6G R&D Vision: Requirements and Candidate Technologies

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(Invited paper)

***Abstract*—The Korean Institute of Communications and Information Sciences (KICS), which is the largest information and communication technology institute in Korea, has been active in working towards development and standardization of mobile communication technology. In response to the need to meet upcoming 6G technical challenges in innovative applications such as hologram telepresence, extended reality (XR), digital twin, and connected robotics, the KICS 6G research initiative (KICS 6GRI) group has been created to establish a vision for key 6G technologies and identify research trends and directions. This article, therefore, covers major performance indicators and requirements envisioned by the KICS. In addition, we provide a comprehensive discussion of various candidate 6G technologies including (sub-)terahertz (THz), intelligent reflecting surface (IRS), artificial intelligence (AI)-based techniques, and non-terrestrial network (NTN).**

***Index Terms*—6G, the Korean Institute of Communications and Information Sciences (KICS), mobile communication standard.**

I. INTRODUCTION

FROM the early stages of second-generation mobile communication development to the fifth-generation (5G), the Korean Institute of Communications and Information Sciences (KICS) has solidified its status as a communication powerhouse through engineering and technology education and knowledge transfer via the presentation of demand, research directions, and major research results. Standardization, equipment manufacturing, and mobile communication operations are implemented by telecommunication companies and manufacturers; however, research directions and content related to the new generation of mobile communication are first introduced through the KICS. The KICS has contributed greatly to the introduction and spread of 5G mobile communication technology and laid the groundwork for its completion. As a result, in 2018, Korea commercialized 5G for the first time in the world, and more than 40% of mobile users are currently using 5G.

Considering the standardization and commercialization schedule thus far, it is appropriate to start research and development (R&D) for sixth-generation (6G) at this point, two years after 5G's commercialization. It is time to start full-scale basic research, as noted in [1]–[3]. In fact, since the commercialization of 5G in 2018, the KICS has been continuously holding academic events on major 6G technologies to stimulate interest in such research. In response to the need to further promote this technology, the KICS 6G research initiative (KICS 6GRI) group was created to establish a vision for major 6G technologies and research trends and directions for those technologies.

Considering the 6G performance indicators presented by major countries and organizations, the 6G key performance indicators (KPIs) envisioned by the KICS are shown in Table I. The KICS aims to further enhance the performance of 5G to meet the maximum data rate of 1 Tbps and the user-

TABLE I
KEY PERFORMANCE INDICATORS (KPIS) FOR 6G ENVISIONED BY KICS.

	Performance index		Performance value
5G KPI enhancement	Peak data rate		1 Tbps
	User experience data rate		1 Gbps
	Latency	Air	0.1 ms
		E2E	TBD
	Connection efficiency		10^7
	Spectrum efficiency		2X
	Network energy efficiency		2X
Newly defined KPI	Reliability		10^{-9}
	High-precision positioning		10 cm
	New coverage (Vertical)		10 km

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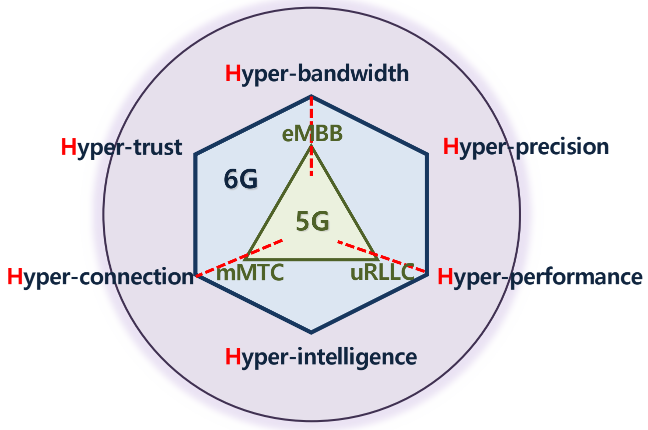

Fig. 1. 6G vision with six hyper-performance axes.

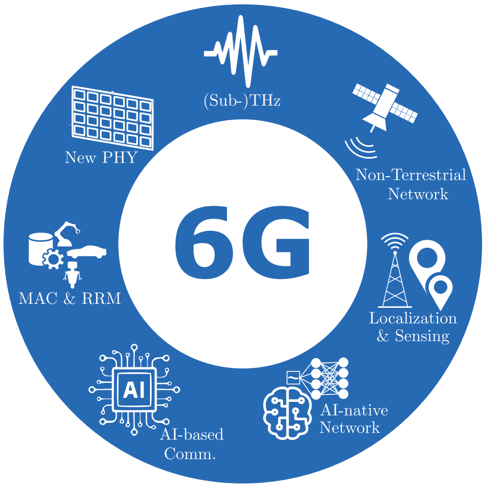

Fig. 2. Key candidate technologies of 6G.

experience data rate of 1 Gbps. It also aims to support devices with a latency time of less than 0.1 ms and 10 times more than 5G with more than twice the spectrum and network efficiency. In addition, performance indicators newly required in 6G include 10^{-9} reliability, precise location estimation, and coverage beyond the terrestrial area. In 6G, it is necessary to more effectively support and activate lots of object oriented communications that have been started in 5G. A much higher level of reliability is required to control for connected robots and automated systems as well as deal with medical information generated in the e-healthcare area. In order to recognize or control things, a much higher level of precise location estimation is required, and precise location estimation is required for services for the vulnerable populations. Non-terrestrial communication is required not only for providing coverage to areas that 5G cannot cover, but also for control and communication of urban air mobility (UAM)/unmanned aerial vehicle (UAV) services that have recently begun to be considered [4].

To satisfy the above-mentioned performance metrics, various candidate 6G technologies such as (sub-)terahertz (THz), intelligent reflecting surface (IRS), artificial intelligence (AI)-based algorithms, and non-terrestrial network (NTN) are being actively investigated. This vision document aims to promote and stimulate 6G research by presenting research trends and directions for major 6G technologies.

The keywords for 6G envisioned by the KICS are hyper-bandwidth, hyper-reliable low latency, hyper-connection, hyper-precision, hyper-trust, and hyper-intelligence which are six types of hyper-performances. Considering 5G to have been developed around three axes, enhanced mobile broadband (eMBB), ultra-reliable low latency communication (uRLLC), and massive machine-type communication (mMTC), in 6G, the three axes of 5G are further evolved and new requirements of hyper-precision, hyper-intelligence, and hyper-reliability have been added.

Fig. 1 shows the main technical requirements for 6G envisioned by the KICS. While the main requirements of 5G are expressed in a triangle, the main requirements of 6G are expressed in a hexagon, adding three more. In the next section, the research necessity and characteristics, and technology trends and directions, which are being primarily studied to satisfy these 6G technical requirements are described.

The remainder of this article is organized as follows. In Sections II to VIII, we discuss major candidate technologies of 6G including (sub-)THz communications, new physical-layer (PHY) techniques, medium access control (MAC) and radio resource management (RRM), AI-based communication system, AI-native network, localization and sensing, and NTN. These key candidate technologies are shown in Fig. 2. Finally, this article is concluded in Section IX by sharing the KICS 6GRI R&D strategy. In addition, Table II shows a list of acronyms used in this paper.

II. (Sub-)THz Communications

A. The Necessity and Characteristics

In the 6G communication system, (sub-)THz band communication is being considered for large data transmission for augmented reality (AR), virtual reality (VR), and XR services. Fig. 3 shows an example 6G network with (sub-)THz communications. Within the ultra-high frequency band of 0.1-10 THz, 0.1-0.3 THz is being called as the (sub-)THz communication frequency band [5]. In 2017, IEEE802.15.3d, a related standard, began to be enacted [6]. However, in the case of a very high frequency band of 0.2 THz or more, it is mainly considered for short-distance communication due to limitations such as hardware implementation (problems in securing measurement equipment and transmission power, etc.) and severe path loss [7].

The D-band (0.130-0.174 THz band) is also attracting attention for mid-range communication over 10m, and some of the bands (141.8-275 GHz) are licensed bands that are already allocated for earth exploration, satellite observation, and satellite radio systems. However, since March 2019, the Federal Communications Commission (FCC) has opened the 95 GHz-3 THz band for 10 years for experimental use to encourage the development of THz communication technologies and services, making it possible to use the band for

TABLE II
LIST OF ACRONYMS

5G	the fifth generation
6G	the sixth generation
6GRI	6G research initiative
AI	artificial intelligence
AI4Net	AI for network
AirComp	over-the-air computation
AP	access point
AR	augmented reality
BS	base station
CU	centralized unit
CPU	central processing unit
CP-OFDM	cyclic prefix orthogonal frequency-division multiplexing
DAPS	dual active protocol stack
DoF	degree of freedom
DU	distributed unit
E2E	end-to-end
eMBB	enhanced mobile broadband
FBMC	filter-bank multi-carrier
FCC	the Federal Communications Commission
FTN	faster-than-Nyquist
GSMA	the Global System for Mobile Communications Association
HARQ	hybrid automatic repeat request
HTS	high throughput satellites
IoT	Internet of things
IRS	intelligent reflecting surface
KPI	key performance indicator
LoS	line-of-sight
MAC	medium access control
MCS	modulation coding scheme
MIMO	multiple-input multiple-output
ML	machine learning
mMTC	massive machine-type communication
mmWave	millimeter wave
MNO	mobile network operator
Net4AI	network for AI
NFV	network function virtualization
NR	New Radio
NTN	non-terrestrial network
NWDAF	network data analytics function
OTA	over the air
O-RAN	open RAN
PAPR	peak-to-average-power ratio
PCRF	policy and charging rules function
PHY	physical layer
RAN	radio access network
RB	resource block
RF	radio frequency
RIC	RAN intelligent controller
RLC	radio link control
RRM	radio resource management
RU	radio unit
R&D	research and development
SC-FDMA	single carrier frequency division multiple access
SDN	software-defined network
SLA	service level agreement
SLAM	simultaneous localization and sensing
SNO	satellite service provider
STIN	space-terrestrial integrated network
THz	terahertz
UAM	urban air mobility
UAV	unmanned aerial vehicle
UE	user equipment
UM	ultra-massive
uRLLC	ultra-reliable low latency communication
WDA	wireless data aggregation
XR	extended reality

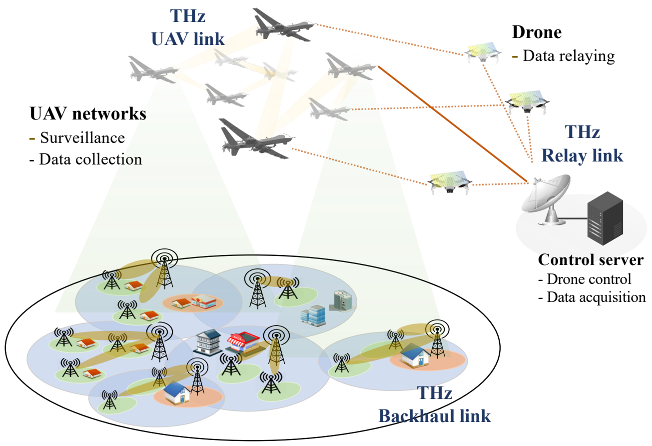

Fig. 3. 6G networks with (sub-)THz communications.

mid-range (sub-)THz communication [8]. In fact, through the D-band, telecommunication equipment manufacturers such as Samsung, LG, and Ericsson announced (sub-)THz communication demonstration and test results in the 0.1-0.2 THz band.

In THz communication using a very high frequency band, the system should be designed in consideration of the molecular absorption noise problem, including the following: 1) serious path loss in the communication channel due to atmospheric attenuation and molecular absorption loss [9], and 2) the short wavelength of the very high frequency band. The following studies are being conducted to overcome the limitations of the propagation distance due to the THz band's propagation characteristics.

B. *Research Trends and Directions*

1) THz Channel Modeling: The ultra-high frequency band to be used in 6G THz communication is sensitive to weather effects, such as rain or fog, due to atmospheric attenuation and molecular absorption loss. Therefore, it is necessary to model the THz communication channel considering the elements of reflection, scattering, and diffraction in the atmosphere. Whereas the THz channel model for short-distance communication in an indoor environment has been studied relatively well, there are only a few studies on the THz channel model for long-distance communication in an outdoor environment [9]. Recently, a research on a deterministic channel model using ray-tracing [10]–[12], and a stochastic channel model [13]–[15] that finds channel's statistical variables is in progress.

2) Ultra-massive MIMO and Intelligent Surface: To overcome the severe free-space path loss of the THz channel, an ultra-massive, multiple-input multiple-output (MIMO) technology is being explored. Due to the short wavelength of the THz band, a very large antenna array can be configured by integrating more than 10,000 very small antennas, through which an ultra-narrow beam can be formed to overcome path loss [16]. The super-capacity multi-antenna technology can reduce co-channel interference by forming an ultra-narrow beam, and has the advantage of forming hundreds of beams to support a large number of users at the same time. However, due to the short distance between the antennas, it may suffer from mutual coupling effect and correlations between the neighboring elements [17].

Intelligent reflecting surface (IRS) technology is being studied as an appealing way to overcome the serious path loss of the THz channel. IRS technology can increase the communication propagation distance by overcoming path loss and securing line-of-sight (LoS) by controlling the wireless channel environment using an additional intelligent antenna between base stations [16]. In addition, it has the advantages of low cost and low power consumption compared to the existing repeater method.

3) Signal Processing for Ultra-Broadband: In 6G THz communication, a wide bandwidth of 10 GHz or more can be used to achieve high-speed transmission, but it will significantly increase the noise floor and cause technical challenges in radio frequency (RF) equipment implementation. Just as in 5G new radio (NR) millimeter wave (mmWave) communication, 400 MHz bandwidth was realized by aggregating four carriers with 100 MHz bandwidth; thus, a method of configuring ultra-wideband by aggregating multiple carriers in THz communication is considered. To achieve this, hardware calibration of phase noise and the carrier frequency of multiple carriers is needed. Time-frequency synchronization of each carrier signal and design of the receiving end channel equalization are also of importance [16].

III. 6G Physical Layer Techniques

A. The Necessity and Characteristics

For the 5G mobile communication service, commercialized in April 2019, techniques such as the millimeter wave technique and massive MIMO were used. According to Zhang *et al.* [18], the desired characteristics of next-generation 6G mobile communication are ultra-high speed, 50 times faster than 5G, ultra-high connection with 10 times higher connection density, and ultra-low latency (i.e., one-tenth shorter than is currently the case).

In the existing cell structure, a user located at the cell boundary receives a low signal level due to path loss, suffering the performance degradation caused by the interference between adjacent cells. Research is underway to reduce the interference for improved communication speed. Meanwhile, the Global System for Mobile Communications Association (GSMA) estimates that the number of Internet of things (IoT) devices will increase to 75 billions by 2025, and active research is also being conducted on the low-latency network structures that do not require a central processing unit.

The mmWave and (sub-)THz bands, as their carrier frequency is high, can provide a very large bandwidth, but they are more vulnerable to shadowing due to a weakening of the diffraction phenomenon and also have limited utility in spatial multiplexing and beamforming techniques. Until now, the radio channel has random characteristics, and its high-capacity and high-reliability communication has been realized using simple closed-loop control and hybrid automatic repeat request (HARQ) technology. However, it will be very difficult to meet the stringent requirements of 6G with a simple extension of existing technologies in the high-frequency bands above mmWave [19].

IRS is a technique that can manipulate internal scattering particles using external stimuli and control the reflection and diffraction of electromagnetic waves [20]. IRS operates by only a simple software maneuver, through which a smart radio environment can be built for reliable communication between transmitters and receivers [19], [21]. In the wireless communication setting, IRS passively reflects incoming radio waves toward a desired direction and has the advantage of establishing a good and adaptive wireless network environment at a low cost.

Meanwhile, 5G NR currently supports only two orthogonal waveforms: Cyclic prefix orthogonal frequency-division multiplexing (CP-OFDM) and single carrier frequency division multiple access (SC-FDMA) [22]. However, the increase in bandwidth requires a wider CP section, thus efficiency can be reduced, and the increase in the nonlinearity of the power amplifier of high-frequency broadband can exacerbate the OFDM peak-to-average-power ratio (PAPR) problem [23]. For more resource-efficient transmission, research on new waveforms is required, and the design of new waveforms should take into account suppression of PAPR, robustness to time- and frequency-dispersion, frequency localization, and bandwidth occupation. Factors such as the characteristics of used bands [22] should be considered, too.

B. Research Trends and Directions

1) Cell-Free Massive MIMO: Cell-free massive MIMO is a system proposed to reduce the interference between cells [24]. Multiple access points (APs) are distributed over a wide area to support multiple users simultaneously, and the central processing unit (CPU) is used to match users and APs. Because there is no notion of cell, it is free from the boundary effects caused by inter-cell interference, and because APs are distributed throughout the region, there is no dead zone and macro-diversity gain and network connectivity can be improved. Unlike existing massive MIMO, in which multiple antennas are installed, each AP is equipped with a small number of antennas, thereby reducing the cost and power required, and also operating the AP with simple signal processing technology [25]. Since all APs support all users through one or several backhaul links, a potential drawback is that scaling is impossible as the network size increases, so research is needed to improve this aspect.

2) Intelligent Reflecting Surface (IRS): Although many methods for enhancing transmission rate and connectivity have been studied, system complexity, hardware cost, and power consumption are important problems that remain to be solved. IRS technology is proposed to solve this problem and reconfigure the wireless communication environment [25]. As shown in Fig. 4, IRS is composed of a number of sub-wavelength reflection units, and each unit is designed to enable detailed 3D reflection beamforming cooperatively by independently adjusting the magnitude or phase of the incident signal. It is a technology that can support a smart

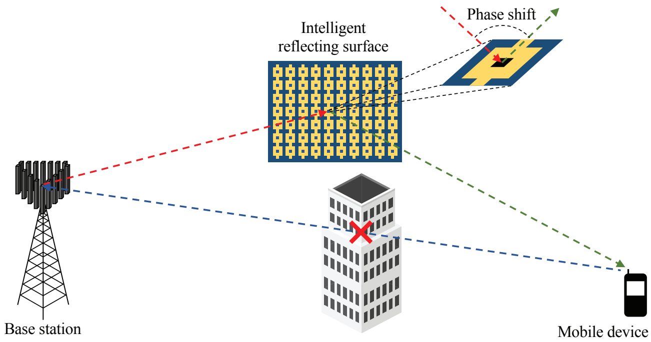

Fig. 4. Intelligent reflecting surface (IRS)-assisted communication system.

and programmable wireless communication environment by providing a new degree of freedom (DoF) through an artificial modification of the channel using controllable and intelligent signal reflection processing. By acting as a relay, the IRS can increase coverage while supporting users located in signal blind spots or at cell boundaries. IRS is developed and implemented through various methods such as mechanical actuation, functional materials, and structures using electric circuits. In addition, since IRS does not require an RF chain on the transmitting side, it can be installed densely with low power and cheaply without complicated interference management between passive IRSs [26].

The communication theoretic channel model of IRS is different from the existing channel model in that it artificially builds a good channel environment by sensing the environment [20]. For the optimization of IRS control, the establishment of a channel model and parameter measurement are required, and the study on a suitable channel estimation method for the new model is also important [27]. Research on protocols and optimization techniques for optimal IRS control, including environmental sensing and computing, is being conducted. In particular, IRS element modeling and network optimization studies on wireless networks are needed. It is also necessary to analyze and optimize the case where IRS technology is applied to MIMO and OFDM systems, which are key elements of current wireless networks [27].

3) Over The Air (OTA): OTA basically borrows a distributed structure, where a number of base stations (BSs) process data from a number of devices without a CPU, and a shorter delay time is required due to the absence of backhaul. OTA aggregates data transmitted from multiple devices by using waveform overlap characteristics in a wireless communication channel. Each device can access all radio resources through simultaneous transmission of AirComp (over-the-air computation), whereas in the existing orthogonal multiple access method only a portion of radio resources can be used, thereby obtaining high spectral efficiency wireless data aggregation (WDA) [28]. OTA is vulnerable to hacking as it has access to all radio resources, thus security research is being actively conducted.

4) New Waveform for 6G: Research on waveform design considering the advantages and disadvantages of various waveforms, such as OFDM and filter-bank multi-carrier (FBMC) is being conducted. An AI-based waveform parameter optimization method is also studied [22]. In addition, for high spectral efficiency, faster-than-Nyquist (FTN) transmission, which transmits at a higher rate than the Nyquist rate, has been studied [29]. This technique requires complex computation at the receiver for reducing inter-symbol interference; however, improved transmission efficiency can be obtained. A combination of FTN and CP-OFDM can be considered for further enhancement [29]. Recently, the study on FTN is extended to coded systems [30] and MIMO [31].

IV. 6G MAC LAYER TECHNIQUES

A. The Necessity and Characteristics

The wireless data transmission rate of the 5G communication system is approaching 1 Gbps and that of the 6G communication system is expected to reach several Gbps to several tens of Gbps thanks to the increase in frequency bandwidth using (sub-)THz [32]. This will greatly increase the total amount of radio resources that the 6G communication system can handle, and will go in a direction similar to or larger than the wired network transmission rate.

MAC scheduling is an operation for distributing radio resources, standardized in time and frequency domain, to UEs in downlink and uplink, expressed in resource blocks (RBs). MAC scheduling in 5G and LTE receives 1) policy and QoS requirements through policy and charging rules function (PCRF), and 2) higher levels of transmission data blocks through radio link control (RLC). By combining layer information and 3) channel characteristic information for each terminal received through the PHY layer, RB allocation is performed for each terminal. The widely used MAC scheduling includes 1) proportional fairness [33], 2) maximum C/I, and 3) delay-limited. Proportional fairness is a technique to balance the QoS priority and channel state of each terminal and the total amount actually transmitted. Maximum C/I allocates resources to the terminal measured/estimated to have the highest channel state for the RB, and delay-limited is a technique that provides the priority of RB allocation to a terminal that has a requirement for delay time.

While the MAC schedulers are effective, we need a new design to support new services appearing in 6G including XR, metaverse, remote reality (telepresence), and the underlying neural network service (networked inference) and user experience performance (i.e., application service performance). In particular, it is necessary to re-design the system at an innovative level in order to ensure that it always meets user requirements (service level agreement (SLA)) rather than improving application service performance.

B. Research Trends and Directions

In order to design a MAC scheduler that guarantees application service performance, it is necessary to understand the difference between it and packet level performance. The packet (or frame) level performance index is derived by measuring throughput and latency in a packet unit and averaging them. However, application service performance is measured by how quickly the service unit (e.g., video frame in video analytics application) for each application service can be delivered. The service unit delay can be understood as the sum of signal arrival delay (including propagation delay, signaling delay, processing delay, scheduling delay etc.) and service unit transmission time. In other words, to maintain the service unit delay within a certain level to ensure application performance, it is necessary to maintain the signal arrival delay within a certain level and simultaneously maintain the service unit transfer time within a certain level.

When the service unit is very small (e.g., several tens of bytes), there is no significant difference between service unit delay and packet delay, but when the size is large (e.g., multimedia data having a size of several tens of MB or more [34], or neural network input data [35]), there is a big gap between satisfying packet-level performance and maintaining application-level performance. Existing 5G URLLC-related techniques [36]–[38] mostly focus on reducing packet-level delay, meaning that they are focused primarily on the reduction of the signal arrival delay. However, by the nature, their impact to application performance would be highly limited.

In order to solve the above problem, it is necessary to implement a MAC scheduler that can keep the service unit transmission time for each application at a constant level in accordance with the application performance requirements of multiple terminals along with URLLC techniques. The MAC scheduler must 1) be able to understand the service unit emitted by the application, 2) be able to understand the channel that the service target terminal will experience in the future, and 3) transmit the service unit according to the estimated network characteristics. It should be possible to adjust the radio resource amount to keep time at a constant level in multi-timeslot units. For reference, although the so-called RAN slicing technique is expected to exert a similar effect, there is a large gap between setting the nominal resource amount at a certain level and maintaining the actual transmission amount at a certain level irrespective of the highly volatile channel environment.

To provide the above capability to the MAC scheduler, first, all frequency (f) and time (t) radio resources for a specific terminal (i.e., UE) u, denoted by $\mathrm{RB}(f,t,u)$, can be converted and predicted in units of transmission amount (b bytes). It is necessary to design a predictor $(P1)$ based on machine learning with $b(f,t,u) = P_1(\mathrm{RB}(f,t,u))$. When the output of P_1 is prepared as the transmission amount prediction map for each radio resource for each terminal, the MAC scheduler uses another machine learning (or reinforcement learning)-based predictor (P_2) to ensure service unit delay by using a terminal allocation map for each RB (this can be understood as a technique for outputting $P_2 : \mathrm{RB}(f,t) \rightarrow u$). Note that if policy requirements such as user requirements (e.g., priority according to service plan) and fairness are given, a 6G MAC scheduler should be made in such a way that it can simultaneously guarantee application service performance as well as the requirements.

In order to design and implement the above technology, various technical modules that did not exist in the 5G communication system are newly required. For instance, when converting an RB into a transmission amount, the optimization of various radio resource management (RRM) elements such as antenna, transmission power, and modulation coding scheme (MCS) must be simultaneously performed. P_1 and P_2 can be pre-trained, but in order to operate/re-learn them in real-time, a powerful real-time RAN intelligent controller (RIC) for the high-speed calculation of learning techniques must be driven at the base station (e.g., O-RAN architecture [39]). In addition, in order to run P_1 and P_2, RIC-dedicated message interfaces must be designed to collect application service-related information that can be collected from the terminals/servers, and the status information in the communication systems that can be collected from RU/DU/CU [40].

Since the above innovative MAC scheduler redesign creates many modifications in the communication systems of cellular networks, the burden may increase in terms of the installation and operation costs of the communication systems, which may need to be amortized through reshaping the network business models. However, to play the role of a communication infrastructure incubating next-generation communication/network services, the above structural redesign is crucial for 6G communication systems.

V. AI-Native Communications

A. The Necessity and Characteristics

The 6G communication system is expected to open a hyper-connected network in which various objects (sensors, automobiles, robots, drones, machines) constantly exchange data beyond existing human-to-human communication. In order to perform the mission-critical tasks that require iso-synchronous operation in the correct order, such as autonomous vehicles, smart factories, AR, VR, remote surgery, and medical treatment, it is necessary to reduce the delay time from production to consumption. In fact, in 6G, the communication requirements are much more complex and strict than in the 5G standard; for example, end-to-end latency must be guaranteed to be less than 0.1 ms, which is 10 times faster than 5G URLLC requirement [41]. When a large number of devices are connected to the network, such as in a hyper-connected network, when the CPU processes all network operations, signal overhead increases considerably and service delay time increases, making it difficult to transmit in a timely manner. This causes problems including decreases in the energy efficiency of the network. Thus, it can be expected that service delay time will be reduced by diversifying signal processing and computational subjects and through utilizing AI-based distributed learning [42]–[46].

In addition, to solve the problem of dead zones or path loss during ultra-broadband communication in the THz band, an ultra-dense network controlled by AI, AI-based ultra-massive (UM) MIMO system, and AI-controlled IRS technologies are currently being studied. In combination with artificial intelligence, transmission overhead can be reduced, resources can be used efficiently, and the error rate can be lowered, while delay time can be greatly reduced, as illustrated in Fig. 5.

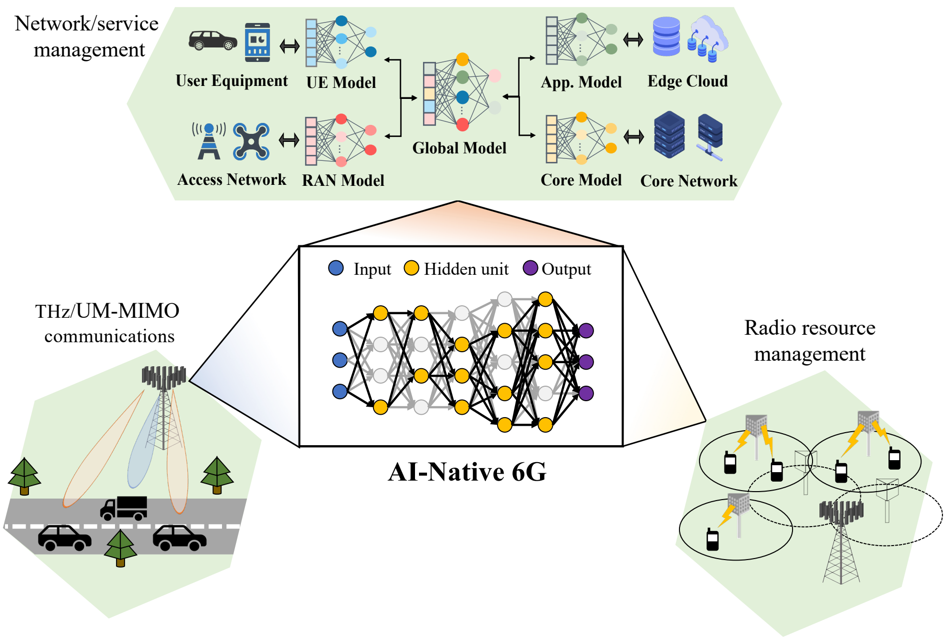

Fig. 5. An illustration of AI-native 6G.

B. Research Trends and Directions

Recently, studies using AI technology in the transmission/reception process of the physical layer are being actively conducted (e.g., channel estimation, channel coding/decoding, resource allocation). In the case of the current 4G LTE and 5G NR systems, it is very difficult to secure learning data and also apply them with a small modification.

6G communication aims to build a hyper-connected network scenario where numerous objects (e.g., sensors, cars, robots, drones, machines) can exchange information with each other. When the existing central unit processes information generated from all things alone, signal overhead is very high, and it is also inefficient in terms of energy efficiency of the network. At this time, by using the multi-agent deep reinforcement learning, the signal processing and computational subjects are distributed, lowering the signal overhead that each agent has to process. It will be possible to implement an AI-based hyper-connected network by making it learn with the goal of improving overall network efficiency.

In addition, 6G communication goes one step further from 5G NR in terms of high frequency band use, aiming for THz band communication. Due to the significant path loss and strong directivity in THz communications, the straight path between the base station and the terminal in the middle of a city center with high-rise buildings or in a long tunnel makes it difficult to secure LoS (coverage hole).

As a result, research on a UAV-based network and IRS based on AI that enables a path between the base station and a secure terminal is being actively conducted. For the realization of IRS-based UAV networks, further research should be conducted on specific techniques such as UAV route optimization and resource allocation, IRS channel estimation and phase shift optimization, as well as efficient information exchange between base stations, UAVs, IRSs, and terminals.

VI. AI-NATIVE NETWORKING

A. The Necessity and Characteristics

1) AI for Network (AI4Net): Technologies such as network slicing, edge computing, specialized network, and network virtualization are being applied to support vertical service, a central keyword for 5G, and the types of supported services are also developing in a very diverse form. As a result, the complexity of networks managed by telecommunication service providers is increasing exponentially, and the need for automation techniques to solve this problem is emerging.

Although there has been a continuous demand for automatic network management in the past, as described above, the complexity of the network to be managed is increasing exponentially as the network evolves; thus, a more scalable automatic network management technique is required. In addition, in order to effectively reflect the complex and variable network services, traffic, and user patterns, it is essential to automatically manage networks using data-based AI learning models rather than traditional statistical numerical models or rule-based techniques [47].

2) Network for AI (Net4AI): With the surge in interest in AI technologies, various learning algorithms/models have been proposed recently. In the case of distributed learning/federated learning, the load on the network is considerable because the model or parameters must be frequently passed through the network. However, the current network has been designed to be independent of such AI model/parameter transmissions, and mostly follows the traditional network protocol structure and processing method. Therefore, there are many cases where the network acts as a bottleneck when learning the overall AI model.

In the case of an existing network node, the application data has been optimized for packet deliver in an independent form. In addition, it is impossible for traditional network equipments to adaptively operate based on the application data, etc. because only functions defined/implemented by the equipment maker in advance were processed. However, in the case of a programmable switch and smart NIC, applied in a data center environment, it has the ability to handle various functions besides packet forwarding/processing through software programming. Therefore, the concept of an in-network computing, in which network nodes directly process the learning model and parameter processing that occur in distributed/federated learning using a programmable network device is being currently discussed [48].

B. Research Trends and Directions

1) AI4Net: 3GPP defines the network data analytics function (NWDAF) for network data analysis as a 5G core network component, defining the basic framework for collecting and analyzing data on the network [49]. Currently, standardization work for additional function definition and advancement related to NWDAF is in progress. In 5G, the work on a single NWDAF is focused, but with the advent of new learning models, such as distributed/federated learning, research on the distributed NWDAF structure is expected to proceed in the future. In addition, it is expected that research on the self-driving network technology to autonomously optimize and operate various types of NFs existing in the core mobile network will be conducted.

In addition, the Open RAN (O-RAN) environment, based on an open interface, has become more advanced, with the components of radio unit (RU), distributed unit (DU), centralized unit (CU), and RAN intelligent controller (RIC). Research is expected to proceed actively on the structure and algorithm design to build the microservice-based and intelligent control plane and accelerated data plane in edge cloud environments, and autonomously operate/optimize it [39]. A study on how to derive a network improvement plan based on the data collected in RAN/core network environments, even in the end-to-end network management framework which integrates the mobile core network and RAN, and autonomously optimize it in a form with minimal administrator intervention is required. Moreover, research on the autonomous optimization of the network based on intent that can describe and manage all these processes through high-level intent is expected [50].

2) Net4AI: In the case of P4, a higher-level programming language allows you to add desired functionality to a programmable network device. Through this, basic research is being conducted on how to use it for parameters in distributed learning or data aggregation in distributed data processing [51]. To this end, it is necessary to propose a new structure of programmable switch or study a data structure and algorithm that more effectively aggregates parameters or data on a given switch structure. In particular, a method to reduce the distributed learning data load in terms of the entire network rather than individual switches is required.

Meanwhile, it has been experimentally proven that a binarized neural network can be implemented in a programmable network device. For use in 6G, ways to accommodate more advanced learning models by improving the switch structure and designing neural network algorithms applicable to hardware are expected. Through this, the vision of in-network computing that can reduce end-to-end latency by performing various computing operations inside the network can be realized. As mentioned earlier, the current network follows the traditional 3GPP and TCP/IP protocol models. However, if the aforementioned programmable devices become common in the future, it is expected that the design of the network structure in consideration of such factors, and the design of a new protocol model accordingly, will also be required. In addition, research on split computing, a generalized/advanced form of edge computing, is needed to support advanced AI models, considering communication/computing capabilities in an in-network computing-based network structure.

VII. Localization and Sensing in 6G

A. The Necessity and Characteristics

In 5G networks, we are experiencing improved performance on localization due to the large signal bandwidth, highly direction signal transmission, massive connectivity, and machine learning capability, and wireless localization is expected to further advance as an important sensing tool for our life as we move on towards 6G communications [52]. As the wireless communication continues developing and improving, it will become essential to have external sensing assistance to maintain the communication quality under highly mobile and mass connectivity of the networks, which is now considered to be situational awareness in wireless communication.

Towards this end, the localization and sensing in 6G is needed to provide a useful situational information about where the transmitter and receivers are, and what the channel in between look like. Recently, various research topics have appeared to enable such functionality. These include IRS, mmWave [53] and THz communication, device to device communication, radio simultaneous localization and sensing (SLAM), machine learning (ML)-based localization and sensing. Improved computing power allows us to exploit multipath in understanding surroundings, and high timing and direction resolution will provide us an enhanced localization and sensing results which will be again useful for transmission management. Specific research trends and directions are given as follows:

B. Research Trends and Directions

1) Intelligent Localization and Sensing with Advanced Signal Processing and AI: Intelligent localization and sensing is one of the important research direction for 6G. IRS, which is now being considered to overcome path attenuation and weak diffraction characteristics for mmWave and THz signals, is also a useful tool for localization and sensing. IRS that uses low-cost meta-surface devices to adjust propagation characteristics, such as phase, amplitude, frequency, and polarization has recently been used for precision positioning and mmWave/THz communication [54].

Positioning technology based on machine learning estimates the location of indoor and outdoor users through regression and classification. The use of machine learning in 6G systems is expected to provide new opportunities for THz band positioning and sensing technologies as well as wireless communication [55].

2) Joint Radar and Communication: Passive sensing refers to a technology that detects the state of an object by receiving a signal reflected from a stationary or moving object and processing it. This is a principle similar to that of bi-static radar (RADAR), and in some cases, a peripheral AP such as mobile communication or Wi-Fi may be utilized. In general, passive sensing uses a fixed transmission signal source to detect nearby objects with low mobility [56].

An active sensing system transmits a wideband signal to the surroundings and receives a signal reflected from a surrounding object. Through dynamic sensing, the distance to an object and the movement speed of the object can be estimated, and the angle of arrival of a signal can also be estimated when an array element is used. Recently, although cognitive radio technology and beamforming used in dynamic sensing are being studied for mobile communication, the commercialization of mmWave/THz bands is essential because the bandwidth used for mobile communication is insufficient at present [57].

3) Radio Simultaneous Localization and Mapping: SLAM technology refers to a technique that estimates the location of a mobile user and simultaneously locate objects (also referred to landmark) in the wireless environment [58]. Radio SLAM technology using 6G signal exploits not only LoS signals received by users, but also non-LoS signals due to landmarks in the channel. As the signal frequency goes up beyond mmWave and THz, the propagation characteristic become more and more directive and reflective similar to the light. Due to this, it is expected that many of vision-based techniques can be used for radio SLAM, and this will be an important research direction for 6G sensing and localization.

4) Context-Aware and Privacy-Preserving Localization: Context-awareness technology can intelligently assist localization by understanding the context and characteristics between transmitter and receiver, thereby improving the effectiveness of localization and sensing. Especially for transportation and autonomous driving, proactive estimation of their location is essential and beneficial with the context information which are different for different objects. Contextual awareness also enables multi-model localization, where mobile devices can transform communication technologies between different channels depending on their current location and context.

Personal privacy is also becoming more and more important and people do not want to release their personal information to networks. When massive amount of dataset is needed for machine learning and localization, the system may rely on the personal data collection which might lead to the leak of personal private location information. To avoid this, federated learning techniques can be considered where the actual private data is not shared in the network, but still achieves an efficient collection of information and network training. In this COVID-19 situation, such privacy preserving localization techniques are also getting attentions, and will become important in 6G localization and sensing as well.

VIII. NON-TERRESTRIAL NETWORK (NTN)

A. The Necessity and Characteristics

6G networks should seamlessly integrate space networks with terrestrial networks. This is defined as hyper-connection and is changing the existing connectivity paradigm based on 3 dimensional heterogeneous networks [59].

In Rel.14 specification of 3GPP, a total of 15 deployment scenarios were defined by adding three new deployment scenarios, such as "air-to-ground," "light aircraft," and "satellite to terrestrial" from the existing nine deployment scenarios. In Rel.15, the channel model for applying new radio (NR), segmentation of deployment scenarios, and requirements for NR application are defined. In Rel.16, the analysis results for L2 and L3 and the RAN structure are also discussed [60], [61]. In addition, competition in the space industry is intensifying. In the United States, an existing space power, space-related companies such as SpaceX periodically launch swarming small satellites to support satellite internet services [62].

The main characteristics of an NTN are as follows: 1) It has wide service coverage capabilities and reduced vulnerability of space/airborne vehicles to physical attacks and natural disasters; 2) it is expected to foster the roll-out of service in un-served areas that cannot be covered by terrestrial 5G network (isolated/remote areas, onboard aircraft or vessels) and underserved areas (e.g., suburban/rural areas) to upgrade the performance of limited terrestrial networks in cost-effective manner; 3) it is also expected to reinforce the service reliability by providing service continuity for M2M/IoT devices or for passengers onboard moving platforms (e.g., passenger vehicles-aircraft, ships, high-speed trains, bus) or ensuring service availability anywhere, especially for critical communications, future railway/maritime/ aeronautical communications; 4) flexible network scalability can be guaranteed by providing efficient multicast/broadcast resources for service delivery towards the network edges or even user terminal [63], [64].

B. Research Trends and Directions

1) Network Structure: In 3GPP, the Rel.16 TR 38.821 document discussed the RAN structure and deployment issues for NTN nodes (satellites, unmanned aerial vehicles), including discussions about compatibility with terrestrial networks. This network is defined as a space-terrestrial integrated network (STIN). At this stage, only single-satellite and satellite-terrestrial networks are yet defined, and inter-satellite communication is not yet standardized. It is necessary to establish an evolutionary network model that reflects this, and a network technology suitable for each evolutionary stage by applying the concepts of limited-STIN, heterogeneous STIN, and hypercubic-STIN, which includes a small number of low-orbit satellites. Moreover, methods for applying optical communication and mmWave in inter-satellite links are being studied [65].

2) Frequency Problem: The bands used by the satellites are representative of the C band (approximately 12-18 GHz) and the Ka band (approximately 27-40 GHz); however, as 5G is deployed, it causes interference to existing satellite services. Therefore, it is necessary to develop a technology allowing use of the same frequency for both networks and a technology for using a different frequency domain. In the former case, a method of applying the CR technology is being studied, which can strengthen the network's capacity and reduce the frequency license cost. In the latter case, a method to apply the new Q/V band (40-50 GHz) to the satellite network is being studied, which can provide a wide bandwidth and thus can be applied to the operation of high throughput satellites (HTS). Currently, foreign satellite-related companies are waiting for FCC certification to use the band [66], [67].

3) Design Details for Each Communication Layer: In terms of the design of each communication layer, there is an application problem in the physical layer for IRS technology that can be dynamically reconfigured based on an adaptive LoS MIMO antenna array, solving the high Doppler problem and the high round trip time problem. Not only is this being discussed, but also a new modulation technique, flexible OFDM, and GFDM-based candidates are being discussed. Efforts are being made to satisfy the QoS of various services through these technologies [67].

In the upper layer, technologies for overcoming mobility are being developed, and currently 5G standardized technology conditional handover and dual active protocol stack (DAPS) handover technologies are being discussed. As for conditional handover research, various methods such as location-based information, time-series-based, and timing-advanced technology are being studied in addition to the existing measurement-based triggering method. In addition, discussions and studies on the application of Software-defined network (SDN)/network function virtualization (NFV) technology are in progress in "Sat5G" with 5 research pillars; 1) implementing 5G SDN and NFV in Satcom, 2) Integrated Sat5G network management and orchestration, 3) Multi-link and heterogeneous transport, 4) Common 5G-Satcom control plane/user plane functions à 5G Security extensions to Satcom, 5) Caching and multicast for content/VNF distribution to the edge over Satcom. Finally, it is a very important issue to harmonize satellite service providers (SNOs) and telecommunication operators (MNOs) for the success of NTN services, unlike in the past [68].

IX. Concluding Remarks: KICS 6GRI R&D Strategy

The 6G era is expected to be a hyper-collaboration society. It is expected that various services will converge, and for this purpose, various research findings will converge to open up a new world. To make a good preparation for 6G, multidisciplinary research is needed, and the KICS will play a leading role in establishing a platform for active exchange and connection in all fields of service, technology, and policy for this purpose and in pioneering the foundation for 6G. KICS 6GRI aims to provide a platform to expand and integrate emerging software and computing technologies as well as future wireless communication and network technologies that can be used for 6G. In the deployment of the 6G network, it is expected that software-based network architecture using software-defined radio/infrastructure will be widely employed. The KICS is fully aware of this and will be able to gather research capabilities in this field. Finally, in terms of the role of society in 6G, joint research of industry, universities, research institutes must be implemented, and hyper-collaborative research in which industry, universities, and related institutions can cooperate organically by linking society and government policies will be carried out.

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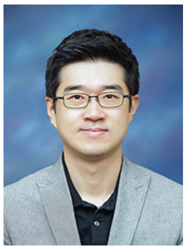

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