AI-Native & Sustainable Communication

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Samsung 6G Vision

Contents

1 Introduction

Mobile communication systems have evolved from generation to generation approximately every 10 years in the direction of providing enhanced performance (e.g., higher data rates and larger capacity). Each generation has offered innovative new services ranging from 1G analog voice call services to 4G mobile broadband services. In the late 2010s, 5G was introduced to provide massive broadband capacity and expand its range of services into vertical industries (e.g., IoT). As the next evolutionary step of 5G as well as a bridge towards 6G, the development of 5G-Advanced is actively ongoing in 3GPP to further enhance the performance of mobile broadband operation and broaden the verticals of 5G.

In parallel to the industry effort for evolution of 5G commercial networks, the International Telecommunication Union (ITU) has already started discussions on 6G from 2020, which is expected to be commercialized around 2030. There also is significant effort from both academia and industry to prepare for 6G, following the commercialization of 5G technologies.

We expect 6G will need to address the demands from the end users, the industry, and the whole society. Since we published the previous white paper on 6G in 2020 [1], we have been continuously evaluating how such demands evolve, taking also into account the lessons learned from 5G deployments. In this white paper, we aim to provide readers with our updated views on various aspects of 6G, including market and technology trends, emerging services, key attributes of 6G, spectrum, enabling technologies, and timeline. The rest of this white paper is organized as follows:

- Section 2 introduces the market and technology trends driving 6G development.
- Section 3 discusses emerging services in the 6G era which will revolutionize the way people interact with technology.
- Section 4 describes the key 6G attributes which will enable 6G networks to create significant economic and societal value.
- Section 5 provides the latest status of 6G spectrum as related to the outcomes of ITU World Radiocommunication Conference 2023 (WRC-23).
- Section 6 introduces the enabling technologies to realize the 6G key attributes.
- Section 7 describes our expectation on the 6G timeline.
- Section 8 provides concluding remarks.

2 Market and Technology Trends toward 6G

Market Trends

In the upcoming years, the development of 6G will be influenced by a number of market trends. In particular, these market trends include a drive for new systems with more traffic capacity, more efficiency in costs and energy, and also carbon neutrality driven by policies introduced in various countries across the globe.

Mobile data traffic has significantly increased in the last decade, and this trend is projected to continue with evolution towards 6G [2, 3]. For example, [3] estimated that the global mobile traffic would increase from 109.5 Exabytes per month in 2023 to 603.5 Exabytes per month by 2030, growing at a CAGR of 23.8%. The growth in mobile traffic is primarily driven by factors such as increasing 5G penetration, rising demand for streaming media (e.g., YouTube, OTT), and expansion of fixed wireless access (FWA) market. Societal changes pursuing connected life due to aging population, declining birth rate, and digital transformation of life (e.g., transition of spending patterns from offline to online) have also contributed to the proliferation of connections of various type of devices including smartphones, internet of things (IoT) devices and machines, further fueling the growth of mobile traffic. With the advent of new technologies such as AI, it is expected that global mobile traffic will continue to grow rapidly worldwide.

Since the commercialization of 5G in 2019, the requirements for mobile communication services from users and mobile network operators have been changing. From the end-user's point of view, the requirements are changing from demanding higher performance to better user experience, i.e., in the direction of better connectivity and battery life rather than simply enhancing communication performance, e.g., data rates and latency. In some countries, surveys show that user satisfaction with the 5G system is relatively lower than that of the 4G system due to limited coverage and increased power consumption in using 5G services [4, 5]. Also, mobile network operators have been facing stagnant average revenue per user (ARPU) and increased investment and operational costs of introducing new systems. Due to these constraints, operational and energy efficiency as well as cost has become more important than peak performance improvements. In particular, in the case of 5G, the overall network deployment cost burden has increased significantly compared to the previous generations. This has been due to the reduced coverage per cell that use higher frequency bands, and also especially in recent years, due to decline in operators' ARPU [6, 7].

Finally, it is worth noting that with the introduction of carbon neutrality policies in various countries such as the U.S., Europe, and China, some operators have declared they will achieve carbon neutrality in the 2030s and Net Zero by 2040s~2050s. According to a survey on operator requirements [8], operators are increasingly interested in cost-saving technologies for higher energy efficiency, security, open networks, virtualized radio access network (vRAN), AI automation, and cloudification.

Technology Trends

As communication systems evolve towards broadband real-time services, wireless communication and networking technologies are expected to continue to advance in efficient delivery of more data at higher speed, with lower latency, and more efficient spectrum usage.

More importantly, at the same time, diversified market and user demands, as well as new perspectives of societal and environmental needs are also driving new technology trends for new system design and requirements. Furthermore, mobile network architecture and functions are changing to improve efficiency through more flexible and expandable capabilities based on softwarization and virtualization.

To satisfy such diverse needs and requirements of 6G communications systems, a number of technology trends, including AI, sustainability, ubiquitous coverage, and secure and resilient network, will dominate 6G developments. We discuss each of the above trends in more detail in the rest of this section.

As AI technology flourishes, the demand and necessity to apply AI technology to communication systems are rapidly emerging. First of all, AI is expected to be a key technology for 6G to improve operational efficiency, reduce costs, and enhance overall performance. Also, AI will play an important role in differentiating operators' services and technologies as the trend of softwarization and virtualization continues to be stronger in communication networks. Furthermore, 6G systems and networks will be AI-native, which means that their architecture and computing functions will have AI-related capabilities by design.

Another trend that has drawn global attention is sustainability, which is becoming more important. Many countries and mobile operators have declared eco-friendly policies for both environment and business growth. Various approaches for green networks are under trial to reduce power consumption, adopt renewable energy, and re-use materials used in communication systems.

In recent years, the cost of launching communication satellites has decreased while the priority to provide communication services to underserved areas has increased. Accordingly, technologies for seamless operation and interworking between terrestrial networks and non-terrestrial networks are receiving more attention.

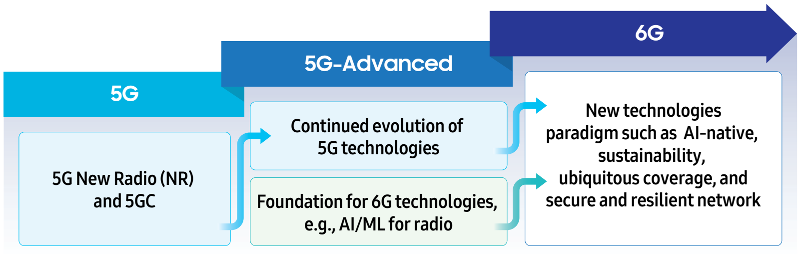
With increasing computing power in networks and devices, technologies for security are regarded as essential for 6G systems. Also, with the prevalence of AI applications, security has become a significant consideration for data collection, processing and transmission.

5G-Advanced: evolution of 5G and preparation for 6G

As a stepping stone of 5G evolution towards 6G, 5G-Advanced will provide enhanced 5G performance and support new services and use cases. It will improve 5G network performance with key features such as the continued evolution of MIMO, duplex evolution, AI/ML for air interface and NG-RAN, network energy saving, and coverage enhancements. It will also strengthen the support of new services and devices such as extended reality (XR), uncrewed aerial vehicle (UAV), and non-terrestrial networks (NTN) with satellites. At the same time, 5G-Advanced will play an important role as a foundation for developing technologies for 6G.

Figure 1

Evolution toward 6G



3 Emerging Services

We envision that emerging services in the 6G era will revolutionize the way people interact with technology and also address economic, environmental, and societal needs. It will integrate wireless communication technologies with the advances of other technologies such as AI while continuing the evolution of 5G services. In this section, we highlight some key emerging services expected to be available in 6G, as illustrated in Figure 2.

- Immersive Extended Reality (XR)
  XR has attracted great attention in various fields including entertainment, medicine, science, education, and manufacturing industries. XR technology in the 6G era is expected to provide a truly immersive user experience that is close to the perception capability of humans. It is anticipated that the market for VR and AR will grow to reach $442 billion [9] and $598 billion [10], respectively, by 2030.

- Digital Twin
  With the help of advanced sensors, AI, and communication technologies, it will be possible to replicate physical entities, including people, devices, objects, systems, and even places, in a virtual world. This digital replica of a physical entity is called a digital twin. In a 6G environment, through digital twins, users will be able to explore and monitor the physical entities in a virtual world, without temporal or spatial constraints, and observe changes or detect problems remotely. Users will be even able to interact with digital twins, using VR devices or holographic displays, resulting in actions in the physical world.

- Massive Communication
  In the 6G era, a huge number of devices, machines, sensors, and objects are expected to communicate at the same time; as a result, networks will have to process an enormous amount of data traffic promptly, with stable service. We expect the massive communication capability of 6G system to enable automation and management of numerous devices and objects, such as smart homes, smart factories, and smart cities.

- Ubiquitous Connectivity
  6G systems are expected to expand the coverage of terrestrial networks. In current terrestrial networks, it is not economically viable to provide communication services in sparsely populated areas, such as deserts, mountains, and seas. By virtue of recent advancements in aerospace technology, support of communication services in those areas will become feasible by interworking or integration between terrestrial networks and non-terrestrial network

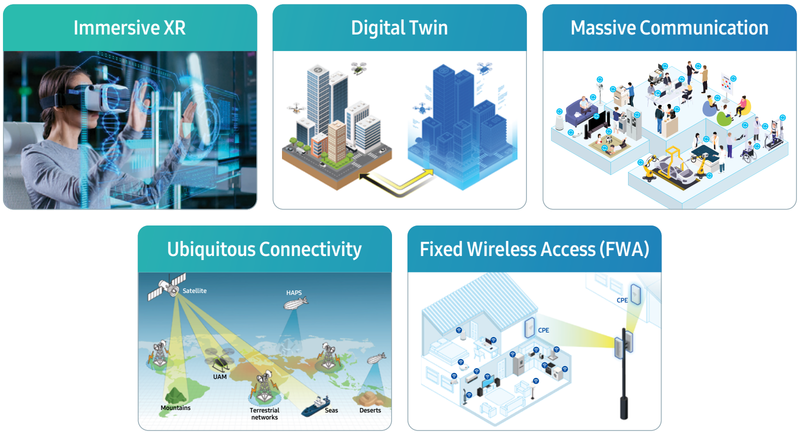
components, e.g., satellites and high-altitude platform station (HAPS). Furthermore, non-terrestrial networks will complement communication services during disasters and emergencies with uninterrupted connectivity, by ensuring diverse connectivity and flexible deployment.

- Fixed Wireless Access (FWA)

  FWA has been a key driver of growth in mobile network operator subscriptions, by enabling the use of wireless air interface to provide broadband access to customers in the comfort of their home or office. It should also be noted that FWA has been recognized as a key driver for expanding the overall broadband market with a significant number of new users entering the market. Taking into account the growing FWA connections worldwide, this trend is expected to continue in the 6G era.

Figure 2

Key emerging services in the 6G era



4 6G Key Attributes

From 2G to 5G, mobile communication systems have evolved with the aim of achieving significant performance improvement with enhanced capabilities. For example, from 4G to 5G, a huge performance improvement (e.g., 10 times or 20 times) of important key performance indicators (KPIs) such as peak data rate, spectral efficiency, and latency was targeted when developing 5G standard.

Considering the global discussions resulting in the ITU-R IMT-2030 (6G) Framework [11], as well as market trends, needs, and lessons learned from 5G (as discussed in the previous sections), enhancement of KPI targets alone might not be enough to create real value of 6G for both end-users and network operators.

For success of 6G, it would be of the utmost importance to pursue future-proof and sustainable user experience. The market and technology trends (see Section 2) emphasize the importance of the native use of emerging AI technologies and the realization of a sustainable network. Considering this, we observe a paradigm shift toward 'AI-Native and Sustainable Communication' for 6G. Furthermore, ubiquitous coverage, and secure and resilient network operation are also crucial to enable unique user experiences and reliable services. In summary, as illustrated in Figure 3, 6G technologies have to be developed to realize 'AI-Native and Sustainable Communication' with the following four key attributes.

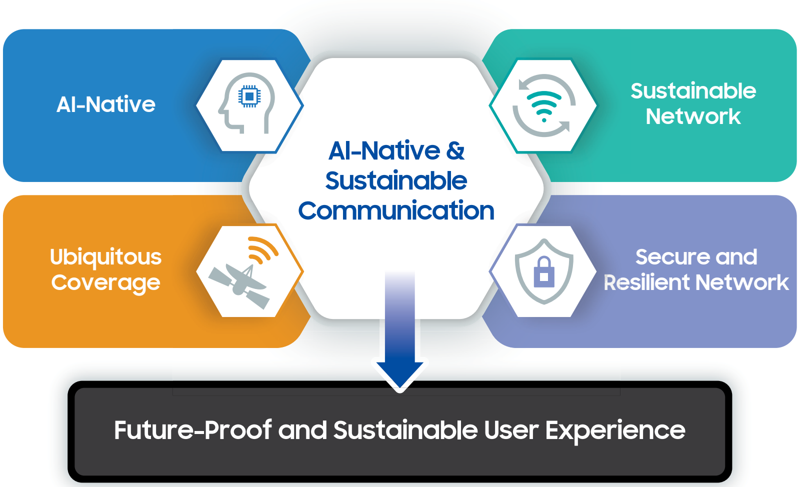
- AI-Native
  Leveraging and incorporating AI into communication functionalities (possible examples are channel state information (CSI) compression and prediction, TX/RX algorithms, and network O&M) from the beginning of system design to the development, management, and operation of systems, in order to achieve the desired performance improvements.
- Sustainable Network
  Reducing operational cost and improving users' satisfaction by improving energy efficiency of both networks and terminals.
- Ubiquitous Coverage
  Reducing capital expenditures (CAPEX) of networks and improving the quality of services experienced by users through expanding communication service area, especially in mid/high bands (i.e., 7-24 GHz, 28 GHz, etc.) and expanding connectivity via interconnecting terrestrial and non-terrestrial networks.

- Secure and Resilient Network

  Ensuring network security, users' privacy, and resilience in preparation for the 2030s when significant advances in computing capability and AI technology are expected.

Figure 3

Four key attributes



5 6G Spectrum

To realize the full potential of 6G with enhanced coverage and capacity for support of various applications and services, it is important to utilize all of the available spectrum in low, mid, and high bands. The existing spectrum for 2G, 3G, 4G, and 5G could be re-farmed for 6G. Nevertheless, the currently available spectrum will not be sufficient to meet the ever-increasing traffic demand in the 6G era. Therefore, it is essential to secure new spectrum for 6G.

In this section, we provide updates to the "6G Spectrum: Expanding the Frontier" white paper [12] as related to the outcomes of WRC-23, which was held from November 20 to December 15, 2023, in Dubai, UAE. We will discuss the candidate bands for IMT identification at WRC-27, which are considered mainly for 6G, and the upper 6 GHz bands identified for IMT at WRC-23, which could be used for 5G as well as 6G.

In the lower and upper mid-band, the candidate bands for IMT identification at WRC-27 are as follows.

- 4 400–4 800 MHz, or parts thereof, in Region 1 and Region 3
- 7 125–8 400 MHz, or parts thereof, in Region 2 and Region 3
- 7 125–7 250 MHz, and 7 750-8 400 MHz, or parts thereof, in Region 1
- 14.8–15.35 GHz

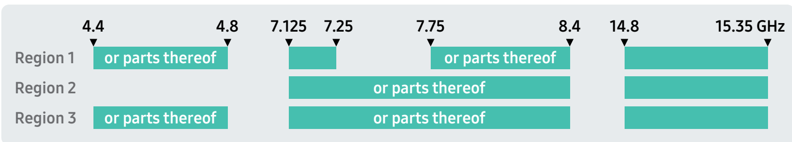


Figure 4

Candidate bands for IMT identification at WRC-27

The outcome of IMT identification at WRC-23 for the upper 6 GHz is as follows.

- 6 425–7 125 MHz, in Region 1, and in Mexico and Brazil in Region 2
- 6 425–7 025 MHz, in Cambodia, Lao, and Maldives in Region 3
- 7 025–7 125 MHz, in Region 3

It is noted that some countries in Region 3 may be added for 6 425-7 025 MHz at WRC-27.

Given the importance of 6G spectrum, we will continue our efforts on the ITU studies and WRC-related activities. Furthermore, we will investigate the 12.7-13.25 GHz as a candidate band for 6G deployment in the U.S., since the band is under rulemaking process in the U.S.

6 Enabling Technologies

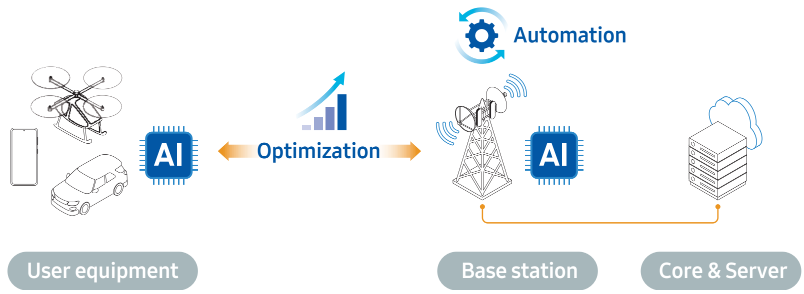
In this section, we discuss a set of enabling technologies to realize the 6G key attributes introduced in Section 4, i.e., AI-native, sustainable network, ubiquitous coverage, and secure and resilient networks. Note that our view on enabling technologies for 6G may evolve based on our continuous effort to take account of evolving market needs.

Technologies for AI-Native

As AI shows its excellent performance of making optimal choices for optimization and automation, it is widely expected that, in the 6G era, the wireless communication system could be automated end-to-end and optimally operated using AI as shown in Figure 5.

Figure 5

AI-based air interface optimization & network automation



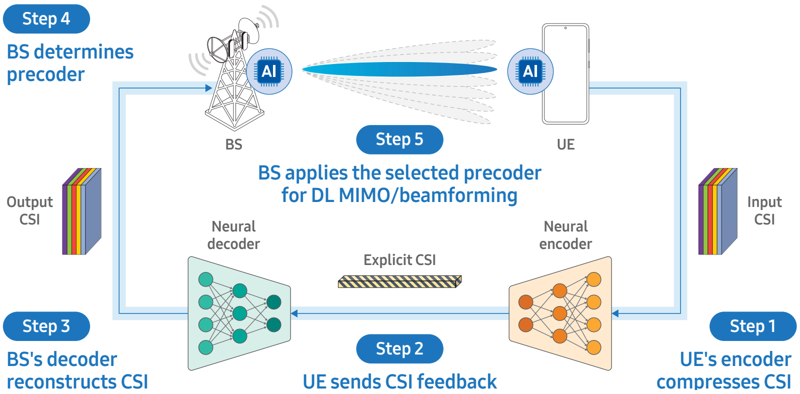
The key motivation behind AI-based air interface optimization is to derive performance improvements in terms of spectral efficiency, reduced signaling load, etc. AI-based network automation enables, e.g., significant reduction of network operation cost, ease of deploying new features and services, and user experience improvements.

AI-based Air Interface Optimization

One example of AI-based air interface optimization is AI-based CSI feedback compression. To fully utilize the potential of massive MIMO, the base station (BS) needs to acquire accurate downlink CSI reported from each user equipment (UE). When the number of antennas and the bandwidth increase, the CSI feedback overhead becomes huge. To reduce CSI feedback overhead, AI models performing compression and reconstruction tasks (e.g., autoencoder consisting of encoder and decoder) can be used as illustrated in Figure 6.

Figure 6

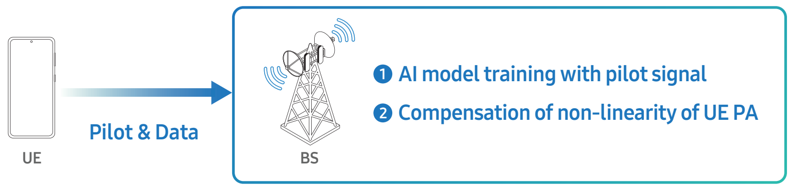
Illustration of autoencoder-based CSI feedback mechanism



A second example is mitigating the nonlinearity of the UE transmit power amplifier (PA) through the use of AI at the BS receiver. The signal quality could be degraded due to the PA nonlinearity, which typically becomes severer with higher transmit power levels. To avoid signal quality degradation, it is necessary to reduce the PA output power to ensure the transmit signal is in the linear range or to reduce the nonlinearity effect. However, the transmit power reduction results in reduced coverage. To overcome this problem, an AI-based nonlinearity compensator (AI-NC) can be considered. To apply an AI-NC, a lightweight AI model can be trained using the pilot signal and is applied at the BS to compensate for the nonlinearity caused to the data channel, as illustrated in Figure 7. With such an approach, the UE can be allowed to increase its transmit power level, thereby improving the coverage of the network.

Figure 7

Procedure of AI-NC



AI-based Network Automation

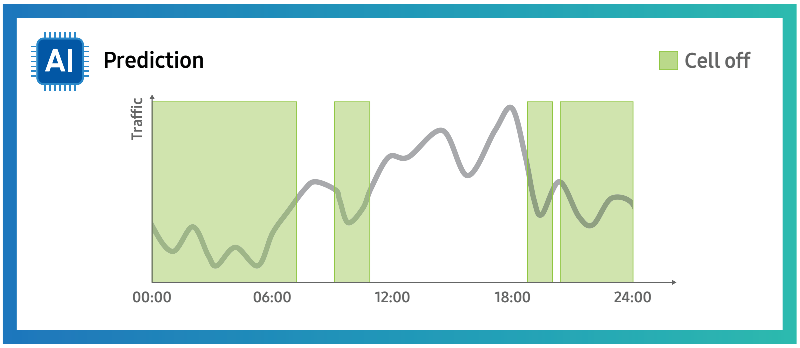
There is a strong demand from mobile network operators to offer agile and flexible network management and vertical services. As today's networks become tremendously complex, it is increasingly difficult to efficiently manage them. Furthermore, a tight interworking is necessary between multiple network entities within the system such as the radio unit (RU), distributed unit (DU), central unit (CU), and core network.

Therefore, AI-based network automation could be considered as an integral part of a fully autonomous 6G network, due to its ability to learn and manage the network without any human intervention. Through AI-based network automation, it is expected to eliminate the complexity of network operation, simplify services launches, and reduce cost to operators.

One of the key use cases of AI-based network automation is AI-based energy saving management (ESM), which provides significant savings in energy consumption by taking appropriate measures, e.g., turning a cell on/off according to the state of the cell and the amount of traffic. By deactivating cells with low traffic volume, the cell on/off technology can efficiently save energy particularly when there are many cells or in areas with sporadic traffic demand. Figure 8 shows an example of how the AI-based cell traffic prediction could be used for energy saving, thus improving the network energy efficiency.

Figure 8

AI-based traffic prediction for energy saving



Technologies for Sustainable Network

In order to realize a sustainable network, it is necessary to design the entire communication system from the perspective of improving energy efficiency while meeting the performance targets. In other words, this principle has to be applied to all components, including the hardware of BS and network, the basic functions of baseband operation such as channel coding, modulation, and waveform, and the scalable computing resource management.

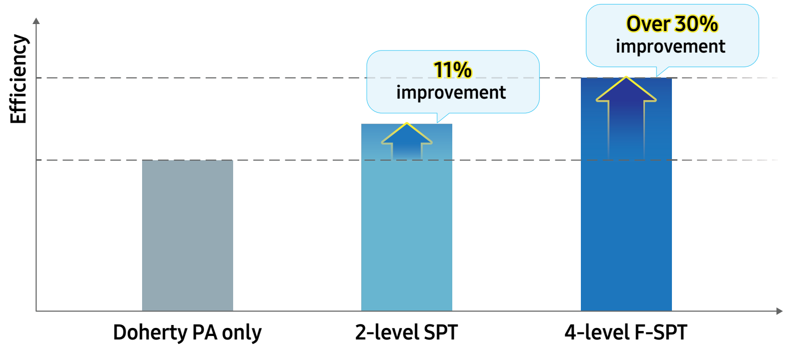
Energy-Efficient Hardware

The energy consumption of PA occupies a significant portion of the overall energy consumption of network hardware. Particularly, for waveforms with high peak-to-average power ratio (PAPR), PA energy efficiency drops dramatically, and therefore, various low power radio frequency (RF) techniques need to be employed. For example, Doherty PA is currently used in commercial network equipment for LTE and 5G to reduce the power consumption. One downside of Doherty PA is its efficiency improvement is only optimized for 100% traffic load conditions. When the traffic is less than peak load, the efficiency of Doherty PA drops significantly, since Doherty PA operation is only optimized for 100% output power condition. In reality, network traffic load varies with usage and dynamically changes, therefore limiting the amount of energy saving that can be achieved with Doherty PA.

One of the promising candidate technologies for improving the PA efficiency, even with dynamically varying traffic load condition, is PA power supply adaptation. For instance, dynamic adaptation of PA's supply voltage at modulated symbol-level, namely symbol-level power tracking (SPT), can improve the Doherty PA's efficiency. Moreover, a scheme with faster supply voltage adaptation than SPT even within a symbol could be considered for further improving the PA efficiency. We call this scheme faster than SPT (F-SPT). As shown in Figure 9, in dynamic traffic load scenarios, F-SPT can achieve over 30% efficiency improvement than Doherty PA, which means that over 30% energy can be saved for signal radiation. Additionally, Doherty PA is not suitable for very wide bandwidth signals, but F-SPT can be applied to wide bandwidth signals.

Figure 9

Efficiency improvement with SPT & F-SPT assuming dynamic traffic conditions



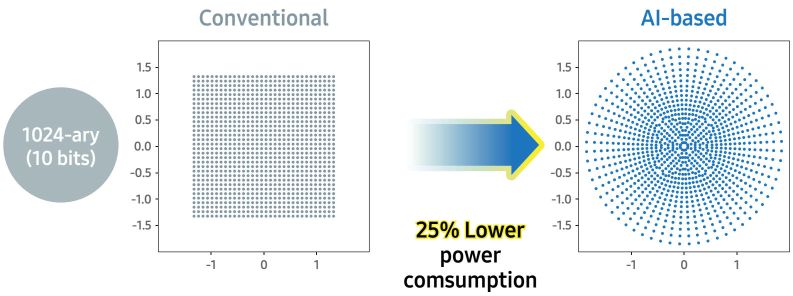
Energy-Efficient Channel Coding, Modulation, and Waveform

Channel coding is essential to provide the required level of capacity, reliability, and data integrity in wireless communication systems. One of the primary requirements for the channel coding scheme in 6G is achieving higher decoding throughput compared to 5G to improve the overall efficiency of baseband operation. A possible approach for 6G may be to reuse the low-density parity check (LDPC) codes and polar codes of 5G NR (possibly with small variations). However, in order to achieve more drastic improvement in 6G, it is necessary to investigate new channel coding schemes for better communication resource efficiency and a higher level of parallelization of the decoder with improved reliability. A recent approach proposed for improving the performance of short block lengths is polarization-adjusted convolutional (PAC) code [13]. Staircase code [14] and product code [15] could also be effective solutions for achieving higher decoding throughput.

Additionally, AI technologies can provide enhancements for modulation constellation that has traditionally been square constellation, e.g., conventional QAM modulations. An optimized non-uniform constellation could be searched by utilizing AI as shown in Figure 10. For robustness to PA/RF impairments, AI can learn the characteristics of a PA and then compensate for the distortion caused by the PA by adjusting the modulation constellation. This enables the PA to operate in the saturation region with lower bias voltage and hence achieve higher power efficiency.

Figure 10

AI-based modulation constellation



From the perspective of waveform design, orthogonal frequency division multiplexing (OFDM) has been widely used in many standards such as 5G NR, 4G LTE, and the IEEE 802.11 family. It offers many advantages: (1) handling of frequency selective channels for broadband communications; (2) flexible spectrum allocation; (3) low implementation complexity by using IFFT/FFT pairs and frequency domain one-tap equalizer; (4) easy integration with MIMO. For these reasons, it is envisioned that OFDM and its simple variant of having additional pre-processing such as discrete Fourier transform spread OFDM (DFT-s-OFDM) would be strong candidate waveforms for 6G. In addition to OFDM, a low PAPR waveform is another area of research to be focused on moving forward. For example, it is worth exploring a DFT-s-OFDM with a well-designed frequency domain spectrum shaping, in order to ensure zero-dB PAPR and consequently enhance the PA efficiency and coverage.

Scalable Computing Resource Management

With the progress of virtualization and cloudification, efficient management of network computing resources is an important topic for sustainable network. To achieve good scalability, flexibility, and efficiency of computing resources, the micro-service based architecture is a popular architectural approach for cloud applications. In the micro-service based architecture, an application is composed of a collection of loosely coupled and independently managed micro-services. With advances in cloud technologies, the telecom industry also considers applying such approaches to vRAN to obtain the scalability, flexibility, and efficiency.

Scalability of vRAN involves the ability to handle changing traffic demand adaptively by scaling computing resources in an efficient manner. Scaling of computing resources can be performed in a semi-static manner, e.g., depending on the traffic demand in a region during the day and night, while dynamic resource scaling according to the real-time traffic changes can be also considered as illustrated in Figure 11. Scalable vRAN can also enable more efficient computing resource allocation and lower energy consumption by allocating only essential resources in each state.

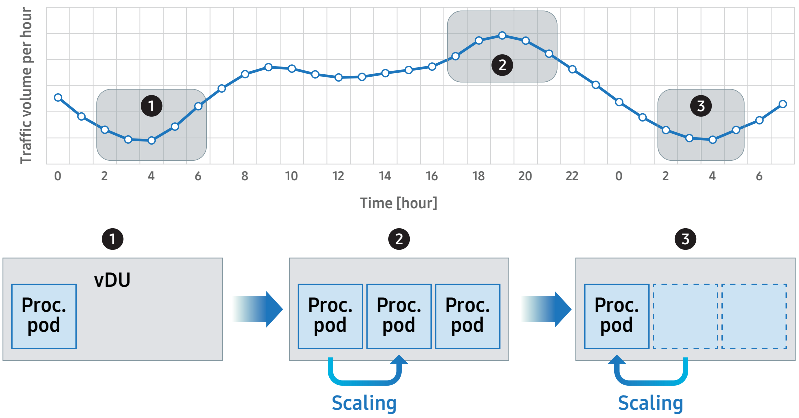


Figure 11

Scalable computing resource management in response to traffic demand

Technologies for Ubiquitous Coverage

Coverage has always been one of the key requirements of mobile communications. With higher frequency, path loss and blockage probability increase, thereby reducing the coverage of the network. With the use of higher frequency bands in each new generation, the mobile industry has observed the increasing importance of fulfilling the end users' requirements on coverage, which has particularly been the case for 5G. If 6G is deployed in a higher frequency band, e.g., 7.125-8.4 GHz or 12.7-13.25 GHz, than the typical 5G band such as 3.5 GHz, it is important to have proper technologies to provide the similar or even better coverage than 5G. In the rest of this section, we will elaborate on a set of technologies for realizing ubiquitous coverage.

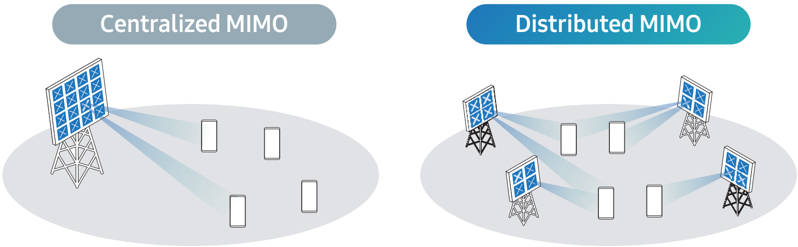
Distributed MIMO (D-MIMO)

Distributed MIMO (D-MIMO) is one of emerging solutions to enhance coverage. D-MIMO refers to systems where distributed transmission and reception points (TRPs), i.e., RUs, serve a single or multiple users in a cooperative manner with advanced signal processing techniques such as joint precoding and coordinated beamforming.

To overcome high path loss, D-MIMO can leverage spatial diversity enabled by its distributed nature, and the additional beamforming gain enabled by the joint use of antennas of multiple TRPs. As depicted in Figure 12, in low frequency bands where propagation loss is less severe, D-MIMO can provide higher spectral efficiency and accommodate more users in a wide area compared to centralized MIMO, which has space limits in deploying a large number of antennas. In order to realize these advantages of D-MIMO, it is necessary to have tight synchronization and calibration among TRPs.

Figure 12

Centralized MIMO vs. Distributed MIMO



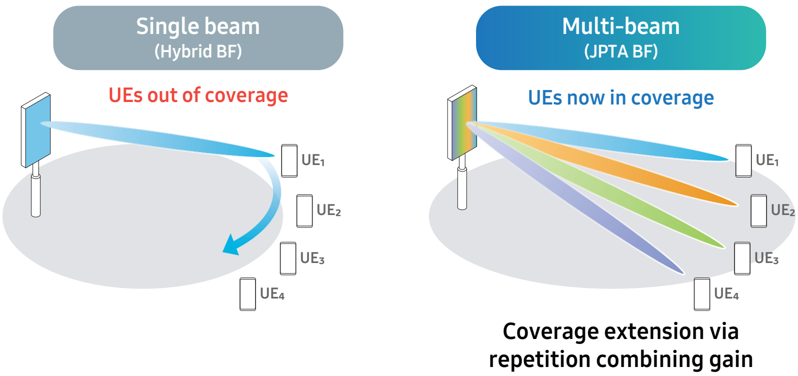
Joint Phase and Time Array (JPTA)

Joint phase and time array (JPTA) is one of the promising technologies that can effectively extend uplink coverage in multi-user environments [16]. By adding true-time delay circuits, beams could be managed in both frequency dependent and independent ways. With this, JPTA can simultaneously support multiple sub-band beams, without duplicating multiple TRX chains.

As shown in Figure 13, JPTA can effectively improve uplink coverage in multi-user environments by forming multiple concurrent beams for different users. Since it is possible to allocate different beams for RX for different sub-bands, each user does not need to wait for its turn, and thereby multiple users can send uplink data in different sub-bands without any delay. This means that each user can utilize more time for uplink transmission, which will eventually increase the uplink coverage in multi-user environments.

Figure 13

JPTA for UL coverage extension



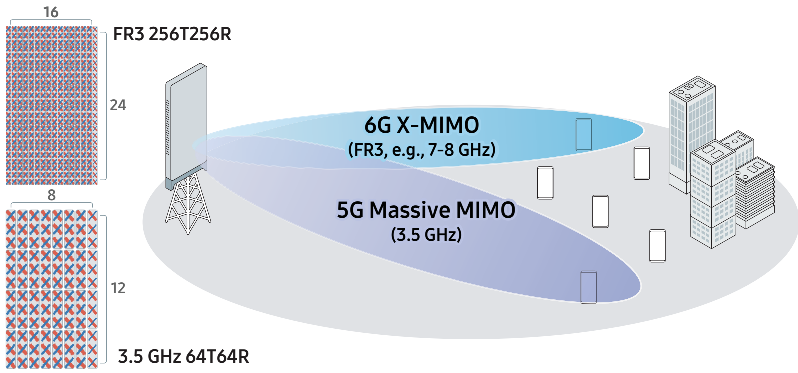
eXtreme MIMO (X-MIMO)

As seen from the outcome of WRC-23 and the ongoing discussion in the U.S., the upper mid-band (or FR3), i.e., 7-24 GHz, is gaining much attention from the mobile industry as new spectrum for realizing 6G vision and requirements. In order to realize ubiquitous coverage in the upper mid-band, it is important to overcome higher path-loss as compared to the existing 5G band such as 3.5 GHz. To this end, the BS needs to adopt an extremely large number of antenna elements and digital ports. In the eXtreme-MIMO (X-MIMO) system, we consider hundreds to thousands of antenna elements (AEs) and hundreds of digital ports at the BS, to meet the requirements of ubiquitous coverage as well as large capacity.

In Figure 14, we show an example of the antenna dimensions of an X-MIMO system in the FR3 band, e.g., 7-8 GHz, with 256T256R and 768 AEs. We also illustrate an example of the 64T64R massive MIMO radio system in 3.5 GHz band for comparison. Due to the increased carrier frequency with shorter wavelength, X-MIMO can accommodate much more AEs compared to massive MIMO radio in the 3.5 GHz band, while maintaining a similar hardware form factor.

Figure 14

Comparison between 5G massive MIMO and 6G X-MIMO



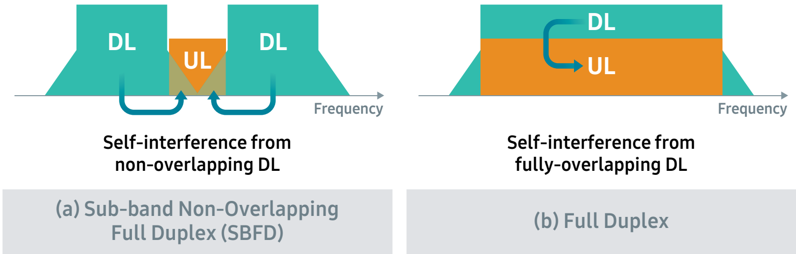
With an extremely large number of antennas and digital ports, the BS can increase its capability of beamforming and spatial multiplexing. Furthermore, it is possible to have a good balance of high beamforming gain and improved power efficiency thanks to its large degrees-of-freedom in designing beamforming weights and precoding.

Duplex Evolution – Sub-band Non-Overlapping Full Duplex (SBFD)

It is expected that TDD bands will continue to be important in 6G. In TDD bands, time domain resources are split between DL and UL. Allocation of limited time resources for the UL results in reduced performance in coverage and throughput. A possible approach to increase the UL resources is sub-band non-overlapping full duplex (SBFD), where the BS performs DL transmission and UL reception simultaneously using non-overlapping sub-bands as shown in Figure 15, while the UE maintains its half-duplex operation. These additional uplink resources increase the uplink transmission energy, hence improving the uplink coverage. SBFD is a variant of full duplex (see the discussion on duplex evolution in our previous 6G white paper [1]) adapted for commercial deployments and is being specified in Rel-19 of 5G-Advanced in 3GPP [17]. Further enhancements of SBFD could be considered for 6G.

Figure 15

Self-interference in SBFD and full duplex



Non-Terrestrial Network (NTN)

As an approach for providing ubiquitous coverage even in the areas where there is no terrestrial network (TN), the use of non-terrestrial network (NTN) components, e.g., satellites, has attracted great attention and there is standard support in 3GPP 5G specifications. It is expected that the support of NTN will be further enhanced in 6G. More details of our view on NTN can be found in our previous 6G white paper [1].

Technologies for Secure and Resilient Network

With the emergence of various critical applications such as connected vehicles, healthcare systems, industrial IoT, emergency communications, enhanced security technologies to provide the robustness against the cyber-attacks as well as the reliability and resiliency of the network will be essential for 6G network.

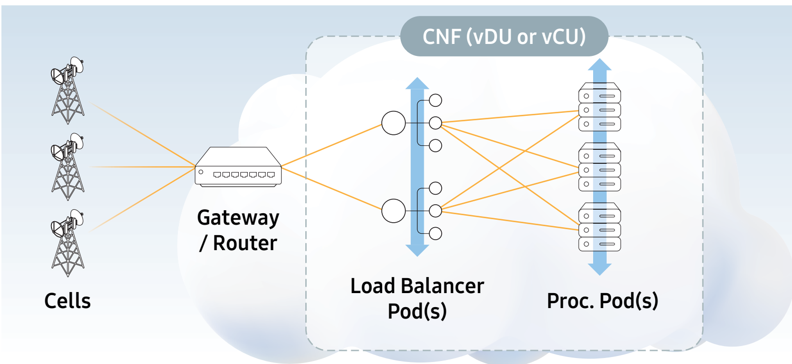
With advances in computing capability, open source software, and open network architecture, there are increasing threats to the security of the whole communication system. In open network architecture, the number of interfaces increases to support interworking among operators, vendors, and cloud systems. Hence, an attacker has more opportunities to attack the system. To mitigate such threats in open networks, we could consider the zero trust architecture approach that applies the concept “Never trust, always verify.” In this approach, all entities in the network are continuously monitored to detect if any entity performs abnormal behavior. Advances in quantum computing technologies may motivate research on post-quantum cryptography (PQC). We need to monitor and evaluate how security threats evolve and to prepare suitable security technologies for 6G.

There are various candidate technologies to provide uninterrupted and reliable communications service even in extreme and unexpected scenarios. Seamless adaptation over multiple carrier frequency bands and heterogeneous networks, e.g., 4G/5G/6G/Wi-Fi/NTN, may be useful to guarantee uninterrupted services by providing alternative traffic routes efficiently. Automated failure detection and recovery technologies could be useful to reduce service downtime. Anomaly prediction could be performed using AI. Distributed cloud and computing technologies could be helpful to support fast recovery from disruptions, for example during natural disasters, by allowing efficient deployment of redundancies, dynamic reconfiguration of resources and services, and dynamic traffic rerouting.

Various functionalities have been applied to enhance the reliability in the vRAN and virtualized core network (vCore) from 5G. For example, the all-active architecture of pods of vRAN and vCore entities with load balancer enables reliable operation of vRAN and vCore even if some pods fail. Highly flexible and dynamic scaling of cloud resources can prevent system overload even when very high traffic demand arises suddenly. Figure 16 shows an example of an all-active and scalable vRAN.

Figure 16

Example of an all-active and scalable vRAN



7 6G Timeline

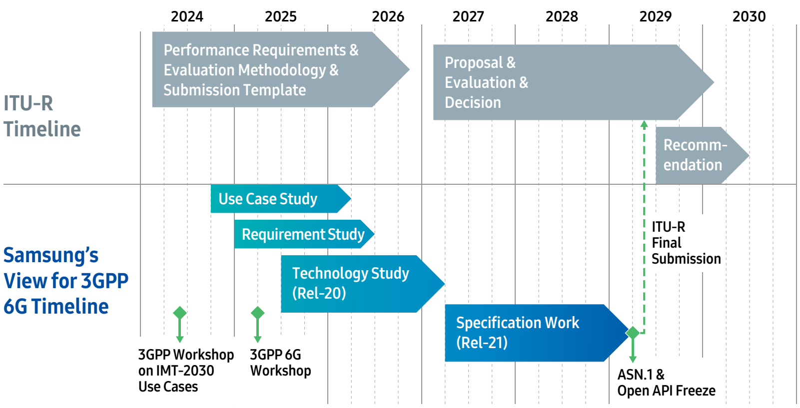
After 5G was first commercialized in 2019, the ITU-R has started their work towards 6G from 2020, targeting completion in 2030. ITU-R recently finished its initial phase setting the basis for the development of 6G, providing the new ITU-R Report on future technology trends [18] and the Recommendation on IMT-2030 (6G) Framework [11]. In the next phase starting from 2024, ITU-R will further define relevant technical performance requirements, evaluation methodologies, and submission templates for potential 6G radio interface technologies. After that, the evaluation process and completion of 6G specification will conclude by 2030.

Along with the ITU-R 6G timeline, Figure 17 shows Samsung's view on 3GPP 6G timeline. We expect 3GPP will begin its initial technology study for 6G from Release 20, and Release 21 is expected to be the 1st set of 6G technical specifications. 3GPP also needs to conduct a study on 6G use cases and requirements before the start of the technology studies, anticipating an overlapping period between the two activities as shown in Figure 17. While the exact timeline needs to be decided in 3GPP, we target March 2029 as the completion date of Rel-21 (in terms of ASN.1 and open API freeze). We expect Rel-21 specifications will be used as the 3GPP submission to ITU-R for IMT-2030 Recommendation.

As the journey towards 6G standardization of ITU-R and 3GPP takes shape, it is expected that research and development of 6G will further accelerate. Leading these global standardization activities, we will continue to do our best to accomplish a unified global 6G standard in close cooperation with many countries as well as industries all over the world.

Figure 17

ITU-R 6G timeline and Samsung's view on 3GPP 6G timeline



8 Concluding Remarks

It has been more than five years since the 5G systems were first commercialized in 2019. While the mobile industry continues its efforts to achieve commercial success with 5G technologies, we believe it is important to prepare for 6G, taking into account the lessons learned from 5G deployments as well as new demands for 6G. In this spirit, this white paper presented our updated views on various aspects of 6G, including market and technology trends, emerging services, key attributes of 6G, spectrum, enabling technologies, and timeline. We will continue our effort to ensure that we will move forward in the direction leading to the successful launch and commercialization of 6G for end users, the mobile communication industry, and the society as a whole.

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