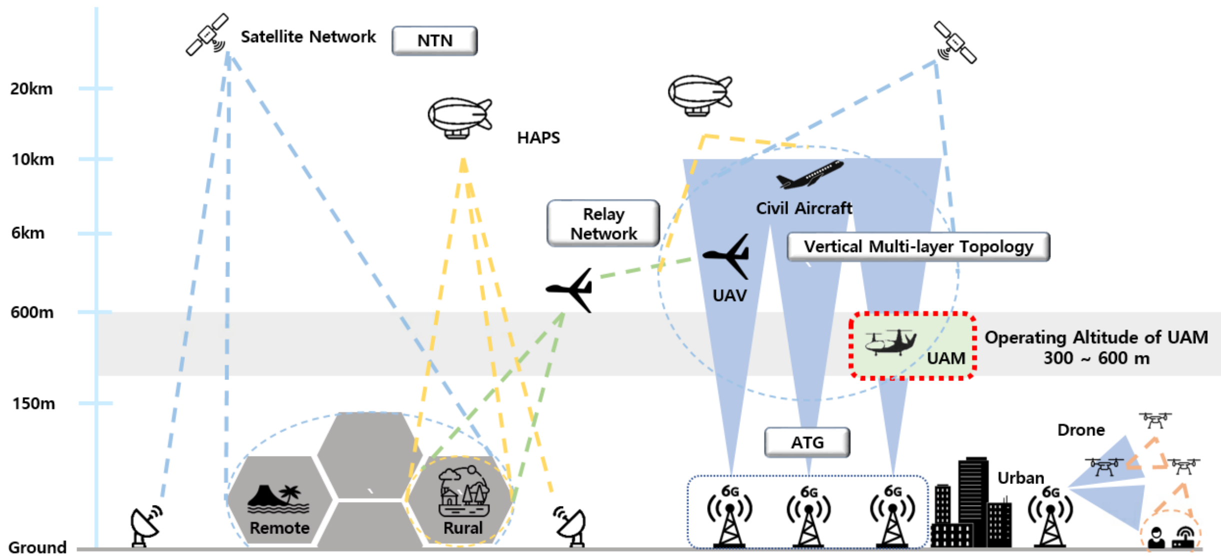
SK telecom joined the IOWN Global Forum in August 2022 and is conducting TF activities and is promoting the demonstration of fronthaul next-generation APN technology between repeater and BS and open APN technology between BS and switching equipment.

In this way, the infrastructure is simplified through the integration of packet networks and optical network equipment to satisfy the requirements for high-speed, high-capacity transmission, low delay, flexibility, and energy saving required in the 6G transmission network. At the same time, it plans to build an APN infrastructure that can realize low power consumption by increasing optical transmission efficiency and minimizing packet switching. We plan to expand into an SDI open platform that enables integrated optical networking services, distributed computing services, and network management for infrastructure composed of multiple APNs and DCIs.

6.9 Aerial Network

To keep pace with 6G roadmap for commercialization around 2030, SK Telecom is expanding its communication service areas for data transmission and reception beyond terrestrial area, reaching into the aerial, ocean, and remote regions where internet connectivity has not been available. This expansion is part of the efforts to achieve 6G vision of providing ubiquitous connectivity with everything, anywhere, and anytime, and the extended service areas enable the efficient delivery of various information to air vehicles including airline, aircraft, and UAM as well as smartphones that are not covered by terrestrial network as an UAM total service provider.

The 6G communication network evolved for this purpose is shown in the figure below. The BS for ground-centric communication services have the improved data transmission and reception capability to provide various customer experiences such as AR/VR. The BSs for aerial communication service coverage possess up-tilted antennas and specialized technologies to make reliable wireless data links with air vehicles. In addition, satellites allow communication services to be used in outdoor environments with LoS and are also expected for high-reliability and low-latency performance in the 6G era when enough low earth orbit satellite groups are established.



[Figure 17] Expansion of the mobile communication network to the aerial network

To expand data communication coverage to the aerial areas above a certain altitude, effective cell planning technology is essential. Basically, cell planning technology provides optimal method for establishing BSs by considering factors such as location, quantity, beam pattern, signal direction, and service region. SK Telecom has been developing the enhanced cell planning technology that reflects 3GPP standard radio wave model[17] and actual measurements to predict and evaluate the signal quality of aerial communication coverage. It also include uplink/downlink data rate, latency, and link stability as well as degradation of the terrestrial networks due to interference.

In addition, the specialized technologies for aerial communication coverage contain beamforming, large-capacity data transmission, handover, network slicing to ensure QoS of different data, dynamic TDD and FDR for flexible uplink/downlink resource utilization. Among these technologies, beamforming using multiple antennas for beam shape control and space-time multiplexing is important to establish wide aerial coverage. Efficient handover and BS cooperation are necessary to secure the quality of communication services based on the flight path of aerial vehicles.

Satellite communication services in the 6G era can be largely classified into satellite broadband services using VSAT, satellite-to-smartphone direct communication services (direct-to-cellular) and satellite IoT services supporting IoT devices. Among these, direct-to-cellular communication can be divided into direct communication driven by new terminals (or chipsets) and direct communication driven by new satellites.

Terminal-led direct-to-cellular communication is a method of communicating with the low-orbit satellite constellation that has already been established using a smartphone with a newly added satellite communication function. Examples of terminal-led direct-to-cellular communication include the Apple iPhone 14 series using Globalstar satellites and the Huawei Mate 50 series using Beidou satellites. This communication method has the advantage of early commercialization in line with the release of new smartphone terminals, but it has the disadvantage that it supports only low-speed and low-capacity services such as emergency message transmission and reception, due to the limitations of the satellite performance used.

On the other hand, direct-to-cellular communication led by new satellites has the advantage of being able to provide services such as VoIP and data communication by launching a new satellite constellation. Although building a new satellite constellation requires cost and time, evolved satellite systems can effectively compensate for propagation delay and Doppler effects, and provide wider satellite coverage. These advantages are crucial for supporting 6G aerial networks, and we are focusing on this satellite-led direct-to-cellular communication and actively collaborating with various global satellite operators.

7. 6G Spectrum

Entering 5G era, the IMT spectrum was expanded by defining two new FRs for the first time to meet diversified usage scenarios and increased service QoS: FR1 is defined as a range of 450 ㎒ – 5,000 ㎒ and FR2 is defined as a range of 24,250 ㎒ – 52,600 ㎒. Since the allocation status of the existing 3G and LTE spectrum and uses of 5G services were different in each country, the 5G spectrum has been allocated depending on each country's spectrum policy. In Korea, the 3.5 ㎓ band in FR1 has been allocated for the general-purpose mobile communication services such as mobile phone, while the 28 ㎓ band in FR2 has been allocated for the services requiring performances of ultra-wideband and ultra-low latency.

However, the utilization of high frequency spectrum hasn’t been activated because investigation on the business cases, creation of market environments, and development of wireless technologies to overcome the poor propagation characteristics of the 28 ㎓ band were insufficient.

With respect to 6G, High-band(24~92 ㎓) including the FR2 and Sub-㎔ band(92~300 ㎓) as well as Mid-band (1~24 ㎓) are being considered to accommodate more extended usage scenarios compared to 5G. Agendas for 6G candidate spectrum will be introduced in World Radiocommunication Conference(WRC)-23 which is scheduled to be held in November 2023, and 6G spectrum will be finalized in WRC-27 which is supposed to be held in 2027.

7.1 6G Candidate Spectrum

In global mobile communication industry, the 7~15 ㎓ band and the Sub-㎔ band are recently getting attention among several 6G candidate bands. The 7~15 ㎓ band has relatively better propagation characteristics within the Upper Mid-band (7~24 ㎓) where both of coverage and capacity can be secured in a balanced way. On the other hand, the Sub-㎔ band can be used for specific applications such as ultra-precision sensing due to the larger available bandwidth.

Band	Domestic	Reflection of Agenda	Status of Country/Industry
6.425~7.125㎓	WiFi	WRC23	• France : Opinion on 6G Utilization ('30y~) • China, Manufacturer(E/N/H): Opinion on 5G Utilization
7.125~10㎓	UWB	-	• Some Manufacturers(E/N), Considering the 6G Core Frequency Band • Samsung/Apple, Opposition(UWB Business)
10~10.5㎓	Unassigned	WRC23	• Brazil's Preferred Band, Europe is the Opposite
12.7~13.25㎓	Satellite	-	• Initiation of USA FCC's Repurpose Process for Mobile Communication
14.8~15.35㎓	Unassigned	-	• Support Band of Cellular Telecommunications and Internet Association (CTIA)

[Figure 18] Current status of major bands of Interest in Mid band

However, multiple bands have been already allocated for non-IMT services such as satellites, UWB, and NATO in the Upper Mid-band of 7 ㎓ or above. Moreover, it is fact that there are difficulties in investigation of new IMT spectrum since the three regions classified by ITU-R for international spectrum management have different interests for the spectrum. Therefore, as reviewed in *5G Lessons Learned*, utilization of Low and Lower Mid bands which are being used for the existing mobile communication networks should be intensively investigated considering the limitations in RF technologies to compensate the poor propagation characteristics of high frequency bands and investment availability for BSs.

Investigation on reuse of the existing IMT spectrum as well as new spectrum

Global mobile operators have already been deploying 5G networks cost-effectively and rapidly by refarming the existing frequency bands of 3G and LTE to 5G. Also, by using the spectrum sharing technology by which multiple radio access technologies share the same spectrum, it is possible to apply technologies such as CA and DC to utilized Mid-band and mmWave. All of these can be good examples to solve the difficulties of securing 6G spectrum.

SK Telecom is considering 4~10 ㎓ band as new 6G candidate spectrum to be finalized in WRC-27. Since it is expected that the band can provide basic services from the early stage of 6G commercialization based on the channel characteristics that can achieve both of coverage and capacity efficiently. Since several other services are already in use within the band, it is necessary to investigate available 6G spectrum by studies on such as coexistence with the existing services and refarming.

To fully utilize the mentioned various bands in 6G, R&D on various bands, such as propagation characteristics, propagation models and the development of BS and devices, should be conducted in advance.

7.2 Penetration Characteristics of 6G Candidate Spectrum

SK Telecom aims to establish well-defined and clear requirements from the early stage of 6G by proactively conducting studies on the coverage/capacity characteristics and the usage scenarios for each of 6G candidate spectrum.

High penetration loss of high frequency and compensation method

As the first step, we have simulated and measured the penetration losses of Upper Mid and Sub-㎔ bands among the various bands being discussed as 6G candidate spectrum and compared them with those of 5G spectrum. [Table 2] shows the detailed frequency bands assumed in the experiment, and [Table 3] shows the simulation results of penetration and path losses for each spectrum. The penetration losses were simulated with normal glass compared to the air while the path losses were estimated based on FSPL model, and the results were normalized based on that of 3.5 ㎓ band for comparison. From the results, the following messages were derived.

- The penetration loss increases by 0.7 ㏈ (1.17 times) in 7 ㎓ band compared to 3.5 ㎓ band, while it decreases by 1.4 ㏈(1.38 times) in 10 ㎓ band
- The penetration loss increases by 0.8 ㏈ (1.2 times) in the 140 ㎓ band compared to 28 ㎓ band
- The total loss including path loss increases by 6.4~33.6 ㏈ about 4~2000 times in 6G candidate spectrum compared to 3.5 ㎓ band

[Table 2] Frequency bands considered in the experiment

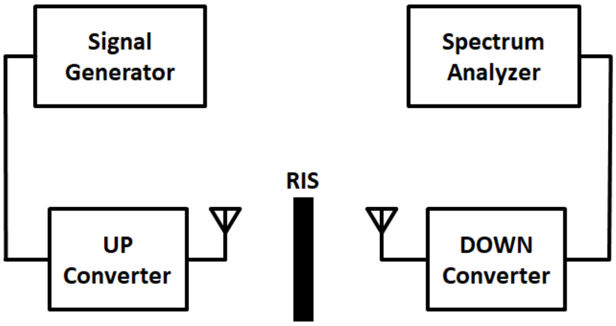
Category	Band (GHz)	Bandwidth (MHz)	Description
5G	3.7 ~ 3.8	100	3.5GHz band (Sub-6)
	28.1 ~ 28.9	800	28GHz band (mmWave)
6G	7.0 ~ 7.1	100	Upper Mid & Unlicensed band
	10.0 ~ 10.1	100	Upper Mid-band
	140.0 ~ 140.8	800	Sub-THz band

[Table 3] Simulation results for penetration and path losses in each spectrum

Category	Band				
	5G		6G		
	3.5 GHz (Ref*)	28 GHz	7 GHz	10 GHz	140 GHz
Center Frequency (GHz)	3.65	28.5	7.05	10.05	140.4
Penetration Loss (dB)	0	1.1	0.7	-1.4	1.9
Path Loss (dB)	0	17.9	5.7	8.8	31.7
Total Loss (dB)	0	19	6.4	7.4	33.6

* Data was normalized based on the 5G 3.5 GHz band

To mitigate the degradation of channel characteristics in 6G spectrum, SK telecom has developed the world's first RIS for 6G candidate spectrum[18]. As a field of metamaterial applications, RIS is a technology that can improve coverage by adjusting the degree of reflection, penetration, and absorption occurring when radio waves pass through a medium. SK Telecom has developed the RIS focusing on improvement of penetration rate first and present the first results in this white paper. We measured the penetration characteristics of 5G 28 GHz band and the 10 GHz/140 GHz bands among the 6G candidate spectrum depending on the medium. [Figure 19] shows the test configuration and the results are in [Table 4]. The used mediums are air, Low-E glass, wood, normal glass, and RIS for normal glass, and the results show that the penetration loss and EVM characteristics generally deteriorated as the frequency increases. Moreover, when applying RIS to 10 GHz and 140 GHz bands, performance was improved by 1.4 dB(1.38 times) and 1.2 dB(1.32 times) respectively in terms of penetration loss compared to normal glass. Since this development is a prototype, and it is expected that there will be further improvements by optimization.



[Figure 19] RIS test configuration

[Table 4] Measurement results of propagation characteristics for each medium according to frequency band

Band	Metrics	Medium					RIS Gain (B – A)
		Air (Ref)	Low-E Glass	Wood	Normal Glass (A)	Normal Glass + RIS (B)	
10 ㎓	Penetration (dB)	0	36.8	2.6	3.0	1.6	1.4 dB
	EVM (%)	0.3	4.2	0.41	0.41	0.41	-
28 ㎓	Penetration (dB)	0	40.3	3.7	4.0	2.9	1.1 dB
	EVM (%)	1.51	21.3	1.9	1.83	1.83	-
140 ㎓	Penetration (dB)	0	39.1	33.8	9.3	8.1	1.2 dB
	EVM (%)	2.3	22	11.7	3	2.7	-

Low-E glass is a glass used to enhance the insulation performance of buildings by coating the surface with metal films which have high infrared reflectance. It can reduce heat loss while maintaining the transparency of the glass, which means it has advantages in terms of ESG because it can reduce costs for heating and cooling. However, as shown in [Table 4], the Low-E glass has the disadvantage of severely blocking the radio wave compared to the normal glass. We are developing Low-E glass targeted RIS technology as one of the use cases of RIS, of which the objective is to improve the penetration characteristics of the radio wave while maintaining the insulation performance of Low-E glass. [Table 5] shows the simulation results of applying RIS to Low-E glass for each frequency band. Due to the difficulties of simulation, the penetration loss of the Low-E glass was conservatively assumed with 35 dB based on the measured values in [Table 4]. From the results, it was confirmed that the Low-E glass targeted RIS has gains of about 30 dB or more for all considered frequency bands. However, in terms of the heat transmission coefficient, how to verify the effect is still being investigated.

[Table 5] Gain of penetration characteristics with Low-E glass targeted RIS

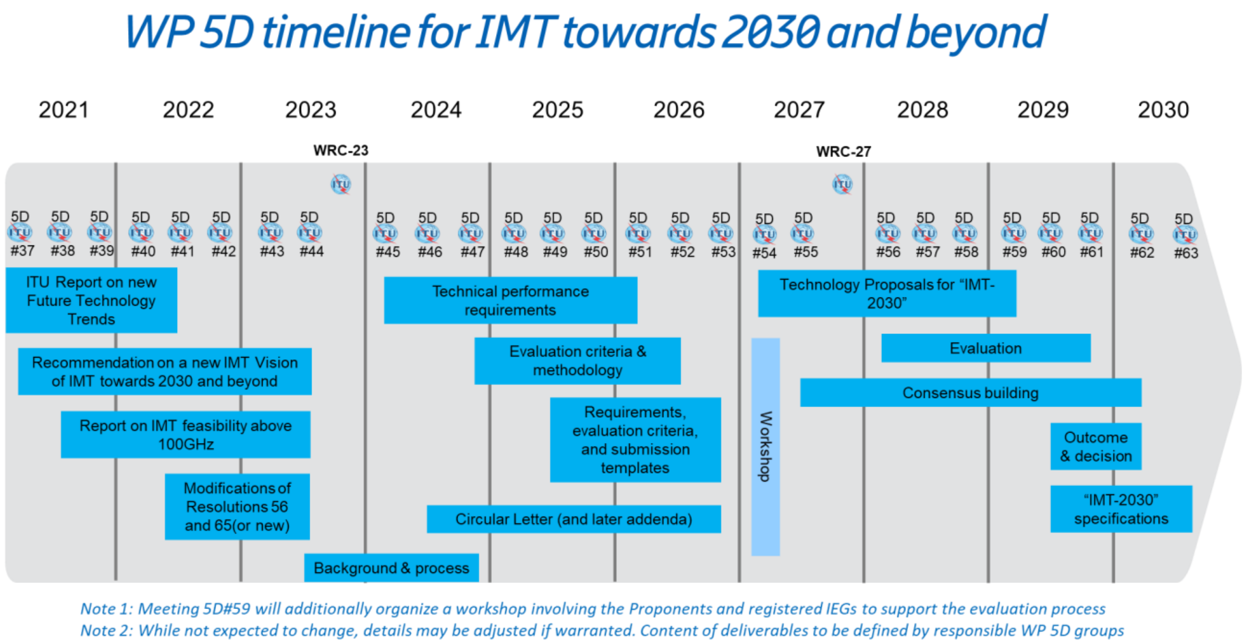
Category		Band				
		5G		6G		
		3.5 GHz	28 GHz	7 GHz	10 GHz	140 GHz
Center Frequency (GHz)		3.65	28.5	7.05	10.05	140.4
Penetration Loss (dB)	Air (Ref)	0	0	0	0	0
	Low-E Glass (A)	35*				
	Low-E Glass + RIS (B)	3.3	4.4	3.4	3.3	5.9
RIS Gain (A – B) [dB]		36.7	30.6	31.6	31.7	29.1

* Data was assumed based on measurement results in [Table 4]

Starting with the research on the penetration characteristics of 6G candidate spectrum, we are planning to analyze the overall propagation characteristic deterioration in the 6G candidate spectrum by the measurement of path loss and O2I coverage in the NLoS/LoS environment and establish the requirements for 6G evolution technologies to secure equivalent coverage to 5G.

8. 6G Timeline

Currently, ITU-R is conducting initial discussions to establish next-generation mobile communication standards. WP 5D, a mobile communication standardization working group under ITU-R, established a roadmap with a schedule for approving 6G standards in 2030. In line with this, following the publication of the 2022 Future Technology Trend Report [19], the 6G Framework Recommendation was completed at the 44th meeting in June 2023. Afterwards, 6G technology performance requirements and evaluation methods will be defined and 6G candidate technologies will be proposed and evaluated, followed by final approval for 6G standard in June 2030.

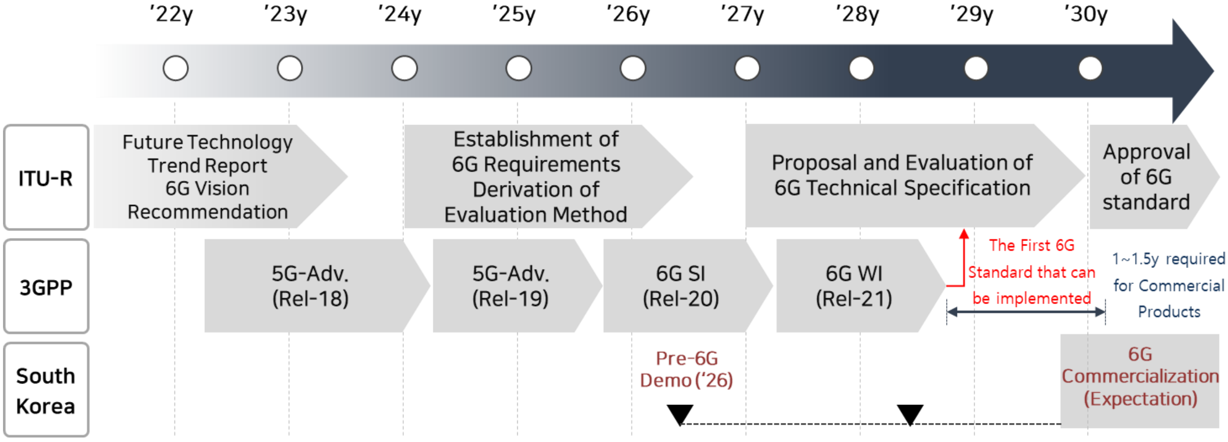


[Figure 20] ITU-R WP 5D 6G timeline [20]

While ITU-R has the authority to evaluate and approve mobile communication standards, actual standards for mobile communication are prepared by 3GPP. Currently, 5G-Advanced standardization work is in progress in 3GPP, aiming to complete the Rel-18 standard in March 2024.

3GPP plans to develop 6G standards that meet the IMT-2030 technical performance requirements presented by ITU-R. Discussion on the 6G standardization schedule will begin at the TSG 101 meeting to be held in September 2023, and an agreement on the 6G standardization schedule will be reached at the TSG 102 meeting in December 2023. Then, the process of submitting Rel-21 standard to ITU-R is expected around the end of 2028.

Considering the development period for commercial products by equipment and device manufacturers after the standards that can be implemented are completed in 3GPP, 6G commercialization is expected to be achieved around 2030.



[Figure 21] 6G timeline for standardization and commercialization

9. Concluding Remarks

SK Telecom is preparing for the 6G era as discussions on 6G begin in domestic and international standardization organizations and various organizations. At this point, four years after the world's first commercialization of 5G, we first looked back at the light and darkness of 5G. Considering this, 6G key requirements from the mobile operator's point of view were presented in order to improve in 6G followed by SK Telecom's future network evolution direction. Finally, the status of standardization discussions on 6G spectrum and our thoughts were presented.

SK Telecom plans to take the lead in developing 6G technology through collaboration with 6G partners in industry, academia and research, and aims to contribute to Korea becoming a leading global ICT country.

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Abbreviations

Abbr.	Full Name	Abbr.	Full Name
3GPP	3rd Generation Partnership Project	**FR**	Frequency Range
3D	Three-dimensional	**FSPL**	Free Space Path Loss
5GC	5G Core Network	**GPS**	Global Positioning System
5GMF	5G Mobile communications Promotion Forum	**GPU**	Graphical Processing Unit
6G IA	6G Smart Networks and Services Industry Association	**GSMA**	Global System for Mobile Association
AI	Artificial Intelligence	**HTTP**	Hypertext Transfer Protocol
AKA	Authentication and Key Agreement	**ID**	Identification
AoA	Angle of Arrival	**IMT**	International Mobile Telecommunications
APN	All-Photonics Network	**IoT**	Internet of Things
AR	Augmented Reality	**IOWN**	Innovative Optical and Wireless Network
ATIS	Alliance for Telecommunications Industry Solutions	**IP**	Internet Protocol
B2B	Business-to-Business	**ISV**	Independent Software Providers
B5GPC	Beyond 5G Promotion Consortium	**ITU**	International Telecommunication Union
BS	Base Station	**ITU-R**	ITU Radiocommunication Sector
BWP	Bandwidth Part	**KPI**	Key Performance Index
CA	Carrier Aggregation	**LCM**	Life Cycle Management
CAPEX	Capital Expenditure	**LiDAR**	Light Detection And Ranging
CDMA	Code Division Multiple Access	**LNA**	Low-Noise Amplifier
CNF	Cloud-native Network Function	**LoS**	Line of Sight
CPU	Central Processing Unit	**Low-E**	Low-Emissivity
CSI	Channel State Information	**LTE**	Long Term Evolution
CU	Central Unit	**MIMO**	Multiple Input Multiple Output
DC	Dual Connectivity	**ML**	Machine Learning
DCI	Data-Centric Infrastructure	**mMIMO**	massive MIMO
DNR	Draft New Recommendation	**mMTC**	massive Machine-Type Communications
DRX	Discontinuous Reception	**MR**	Mixed Reality
DSS	Dynamic Spectrum Sharing	**MSA**	Micro Service Architecture
DU	Distributed Unit	**NATO**	North Atlantic Treaty Organization
E2E	End-to-End	**NF**	Network Function
ECC	Elliptic Curve Cryptography	**NFV**	Network Function Virtualization
eMBB	enhanced Mobile BroadBand	**NGA**	Next G Alliance
E-mMIMO	Extreme massive MIMO	**NGMN**	Next Generation Mobile Networks
EN-DC	E-UTRAN(LTE)-NR(5G) Dual Connectivity	**NG-RAN**	Next-Generation RAN
ESG	Environmental, Social, Governance	**nGRG**	next Generation Research Group
EVM	Error Vector Magnitude	**NPU**	Neural Processing Unit
FDD	Frequency Division Duplex	**NR**	New Radio
FDR	Full Duplex Radio	**NSA**	Non-Standalone
FPGA	Field Programmable Gate Array	**NTN**	Non-terrestrial Network

NWDAF	Network Data Analytics Function	**RU**	Radio Unit
O2I	Outdoor-to-Indoor	**SA**	Standalone
OAM	Operation, Administration, Maintenance	**SBA**	Service Based Architecture
OFDM	Orthogonal Frequency Division Multiplexing	**SBI**	Service Based Interface
OFDMA	Orthogonal Frequency Division Multiple Access	**SCP**	Service Communication Proxy
OPEX	Operation Expenditure	**SDI**	Software-Defined Infrastructure
ORIA	Open RAN Industry Alliance	**SDN**	Software-Defined Network
OS	Operating System	**SI**	Study Item
OTN	Optical Transport Network	**SIM**	Subscriber Identity Module
OTT	Over The Top	**SNR**	Signal-to-Noise Ratio
PA	Power Amplifier	**TANGO**	Telco Advanced Next-Generation OSS
P-index	Power consumption evaluation Index	**TCO**	Total Cost of Ownership
PLL	Phase Locked Loop	**TDD**	Time Division Duplex
POTN	Packet Optical Transport Network	**TF**	Task Force
PQC	Post-Quantum Cryptography	**TRX**	Transceiver
PSU	Power Supply Unit	**TSG**	Technical Specification Group
PTN	Packet Transport Network	**UAI**	UE Assistance Information
QKD	Quantum Key Distribution	**UAM**	Urban Air Mobility
QKDN	QKD Network	**UDP**	User Datagram Protocol
QoS	Quality of Service	**UE**	User Equipment
QRNG	Quantum Random Number Generator	**UHD**	Ultra High Definition
Q-SDN	Quantum-Software Defined Networking	**URLLC**	Ultra-Reliable and Low Latency Communications
QUIC	Quick UDP Internet Connections	**UWB**	Ultra-Wideband
RADAR	Radio Detection And Ranging	**VNF**	Virtual Network Function
RAN	Radio Access Network	**VoIP**	Voice over Internet Protocol
RedCap	Reduced Capability	**VR**	Virtual Reality
RF	Radio Frequency	**VSAT**	Very Small Aperture Terminal
RIC	RAN Intelligent Controller	**WCDMA**	Wideband Code Division Multiple Access
RIS	Reconfigurable Intelligent Surface	**WDM**	Wavelength Division Multiplexing
RNG	Random Number Generator	**WI**	Work Item
ROADM	Reconfigurable Optical Add Drop Multiplexer	**WP 5D**	Working Party 5D
RRC	Radio Resource Control	**WRC**	World Radiocommunication Conferences
RS	Research Stream	**WUS**	Wake-Up Signal
RSA	Rivest-Shamir-Adleman	**XR**	eXtended Reality
RTT	Round Trip Time		

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