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Campus-Based Test-Bed Implementation of 5G+ Networks at the 28 GHz Band: Challenges and Opportunities

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ABSTRACT

The study provides an experimental setup, interconnection sites, and indoor-outdoor cases to reflect the results of a 5G+ millimeter wave (mmWave) network operating from 3.5 to 28 GHz implemented as a campus test-bed case at the Kumoh National Institute of Technology, Gumi, Korea. Moreover, the applications of the 5G+ campus test-bed case are discussed, such as learning management, augmented reality/virtual reality (AR/VR) video streaming, cloud platforms for smart factories, and project-based learning. This study aimed to perform operations at 5G+ frequencies, that is, in the frequency range 1 (FR1) comprising frequency bands < 6 GHz, and at frequency band 2 (FR2) comprising bands in the mmWave range (24-100 GHz), thus making the mmWave range especially suitable for 5G Ultra Wideband operations. The operated channel frequency band used ranges between 3.5 to 28 GHz with channel bandwidths of 100, 200, and 400 MHz. This study establishes a basis for allowing different future operators within South Korea to adopt and employ the concept of infrastructure sharing for a particular indoor scenario. Furthermore, it discusses the research challenges and open issues for future development and collaboration.

Key Words : Frequency range, 5G+, learning management, millimeter wave, test-bed.

Ⅰ. Introduction

The 5th generation (5G) network is currently used worldwide, serving mobile users with upgraded services with respect to preceding cellular network generations. 5G networks will aid in capitalizing on and enhancing the distinctive features of current-generation mobile cellular networks. Some of these vital features are the latency, bandwidth, speed, and energy dissipation. Instead, the major innovation of 5G is the blending of several networks used in different sectors, specialties, and applications, such as multimedia, smart cities, machine-to-machine, Internet of Things (IoT), virtual reality (VR) / augmented reality (AR), and automation[1,2].

Future wireless communication networks will include distributed intelligent communication, sensing, and computing platforms. Ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB) are the three prime usage profiles required to establish 5G as a next-generation network[3], as shown in Fig. 1. Currently, the growth of rare applications and services, such as driverless vehicles and drone-based deliveries, remote medical examinations and operations, artificial intelligence -based personalized assistants, smart cities and factories are being witnessed, and communication tools connected with these rare applications and services, are different from typical human-centric communications in terms of latency, reliability, versatility, connection density, and energy

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effectiveness. Consequently, the concurrence of human-centric and machine-type services with their composites increases the diversity and complexity of wireless settings. The International Telecommunications Union (ITU) classifies 5G services into three categories: mMTC, URLLC, and eMBB[1].

Considering these unique service classes, several performance demands have been presented, including lower latency, higher reliability, massive connectivity, and enhanced energy efficiency. The 3rd Generation Partnership Project (3GPP) launched a new air interface attributed to New Radio (NR) because the contemporary radio access mechanism is unable to maintain these implacable developments[4]. The principal aim of NR is to produce completely distinct characteristics and technologies that do not significantly backfit contemporary 4G long-term evolution (LTE) operations. Recently, meetings for 5G NR standardization have been engaged in standardizing the initial release in 2020[5,6]. Comparable to past experiences, the mobile communications industry announced 3G technology as UMTS, 4G technology as LTE, 5G technologies, and beyond as NR. The 5G NR employs two frequency spans: frequency range 1 (FR1), which covers frequency bands < 6 GHz, and frequency band 2 (FR2), which covers bands in the millimeter wave (mmWave) range (24-100 GHz), thus making the mmWave range particularly useful for enabling 5G Ultra Widebands. 5G NR enables the network to sustain an adaptive bandwidth. The fundamental benefits of 5G NR include added capacity for wireless users, enhanced connections among users, and enhanced data rate speed[7].

mmWave communication has emerged as a fundamental technology in 5G wireless systems owing to its ability to achieve the massive throughput required by future networks. mmWave communication is a physical layer technology that has recently been shown to be a leading research interest. Soon, mmWave communication will be able to satisfy high-rate mobile broadband services and reduce over-the-air latency for NR challenges[8]. In particular, mmWave has become the fundamental focus of the 3GPP NR1 trial. mmWave communication technology utilizes 6 GHz), which are acknowledged for 3GPP NR[9,10].

Small cells (SCs) are an emerging technology operating at mmWave frequencies. By decreasing the size of the cell, the area spectral efficiency is enhanced through higher-frequency reuse, while the transmit power can be decreased such that the power lost during propagation is lower. Additionally, improved coverage is obtained by deploying SC indoors, where acquisition may not be desirable, and offloading traffic from macrocells when required. This solution has become possible with advances in

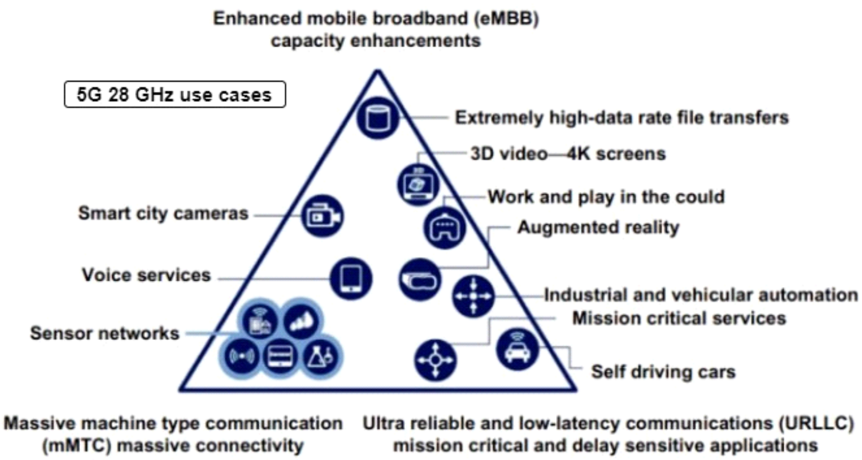


Fig. 1. 5G 28 GHz usage cases reflecting three primary usage cases, i.e., eMBB, mMTC, and URLLC.

hardware miniaturization and corresponding cost reductions[11]. SC technology is the most efficient solution used to achieve ubiquitous 5G and 5G beyond services in an energy-efficient fashion for its users. A low-powered cellular radio accesses the SC nodes, and the SC operates in unlicensed and licensed spectra, which range from 10 m to a few kilometers [12,13]. The New Federal Communications Commission (FCC) regulations provide size and elevation guidelines to assist in the clear definition of SC equipment. Compared with macrocells, SCs are small owing to their lower range and capability of handling fewer concurrent sessions or calls. SC may comprise femtocells, picocells, and microcells and has a small radio footprint ranging from 10 m within urban and in-building locations to 2 km in rural[14].

Concurrently, several 5G test beds and trial networks are commissioned to facilitate the industry to leverage the upgraded capabilities of the new networks, thus exceeding a "faster version of 4G." A notable example is Horizon 2020, Europe's primary research and innovation program. This program supports the advancement, development, and roll-out of 5G networks by establishing consortia made up of small-medium enterprises, vendors, operators, and academic institutions. The Horizon 2020 program was supervised by the 5G Infrastructure Public Private Partnership (5G PPP). The system takes advantage of a range of funding requests (such as ICT calls) intended to seek distinct features of 5G, including the development of a chain of interconnected 5G testbeds throughout Europe. The testbed plan is to confirm that i) the fundamental 5G PPP network key performance indicators (KPIs) can be met and ii) verified, accessed, and utilized by vertical industries to establish examination trials of innovative use cases.

In this study, a 5G+ mmWave campus testbed case evaluation that was not limited to a single frequency range was investigated. The frequencies used in the test-bed case were 3.5 GHz and 28 GHz, and the LG Uplus corporation device was used [15]. Moreover, this study presents applications of the 5G+ testbed, such as learning management and AR/VR video streaming, Google Cloud platforms for smart factories, and project-based learning. This work is an attempt at 5G+ mmWave testbed implementation along with the integration of a particular technology for different educational and industrial applications. Furthermore, the discussion of challenges and open issues to provide opportunities for future development and collaboration are the key points of this study.

The remainder of the paper is organized as follows. Section II details related work at different frequencies in 5G networks. This section also encompasses the frequency range differences and attempts made by different companies, such as AT&T and Qualcomm, 5G projects, and 5G testbed federations. Section III details the contributions of the present work, wherein the experimental setup and test trials are discussed and illustrated graphically. Section IV details the application of 5G+ mmWave on the campus testbed at our center for different cases. Section V discusses the research challenges of 5G and 5G+ technologies. Finally, Section VI concludes the paper.

Ⅱ. Related Works

This section presents related 5G projects and 5G federation test beds. This section highlights the main difference between FR1 and FR2, and the work performed for 5G and 5G+ by AT&T and other companies. In specific, the focus is placed on those that perform one or multiple 5G network purposes and related work conducted while different frequency spans were chosen.

2.1 Fundamental Differences Between FR1 and FR2

The most important issue is to recognize the fundamental differences within the application and advantages of the 3.5 and 28 GHz spectra. The 5G network has the potential to sustain considerable accelerations in mobile broadband speeds and allow the full potential of IoT and IIoT applications. Nevertheless, for 5G to attain its full potential, mobile operators rely on the acquisition of extensively homogenized spectra across three frequency ranges: < 1 GHz, 1-6 GHz, and > 6 GHz. The 3.5 GHz mid-brand spectrum has a pivotal role in producing 5G mainstream and has already been licensed in numerous countries. Conversely, the 28 GHz frequency band was made available by the FCC via re-allocation of the Local Multipoint Distribution Service, which comprises a block subband channel, A1 (utilizing 850 MHz of the allocated spectrum between 27.50-28.35 GHz).

The 28 GHz and other mmWave frequency bands, such as 24 and 37/39 GHz, will play a key role in 5G deployments under the new Upper Microwave Flexible Use License (UMFUS) designation. The UMFUS bands are 3GPP standardized under the 5G New Radio (NR) guidelinesundertheFR2umbrella, whichincludesmmWavefrequencies[16]. The inverse relationship of the frequency with wavelength results in larger coverage at 3.5 GHz i.e., approximately 1-10 km, while for 38 GHz, it is reported to be within the range of 100 to 200 m[17].

2.2 5G Projects and 5G Federation as Trails

The 5G EVE is a 5G PPP stage-3 foundation scheme directed at the construction of a European 5G validation platform for comprehensive tests. One of the principal goals of 5G EVE is to offer an open and completely functional 5G end-to-end foundation that is adaptable enough to perform a plethora of trials for various upright industries, shared among various sites. For example, the work displays the design and outcomes of the first 5G end-to-end test stationed on the 5G EVE foundation. Specifically, in the 5G EVE design, all the actions required to design and perform a simplistic experiment are presented[18].

Three projects were funded by H2020 ICT-17-2018, namely 5G-EVE, 5GENESIS, and 5G-VINNI[19,20]. The three platforms that these projects have developed enable several vertical use cases from dedicated 5G vertical industry projects for demonstration and validation. The platforms are also open to other 5G trials from industry and academic institutions to conduct research on emerging 5G ideas, proving concepts, validating standards, and vendor interoperability testing. An open-source platform that is adaptive and flexible for 5G implementation, called OpenAirInterface, has also been presented. This interface is dependent on software-defined radio and general-purpose processors[21].

Similarly, another test was performed by focusing on the radio propagation characteristics, penetration loss, and outdoor and indoor coverages in a typical Hong Kong environment. In the field trial, 3.5 GHz and 28 GHz cells were set up in the Central and Shatin areas[22]. Moreover, a 5G EVE European project intended to interconnect multiple sites to produce a single 5G end-to-end facility was also executed. A comprehensive architecture of the French test bed which comprised four nodes in diverse locations at

Table 1. Summary of the European projects and their main cases.

Test-bed	Description	eMBB	URLLC	mMTC
ONE5G [23]	E2E-aware optimization and progress for 5G NR edge network. Activities related to factories of the future, enhanced network management, smart cities, and automobile use cases.	X	X	X
5G-Transformer [24]	Supports the need of various vertical industries such as eHealth, automotive, cloud robotics or media etc.	X	X	X
ORCA [25]	Real-time SDR platforms for advanced wireless research		X	
5GCity [26]	Develop a distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G-hosts. Extend the cloud to the Edge.		X	
5GCar [27]	Develop a 5G radio and architecture design that provides very low latency, with very high reliability, at very high vehicle velocities		X	
Fedfire+ [28]	Federating test-beds for 5G, IoT, cloud big data and networking research	X	X	X
5TONIC [29]	Platform for secure exchange of inter-site control and data-plane information,	X	X	X

various sites of the project was also presented[6]. Some of the 5G projects and 5G federation test-beds, such as ONE5G,

5G-Transformer, ORCAm 5GCity, 5GCar, Fed4fire+, and 5TONIC, accompanied by software and hardware practices, are listed in Table 1.

2.3 AT&T and Qualcomm Attempt to Establish 5G+ Networks

AT&T is increasing the availability of its 5G network while also commencing to make its 5G+ network open to customers. At the same time, AT&T also declared that its 5G+ network is going live for consumers in some regions of 35 cities in the United States. 5G+ is closer to people' s expectations of 5G owing to the advantages of its mmWave features. Unlike the low-band spectrum, mmWave is able to achieve notably faster speeds for users. Nevertheless, it is hindered by distance, and it does not perform well when objects exist in the transmission paths. With the appropriate phones, users will be capable of benefiting from the network, and the device signal communication will be capable to bounce within the low- and mmWave bands when and if required[30]. A unique low-latency packet transmission system called ultraminislot transmission fitting for the short packet transmission in the URLL, that is, 5G+ and 6G scenarios was also presented[31]. Recently, Qualcomm declared a successful data call using 5G mmWave in conjunction with acquisitions at frequencies < 6 GHz to establish best practices associated with diverse spectrum assets[32]. Extensive results were presented for rural, suburban, and urban measurement campaigns using apre-standard 5G prototype test bed operating at 3.5 GHz, with outdoor as well as outdoor-indoor scenarios. Path-loss models were evaluated based on the measured results, which are essential for network planning[17].

2.4 Background Research Attempts for Different Frequency Ranges for 5G

Researchers have ascertained their interest in the frequency spectra of 28, 38, 60, and 73 GHz for applications in 5G operations[34,35]. An effort was made to examine the potential efficiency of 28 and 38 GHz mmWave frequency bands and distributed propagation channel characteristics for the 5G network, and the close-in and alpha-beta-gamma propagation path loss models were recognized for their evaluations, such as spectral efficiency, throughput at the cell edge users, mean cell throughput and fairness index. The results show that the 38 GHz frequency band leads to high-throughput performance compared with the 28 GHz frequency band[36].

The propagation channel properties at mmWave frequencies, that is, 25 to 40 GHz, were analyzed based on the considerations of the intra-wagon condition. The results showed a delay spread and path losses at the frequencies of 26, 38, and 38 GHz, thus resulting in information path losses and time distribution features in a specific environment[37]. Similarly, channel evaluations have been attempted[22]. The work presented in [22] is a 2 × 2 mmWave train-to-infrastructure case operating at 60 GHz input-multiple-output (MIMO) testbed which operates at approximately 30 GHz.

Moreover, the work in [33] provides four 5G mmWave deployment examples and details in sequential order for situations and use cases of their likely deployment, including anticipated system architectures and hardware models. The study begins with a 28 GHz outdoor backhauling for fixed wireless access and mobile hot spots, which will be displayed at the PyeongChang Winter Olympic Games. The next deployment case is at the Tokyo-Narita airport operating at 60 GHz pertaining to an indoor unlicensed access system that integrates mobile edge computing (MEC)to facilitate ultra-high-speed content downloads, including low latency. The third case is the mesh network of mmWave intended to be utilized as a micro radio access network for effective cost-back hauling of SC base stations (BSs) in compact urban situations. The final case is the mmWavebased vehicular-to-vehicular and vehicular-to-everything communication systems that facilitate automatic driving by transferring high-definition dynamic map data within cars and roadside units.

Fig. 2 depicts the four scenarios associated with

(a) (b) (c) (d)

Fig. 2. 5G mmWave deployment cases, where (a) PoC in PyeongChang Olympic games on backhaul to moving hot-spots to be demonstrated at IoT street in South Korea, (b) Experimental demonstration at Narita international airport, (c) mmWave mesh node to provide three different back-haul links exhibited in MWC2017, and (d) mmWave based V2V/V2X to exchange HD maps[33].

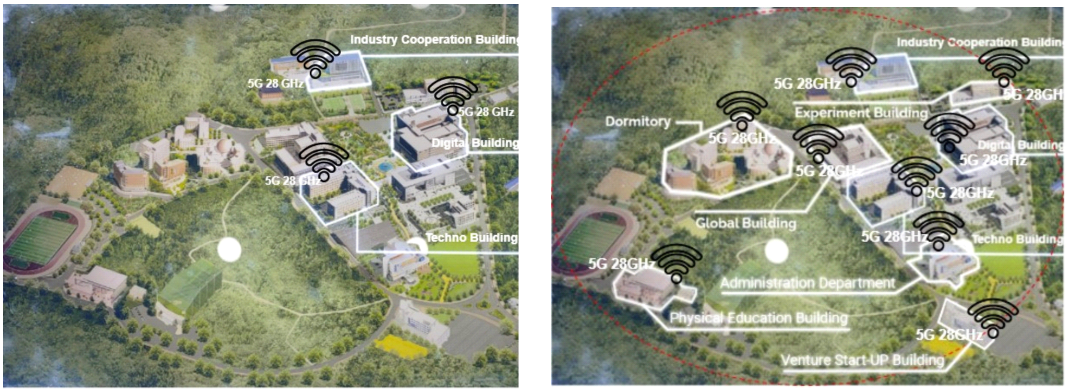
5G mmWave deployment in real-time for respective usage cases, and some results from a 28 GHz channel sounding process were used to investigate the impacts of indoor-tooutdoor penetration on wireless propagation channel characteristics recognizing an urban microcell in a fixed wireless access condition[38]. In addition, contemporary results and progressions of mmWave mobile communication for the Giga Korea 5G project are also presented. To determine the wireless channel characteristics in a mobile communication situation, the ray-tracing simulation outcomes are illustrated[39,40].

Ⅲ. Contribution of Proposed Work

This section provides in-depth details of the measurement campaign, measurement procedure, and set up which were conducted for the particular 5G+ in the 28 GHz mmWave case.

3.1 Environment for the Experimentation

In this section, a detailed implementation phase of 5G+ is presented as executed at the Kumoh National Institute of Technology (KIT), South Korea, shown in Fig. 3. This is the first real-time implementation of a 5G+ case in which the 28 GHz mmWave frequency has been implemented. Thus, for the strategy to implement a stable 5G+ at 28 GHz, an industrial cooperation building was selected where the test bed was installed and operated. LG Uplus Corporation, a major South Korean telecom operator, installed 5G network infrastructure at KIT, allowing the carrier to test mmWave 5G in certain areas of the campus. In the initial phase of case 1, the campus test bed was operated and installed only in three buildings and was later expanded to all campuses which covered all the buildings within the KIT as in



(a) (b)

Fig. 3. 5G+ at 28GHz mmWave demonstration venues at KIT, where (a) testing within three venues of campus as case 1 (b) testing within all campuses as case 2.

case 2. Both cases are shown in Fig. 3. For the particular implementation conducted at KIT, the operated channel frequency band ranged from 27.3 GHz to 29.5 GHz with the frequency bandwidths occupied per channel set at 100 MHz, 200 MHz, and 400 MHz.

3.2 Measurement Procedures and Setup

Table 2 lists the equipment used for 5G+ operations at 28 GHz at KIT. As shown in Fig. 4(a), a radio-base station with a license number 32-2020-61-0017830, and an LGU+ with an assessment number R-C-SEC-AAT1K1 A00 (AT1 KO1-A00), were installed at the industrial building cooperation building at KIT as an access point. The power of the antenna and gain were 3.162 W (34.9 dBm) and 28 dBi, respectively, while the radio-type communications were 100MG7W and 100MMOD7W. The 5G+ test bed case was implemented using a frequency that ranged from 27.3 to 28.1 GHz in the 800 MHz bandwidth. For the downlink and uplink, the maximum transmission speeds were approximately 5 and 1 Gbps, respectively. Fig. 4(b) also shows that our center attempts to make 5G+ the innovation center at KIT.

Anritsu introduced the field master proTM MS2090A handheld spectrum analyzer, as shown in Fig. 5. With continuous frequency coverage from 9 kHz to 54 GHz, the Field Master Pro MS2090A was specifically designed to meet the test challenges of the full range of other wireless technologies in use today, including, 5G, LTE, wireless back-haul, aerospace/defense, satellite systems, and radar. The Field Master Pro MS2090A delivers the highest levels of RF performance available in a handheld, touch-screen spectrum analyzer, with a displayed average noise level (DANL) of -164 dBm and a third-order intercept (TOI) of +20 dBm (typical).

Table 2. Detail of the implementation with hardware and future goals for devices.

	Equipment	Equipment used	2020	2021	Details
Equipment installed	Terminal	Smartphone	50	50	Support 28GHz
		Laptop	50	50	Business laptop
		5G router	30		Connection of the business laptops with the school network
	Access equipment	28 GHz Nokia base station	3		28 GHz wireless signal base station
				150	28 GHz micro-in build station
	Core equipment	Samsung SPGW	1		Division of school internet network and network of common subscribers
			1		Decrease data transmission time and service data in a location adjacent to the users

(a) (b)

Fig. 4. 5G+ mmWave deployment case at our center, where (a) depiction of the radio base station as an access point, (b) depiction of 5G the innovation center at KIT.

Fig. 5. Anritsu field master proTM MS2090A handheld spectrum analyzer[41].

Some of the key features of the Anritsu spectrum analyzer are listed in Table 3. This makes measurements, such as spectrum clearing, radio alignment, harmonics, and distortion even more accurate than previously possible. For modulation measurements on digital systems, 100 MHz modulation bandwidth coupled with best-in-class phase noise performance maximizes measurement precision, while typical amplitude accuracy of 0.5 dB provides confidence when testing transmitter power[36]. Table 4 lists the parameters used during the experiment for 5G+ at KIT.

The technical implementation and application of the testbed at the KIT center are shown in Fig. 6. The setup comprises a system-level design of the experiment of 5G at the 28 GHz radio station as an over-the-air (OTA) inspection protection. For wireless

Table 3. Key features of Anritsu field master proTM MS2090A handheld spectrum analyzer

Features	Specifications
Display	10.1 inch, 1280 × 800 color touchscreen
Traces	6
Detectors	Peak, RMS/Avg., Negative
Battery life	>2 hours
Interfaces	USB 3.0
GNSS	GPS, GLONASS
IQ	Capture and streaming of IQ data

Table 4. Experimental parameters used for the 5G+ test.

Parameters	Configurations
Operating frequency	DL and UL: 27.3 - 28.1GHz
Bandwidth	800MHz
Resource blocks	528
Antenna type	Planar antenna of 8 × 6
Max transmit power	37 dBm
Max antenna gain	27 dBi
No. of RF paths	16

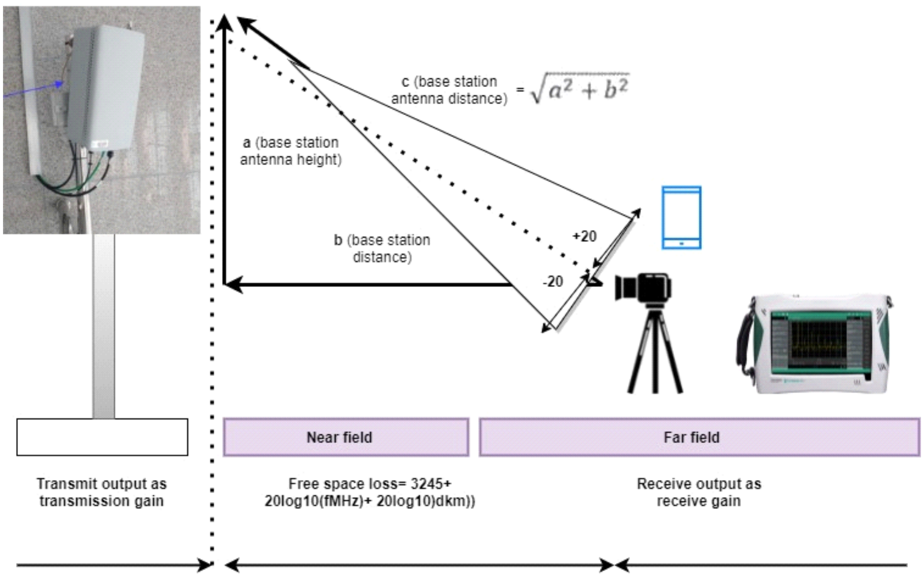


Fig. 6. Test Environment for Over the air (OTA) Frequency Range 28.1GHz - 28.9GHz Measurement

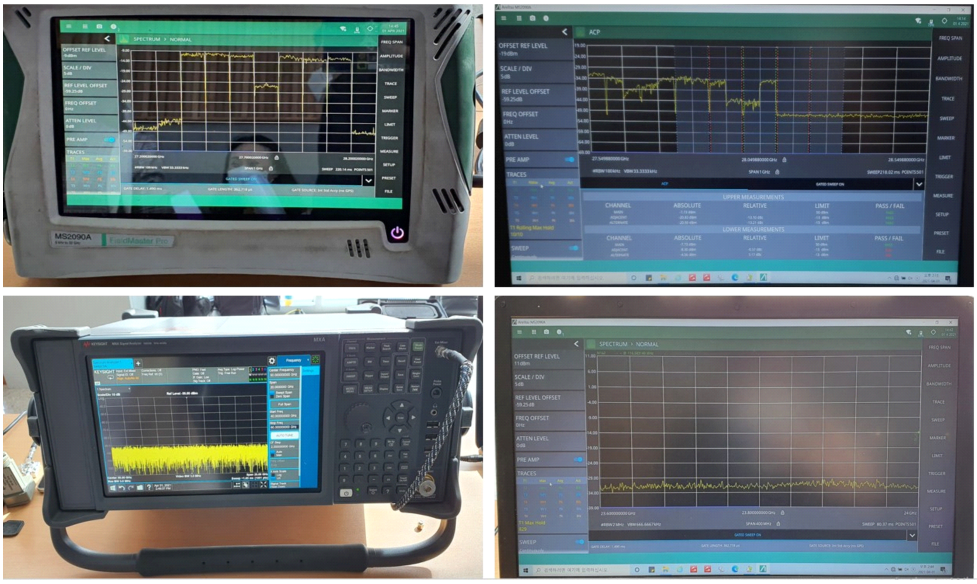


Fig. 7. Some of the results obtained while performing 5G+ test-bed scenario at 28GHz mmWave.

equipment for telecommunications business, the national radio agency notice No. 2021.02 is adhered to. The time-division duplex method is employed as the technical standard for wireless applications in mobile communications. The orthogonal channel noise simulator, a mechanism used to simulate the users or control signals in conjunction with the use of the 5G radio base station and near- and far-field scenarios, is shown in Fig. 6. The experiment has a free space loss of 32.45 dB where the section-able distance of radiation can be expressed as $R \geqslant \frac{2D^2}{\lambda}$.

Fig. 7 shows the results generated from the implementation at the 5G innovation center at KIT using the above parametric frequencies and bandwidth.

Ⅳ. Applications of the Campus Test-bed

This section discusses some of the applications performed at the 5G LG Uplus Center of KIT. Specifically, different applications attempt to make Google smart factories and collaborations with other institutes are discussed.

4.1 K7U Industrial-Academic Collaboration

The industrial-academic collaboration for the 5G+ project includes seven universities: Kunsan National University, Kumoh National Institute of Technology, Pukyong National University, Seoul National University of Science and Technology, Changwon University, Korea National University of Transportation, and Hanbat National University. The state-centered national university (K7U) is linked through the establishment of a 5G-based virtual campus between state-centered national universities, the establishment of distance education, and the sharing of the K7U industry-academia cooperation platform.

The ripple effect includes the demonstration of the integrated virtual campus of the K7U by building a 5G-based integrated cyber platform. The creation of an innovation model for the university coalition was achieved by linking and sharing industrial-academic cooperation and education programs based on resources held by state-centered national universities that represent industrial-academic cooperation in industrial bases at different regions.

4.2 Virtual Desktop Interface (VDI)

Our research center has created a virtual desktop (VD) interface (VDI) that provides a solution for a VD and storage space for each user by employing a virtual server resource. The access/use of various

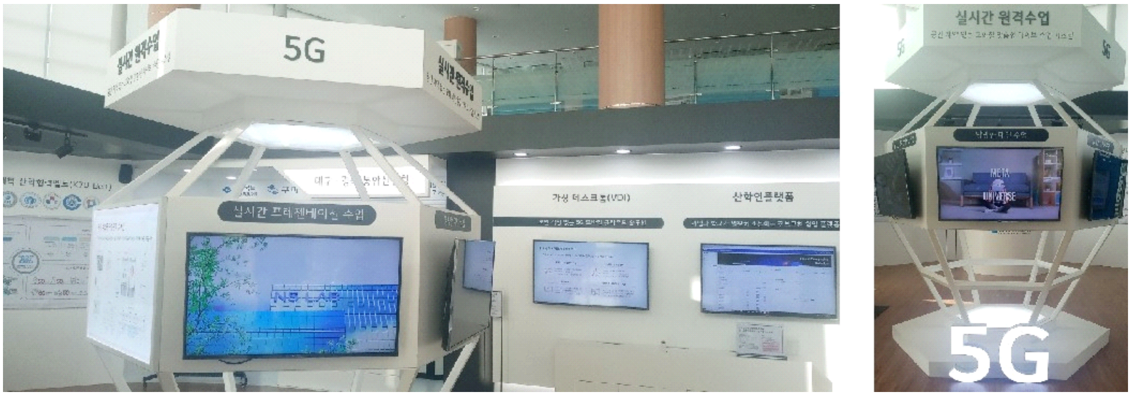


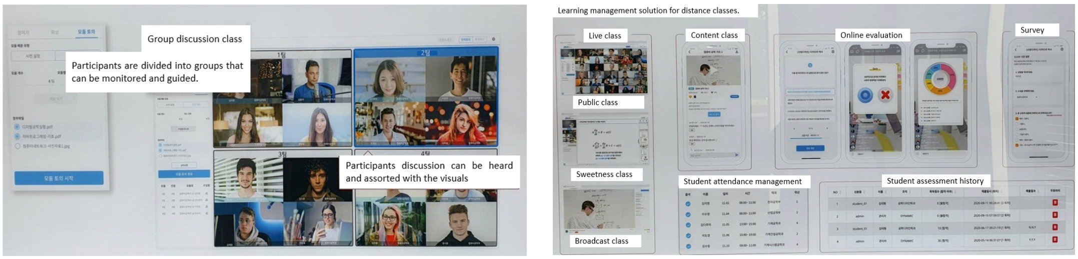
Fig. 8. Example of the Virtual Desktop Interface Connecting the K7U to the Industrial Academic Collaboration Serving the dual Purpose of Online/Distance Education Platform and Technology Exhibition at the Kumoh National Institute of Technology, Korea.

devices to a VD running on a conventional central server using 5G 28 GHz anytime and anywhere allows better performance. A secure, smart work supported by a data leakage prevention mechanism was performed based on the centralized management of business data, and a cloud/fog personal computer work environment was provided. The VD was supported by complete security using a smart work environment and encryption according to the U+ 5G. Fig. 8 shows the depiction of the VDI reflecting different components of the VD located at one of the K7U.

4.3 Learning Management and AR/VR Video Streaming as an Application of the 5G+ 28 GHz mmWave

Nowadays, classrooms can be equipped with stations, which implement practical active learning paradigms for the transformation of current learning endowments into active learning classrooms in a flexible manner[42,43]. As shown in Fig. 9(a), a group discussion can be conducted wherein students are divided into small groups, and the instructor can monitor and guide each group at the same time. In addition, one can listen to the content discussed by the participants of the five ranks of your choice.

Fig. 9(b) shows a learning management solution for the class, wherein it provides features optimized for online classes, such as writing, content, online evaluation, survey, attendance management, and evaluation history. The problemsinclassroomteaching, learning management, and discussions subject to the support of existing communication technology are analyzed, and new scenes of classroom teaching supported by 5G+ technology are explored at our center. The concept of AR is to present virtual information over reality, such as the deformation of real images, whereas in virtual reality VR, the main



(a) (a)

Fig. 9. Application of the 5G+ mmWave campus test-bed, where (a)group discussion class, (b)remote learning and class management system,

idea is to place users in a virtual environment. The streaming service is continuous while the uses of 5G and video content streaming and high-quality high-speed AR are available whenever the user wants.

4.4 Infrastructure and Hardware Sharing

Mobile network operators provide connectivity and communication services over deployed network infrastructure (whether owned or leased). The definition of network infrastructure is not only limited to electronic components but also includes passive elements, such as physical sites and towers that are required to operate the network. Network identification used to address coverage demands in indoor environments has led to increases in the difficulty of acquiring sites for a radio access network. This is mainly attributed to two factors. First, the space within buildings is usually confined and the reasons for aesthetics/civil works limit the choice even further. Second, having more than one mobile operator further complicates the problem because the mobile operators will have to compete for a few sites. Even if the operators are successful in securing and deployingbasestationsinproximitytoanoptimalsite, each operator will have to invest in the civil works of the antenna and transmission lines.

To address these issues, the three South Korean mobile operators, KT, LG Uplus, and SK Telecom, agreed to share their 5G networks in 131 remote locations across the country according to the Ministry of Science and ICT, as depicted in Fig. 10. In this plan, a 5G user would be able to use other carrier networks in regions that are not serviced by their carriers. The ministry said that telecom operators will test the network-sharing system before the end of this year and aim for complete commercialization in phases by 2024. Fig. 10 also depicts the 28 GHz spectrum plan used by three prominent operators in South Korea. The spectrum plan frequencies range from 26.5 to 29.5 GHz in the three operator cases.

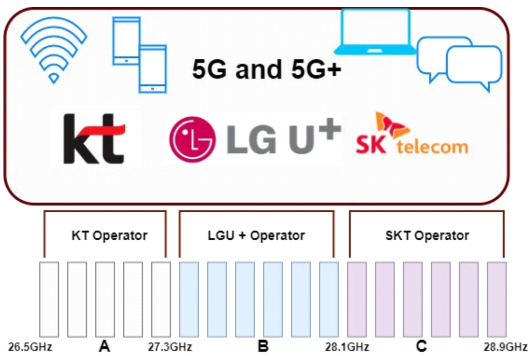


Fig. 10. Infrastructure sharing by the three South Korean operators with their spectrum plan for 5G and 5G+.

4.5 Energy Consumption Monitoring

Using the 5G+ test bed implemented in KIT, the electricity consumption of 39 different factories in the industrial complex in Gumi was monitored. Fig. 12 shows a map of the industrial complex and a list of consumer companies that use the energy platform as the main screen of the smart energy platform and shows the total energy usage. Fig. 11(a) shows the detailed electricity consumption. Fig. 11(b) shows the total power consumption per unit on a day, month, and yearly basis for each factory. If a user wants to see the detailed consumption for a specific factory, the user should simply select the factory to see the detailed information. In brief, the main aim is to

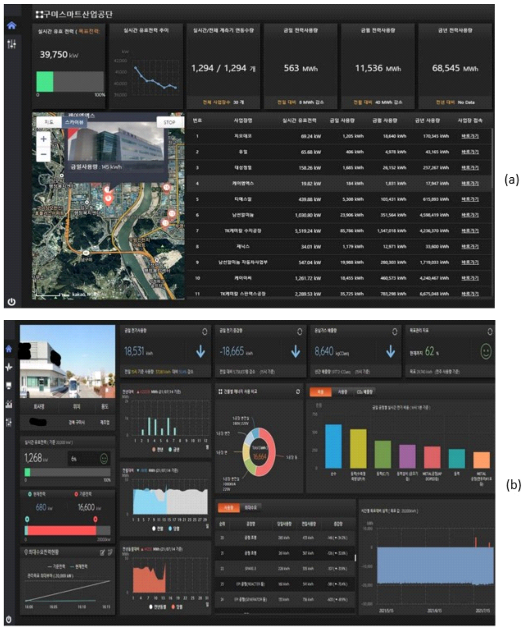


Fig. 11. Monitoring and integration of the 5G+ test bed at 3.5GHz and 28GHz for energy consumption of 39 different companies at Gumi, where the (a) map of the industrial complex and (b) energy consumption for the day, month, and year.

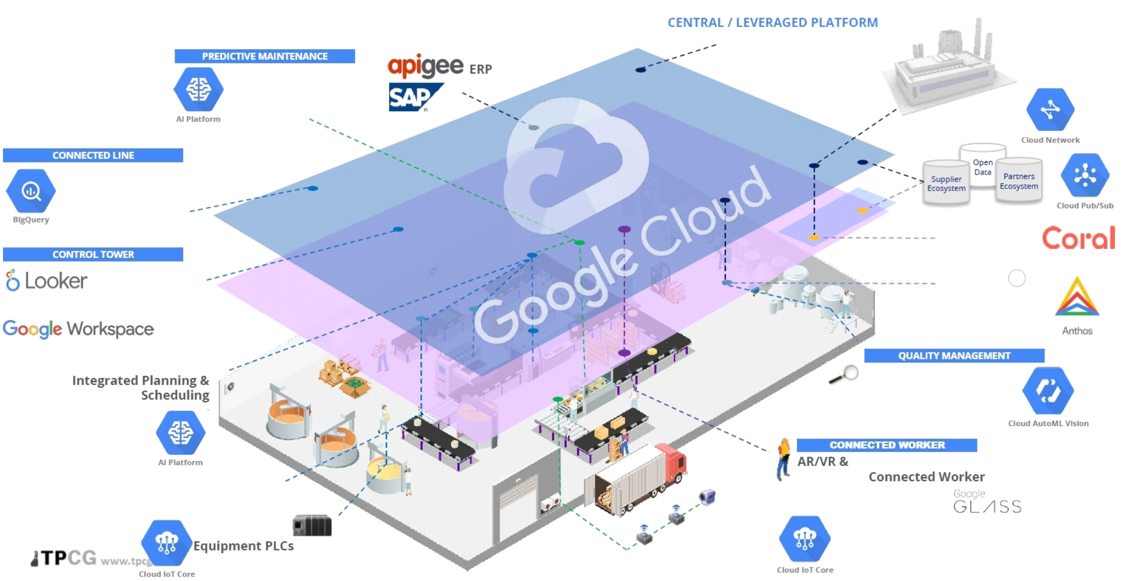


Fig. 12. A depiction of Google cloud platform smart factory.

connect 3.5 GHz and 28 GHz with different industries to achieve high-performance and low-latency applications.

4.6 Cloud Platform Smart Factory

The smart factory is an idea used to display the end aim of digitization in production. It is like an extreme level of digitized shop floor that accumulates and distributes data by connected machines, devices, and generation systems in a continuous manner. Several technologies such as artificial intelligence (AI), big data analysis, industrial IoT, and cloud computing have made smart manufacturing practices comprehensive[44].

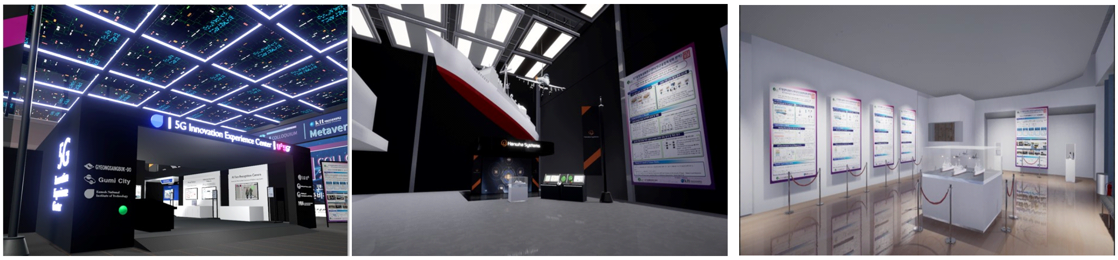
For Google Cloud, a smart factory platform is constructed at the KIT center, encompassing different technologies and interconnected applications. Google Cloud for smart factors includes digital platforms, such as AI for predictive analysis, connected lines for data aggregation, and visualization of the data, control towers, Google workplaces, integrated planning and scheduling for visibility and notices, live display and cooperation, and yield optimization, cloud networks and cloud pub/sub for edge gateways and plant platforms. These platforms are used in conjunction with inline quality inspection, and additional sensor and visual data are included in the smart factor. Fig. 12 shows the smart factory as a Google Cloud smart factory. Moreover, through digital transformation and collaboration environments, information is shared freely with headquarters and onsite clouds that are easily accessible to new business ventures. In the Google workplace, culture management, and technologies are provided through AI cloud search innovation and collaboration experienced by Google. Cloud migration using the operating environment, such as vision AI, IoT, and big data, for workloads, is controlled and managed through virtual desktops that maintain a familiar operating environment and large-capacity data, thus providing an economical cloud environment.

4.7 Deployment of Small Cells (SCs)

To allow Nokia to deploy indoor 5G SC solutions with LG Uplus in South Korea, the company will expand and enhance the LG Uplus 5G network, thus enabling seamless 5G connectivity between indoor and outdoor locations. From this perspective, for the particular 5G+ campus testbed cases, we deployed SC (known for educational purposes as an Idea factory) within our campus and research center provided by LGU+ and Samsung Electronics, as shown in Fig. 14. We deployed the SC both within the room as full indoor and within the main hall of the center as a

(a) (b)

Fig. 13. Small cells (SC) deployed within the center as mmWave solution, where (a) LGU+ and Samsung electronics SC and (b) LGU+ SC deployed at the center.



(a) 5G Innovation Experience Center (b) Building Virtual Space for Exhibition of Naval and Fighter Pilot (c) Building a conference poster session

Fig. 14. The Ultra-realistic Representation of the 5G Innovation Experience Center on the Creativia Platform. Notice how it is created to be as the actual center[48].

semi-indoor, as shown in Fig. 13(a) and Fig. 13(b).

4.8 'Creativia' Metaverse Platform for Experience Sharing

The IEEE Standard Association defined the Metaverse as "*an open-ended digital reality and culture that connects various virtual worlds by operating at multiple levels: parallel to, overlaid on, or interactive with the physical domain through increasing developments in interface technologies and real-time data sharing*"[45,46]. A metaverse prototype platform named "Creativia" was developed leveraging on the 5G+ 28GHz infrastructure[47]. Augmented reality (AR) and virtual reality (VR) are integrated with head-mounted displays (HMDs) for a metaverse experience. In 2021, South Korea declared it would build a national AR and VR platform[46]. In this work, a metaverse platform named **'creativia'**1) platform is proposed to achieve an ultra-realistic exhibition and learning experience using the Unreal Engine 5.0. The prototype for the exhibition was demonstrated using the 5G idea factory center for industry-academic cooperation located at the Kumoh National Institute of Technology (KIT), Gumi, Korea shown in Fig. 4(b)[48].

The metaverse requires an ultrarealistic representation of characters. Creativia project achieved this using the Unreal neural network inference (NNI)- "machine learning deformer". The hardware and software requirements specifications of the unreal engine are enumerated in2). Furthermore, **Metahuman** was used to create various exhibition and learning environments that are near realistic as shown in Fig. 14.

1) http://creativia.tech/

2) https://docs.unrealengine.com/5.0/en-US/hardware-and-software-specifications-for-unreal-engine/

Ⅴ. Research Challenges for 5G and 5G+ Technologies

As challenges are the intrinsic part of the new development effort, 5G and 5G+ technologies also face challenges. We envision the following as significant future research challenges in 5G and 5G+ networks.

5.1 Spectrum Availability and Implementation Issues

5G and 5G+ networks function at larger frequencies up to approximately 300 GHz. These bands have improved functionality that is able to achieve ultrafast speeds which are 20 times greater than the theoretical speed of LTE networks. However, issues such as cost and availability are still faced by operators and demand bidding for large spectral bands to deploy these networks[49].

5.2 Intercell Interference and Network Densification

Owing to a large number of SCs, inter-cell interference is a significant technical problem that needs to be solved. This is because the alterations in the size of macrocells and side-by-side SCs lead to interference[50].

5.3 Efficient Medium Access Control

In a situation wherein dense deployment of access points and user terminals are required, the user throughput will be low, latency will be high, and hotspots will not be competent to cellular technology to provide high throughput. This area needs to be properly researched to optimize the technology [49,51].

5.4 A Comprehensive QoS Framework

Different human-type communication (HTC), machinetype communication (MTC), and combined-type communication (CTC) emerging applications have different and diverse QoS requirements. Invariably, QoS requirements must be satisfied on an end-to-end basis. Therefore, in the future, ultra-large-scale deployment of MTC devices may require an extension to Internet QoS architectures. Simultaneously satisfying the QoS requirements of HTC, MTC, and CTC applications is a challenging task that needs to be addressed by 5G and 5G+ networks[11].

5.5 Internetwork Handover

Handover is inevitable. There are three cases needed to take place to complete an internetwork handover: (i) an access network device malfunctions, (ii) user mobility is documented (non-availability of a current type of access network at a new location), and (iii) there is another access network that may offer better service. Causes (ii) and (iii) for internetwork handovers are peculiar to 5G and 5G+ Hetnets. There are numerous challenges involved in these types of handovers, including the specifications of appropriate metrics to determine a better access network for HTC, MTC, andCTC, energy-efficienthandoversignaling, and smooth and fast handover processes[11].

5.6 Device Capabilities

The devices were not compatible with all wireless communication technologies. Recently, companies have been working on devices supporting 5G. These devices should be able to support 5G+ and all the different wireless communication generations. Devices should also support interaction with different devices using device-to-device (D2D) communication, AI, and XR[51].

5.7 Traffic Management

In comparison with the traditional human-to-human traffic in cellular networks, a large number of machine-tomachine (M2M) devices in a cell within 5G and 5G+ technologies may cause serious system challenges, that is, radio access network challenges, which will cause overload and congestion[51].

Ⅵ. Conclusion

This study provided a practical scenario based on the use of 5G+, which operated at 3.5 GHz, and 28 GHz mmWave was performed as a campus testbed case. Furthermore, we provided an experimental setup, interconnection sites, and indoor-outdoor cases to reflect the results of the 5G+ network as a campus testbed. Moreover, this study presents the potential applications of the 5G+ campus testbed case, such as learning management and AR/VR video streaming, cloud platforms for smart factories, and project-based learning. In particular, this study constitutes an attempt at 5G+ mmWave campus testbed implementation along with the integration of a particular technology for different educational and industrial applications. The findings of this study provide a basis for explaining how future operators in South Korea can adopt and employ the concept of infrastructure sharing for particular cases in indoor scenarios.

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