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Real Challenge of Mobile Networks Toward 5G — An Expectation for Antennas & Propagation —

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SUMMARY The next generation mobile system "5G" are under research, development and standardization for a service start of around year 2020. It is likely to use frequency bands higher than existing bands to have wider bandwidth for high throughput services. This paper reviews technical issues on higher frequency bands applying mobile systems including system trials and use case trials. It identifies expectations for antennas & propagation studies toward 5G era.
key words: *mobile communication systems, 5G, massive MIMO, eMBB, mMTC, URLLC, WRC-19*

1. "5G" and Its Target

Mobile communication service is widely penetrating to all the society as the key infrastructure. It is spreading beyond the conventional telephone service. Wide variety of social services including e-commerce, e-bank, navigation, location, healthcare, and education are offered on the network. It's not too much to say that people can never part with a smartphone as the most frequently use interface between a human and society.

Land mobile communication systems have developed with the 1st generation analog system of the 1980s, the digitized second generation of the 1980s, the 3rd generation of the CDMA scheme of the 2000s, and the 4th generation of the OFDM scheme of the 2010s. It started as a mobile phone, SMS was introduced in the second generation, and data communication spread in the third generation. In the fourth generation, smart phones have spread explosively worldwide. It is no longer a phone but the mobile internet. It becomes one of the most important social infrastructure supporting SNS, music, photography, navigation, and electronic money, etc.

The number of mobile communication devices in the world in 2016 is about 8 billion, which is expected to grow to 11.6 billion in 2021 [1]. The number of mobile phone subscribers in Japan is 164 million in September 2017, which is about 130% of the total population [2]. Approximately 63%, 102 million devices are of the fourth generation type [3].

A new generation system has been introduced almost every ten years. The 5th generation system "5G" is being developed to promote the 2020s. The concepts and targets of 5G are being studied in various organizations. One international consensus is ITU-R Recommendation M.2083 [4], which defines three typical usage scenarios;

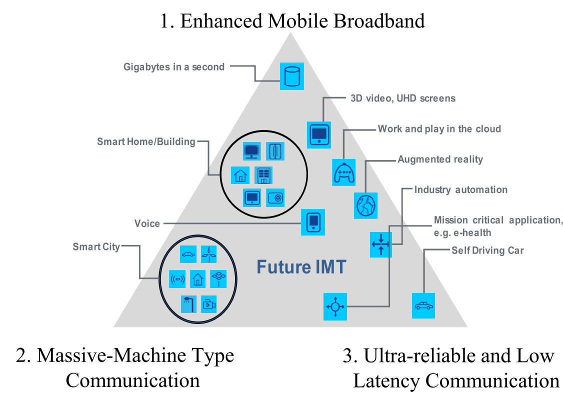

Fig. 1 Three usage scenarios of 5G [4].

- Enhanced Mobile Broadband (eMBB),
- Ultra-reliable and Low latency Communications (URLLC),
- Massive-Machine Type Communications (mMTC).

The conventional mobile systems have been designed mainly for human communications. On the other hand, 5G will cover wider range of usage scene. Among them, URLLC featuring "high reliability communication" or "low delay communication" is technically challenging.

The capability of 5G aims at a considerably higher level than 4G as follows;

- Peak user throughput: 20 Gbps (hundred times),
- Latency (air interface): 1 ms (a few tenths),
- Connection density: 1 million/km^2 (several hundred times),
- Mobility speed: 500 km/h (300 km/h).

Because 5G is assumed to be widely used, the required capability varies depending on the usage scenes and applications. It is not necessary to satisfy all the above high requirements at the same time [5].

2. Frequency Spectrum

Frequency spectrums for 5G will be globally identified by WRC-19 and some of administrations will define the 5G bands before WRC-19 for early service launch. It is likely to use frequency bands higher than existing bands to have wider

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bandwidth for high throughput services. How efficiently use such high frequency, e.g. micro-wave and mm-wave, for mobile services is one of the key research & development topics in parallel to define new radio access technologies.

2.1 Mobile Frequency Allocation

Here, among the radio frequencies for mobile communication, the license bands assigned to mobile operators will be described. In Japan, the frequency bandwidth assigned to mobile phone systems and BWA (Broadband Wireless Access) is currently about 610 MHz in total. In 2010, it was 380 MHz, so it has been expanded to about 1.6 times in 7 years. On the other hand, the total amount of mobile data traffic has expanded from 74 Gbps to about 2,200 Gbps in the past 7 years to about 30 times [6]. Effective utilization of frequency (total traffic volume/bandwidth) has greatly improved due to technological innovation and enhancement of coverage area by large-scale investment. With this innovation, it has been responding to vigorous demand due to the spread of smart phones. The traffic of mobile data is expected to increase rapidly in the future. The global mobile data traffic volume is expected to increase seven times between 2016 and 2021 [1].

It is one of the mission of 5G to cope with such a rapid increase in data demand. In addition to further improving the effective utilization of frequencies, expansion of assigned frequency band is also indispensable for higher speed and larger capacity aiming for “Enhanced Mobile Broadband”. In mobile communication, the 800 MHz band, the 2.1 GHz band, etc. have mainly been used because the propagation loss is relatively small especially in the NLOS (Non-line-of-sight) environment. It is not easy to additionally assign new frequency bands for mobile service in relatively low frequency bands because they are already assigned to other radio services and are used at very high density. Although there is a disadvantage that the propagation loss is large, it is inevitably necessary to utilize higher frequency bands in order to secure a wider bandwidth.

2.2 WRC-19 Agenda

The frequency allocation for 5G will be discussed in World Radiocommunication Conference WRC-19 [7]. The frequency bands to be discussed as 5G candidates are 24.25–27.5 GHz, 37–40.5 GHz, 42.5–43.5 GHz, 45.5–47 GHz, 47.2–50.2 GHz, 50.4–52.6 GHz, 66–76 GHz and 81–86 GHz [8]. Considering that the frequency bands used for mobile communications in major countries such as Japan were up to the 3.5 GHz band, it can be said that these are extremely high frequencies. In USA the Federal Communications Commission took action on July 2016 to spur on the development of faster 5G mobile wireless networks [9]. FCC selected 27.5–28.35 GHz, 37–38.6 GHz, 38.6–40 GHz, and 64–71 GHz bands. In Japan, 27.5–29.5 GHz, 3.6–4.2 GHz, and 4.4–4.9 GHz bands are defined as candidate frequencies for 5G, and frequency allocation will be decided as the end of FY2018 [10]. Proof of concept (PoC) services using 5G system were carried out using the 28 GHz band at the Pyeongchang Olympics and Paralympic Games in Korea.

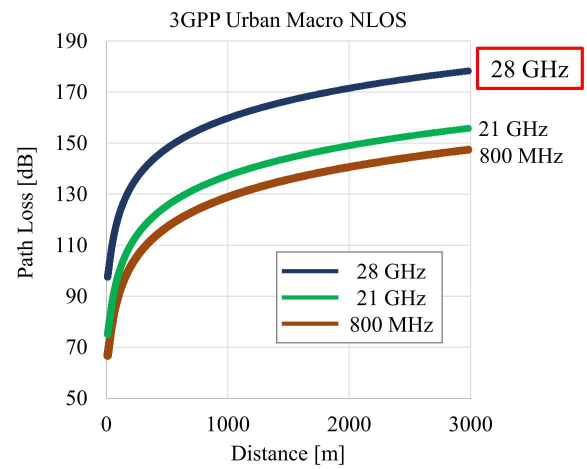


Fig. 2 Propagation loss calculated by 3GPP Urban Macro NLOS.

USA, Japan and Korea make the 28 GHz band a candidate for 5G frequency band, but it should be noted that 28 GHz band is not in the agenda item in WRC-19. Furthermore, it is also necessary to be careful that WRC-19 will discuss the use of 17.7–19.7 GHz (space-to-Earth) and 27.5–29.5 GHz (Earth-to-space) by “earth stations in motion” in the FSS service [7]. Although the 28 GHz band is a strong candidate for 5G, it is a complicated situation how to handle in Radio Regulation.

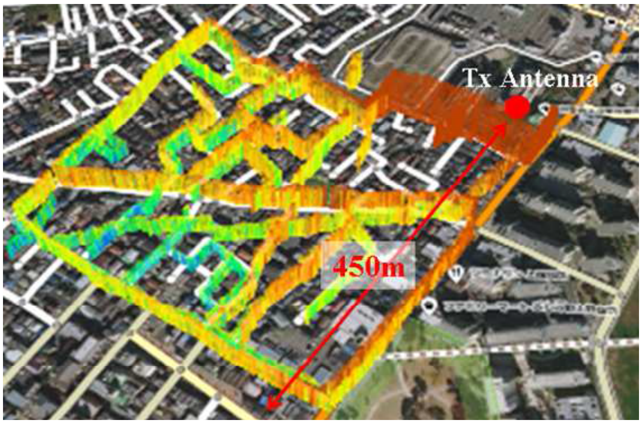
2.3 Challenge for 28 GHz Band

Figure 2 shows the propagation loss calculated by 3GPP Urban Macro NLOS model at 800 MHz, 2.1 GHz and 28 GHz [11]. The propagation loss of 28 GHz is about 30 dB higher as compared with 800 MHz. Figure 3 shows an example of measured propagation loss. It can be seen that the propagation loss is large in the NLOS environment and it is relatively small in the LOS environment.

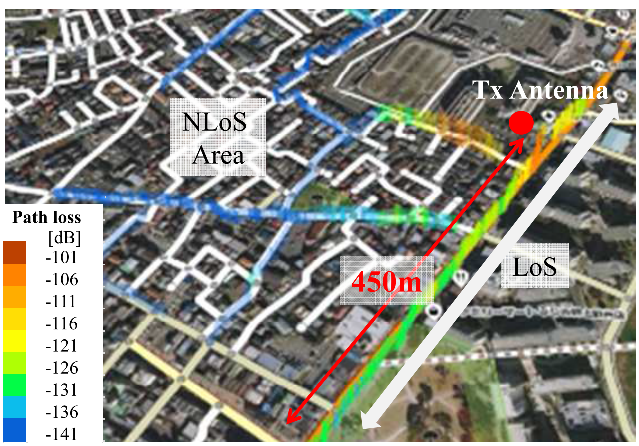
Figures 4 and 5 show a measured example of blocking effect by human bodies, and that by trees, respectively [12]. 28 GHz is expected to have large loss about 10 to 20 dB compared to 2 GHz band due to shielding of human bodies and trees. Electric field intensity fluctuates largely due to the direction of the person with the mobile device and shielding of the surrounding human. In addition, it also fluctuates greatly depending on seasons when leaves grow.

3. Typical Scenarios How to Use Higher Frequency Bands for Full Mobile Systems

How to use the 28 GHz band with large propagation loss and large shielding loss for mobile communication system is one of the key challenges for 5G. Two approaches of (1) “hot spot system” and (2) “massive MIMO” are described as representative examples.



(a) 2.115GHz



(b) 28.0GHz

Fig. 3 Measured propagation loss in a residential area.

Transmit antenna height	20 m
Receive antenna height	2 m
Transmit antenna Gain	1 dBi
Receive antenna Gain	1 dBi
Monopole antennas	

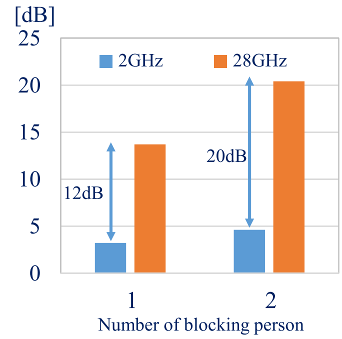


Fig. 4 Measured blocking loss by human bodies.

Carrier Frequency	28.0 GHz/2.115 GHz
Tx & Rx antenna height	1.25 m
Distance between Tx and Rx	7.0 m
Distance between 1st person and Tx	3.5 m
Distance between 2nd person and Tx	4.0m

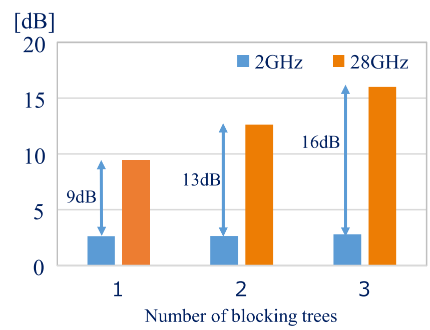


Fig. 5 Measured blocking loss by trees.

Carrier Frequency	28.0 GHz/2.115 GHz
Tx & Rx antenna height	1.25 m
Distance between Tx and Rx	7.0 m
Distance between 1st tree and Tx	3.5 m
Distance between 2nd tree and Tx	4.0 m
Distance between 3rd tree and Tx	4.5 m
Height of tree	2.2 m
Maximum width of tree including leaves	0.8 m

3.1 Hot Spot System

Short-distance communication with an extremely small coverage of about several meters is considered as shown in Fig. 6. Since the beam of the base station antenna can be made sharp thanks for high frequency, interference between beams can be small even for adjacent spots. High speed service can be expected within that hot spot [13].

The issue with this scenario is that the staying time of moving UE would be extremely short. The protocol overhead of location registration and handover etc. is large, wasting control channels, and it cannot make full use of the advantage of super high speed. One solution is to incorporate techniques such as MEC (Multi-access Edge Computing), location prediction, pre-transmission, and etc. In addition, it is also being studied to overcome this problem by adopting Information Centric network architecture such as CCN and ICN [14].

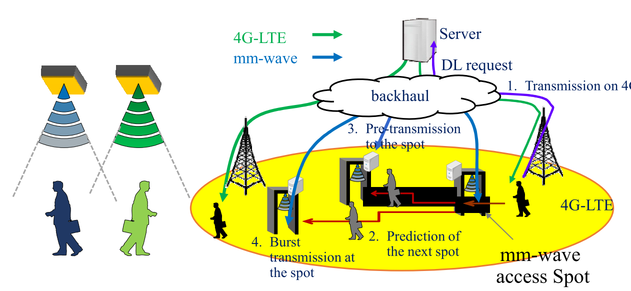


Fig. 6 Hot spot scenario [13].

3.2 Multi-Site with High Gain Antenna

In the high frequency band, physically small sized high gain antenna can be made. If a high gain narrow beam width antenna for the base station is used, it can improve the link budget. Also, if a large number of narrow beams can be radiated simultaneously, it is expected capacity increase by spatial

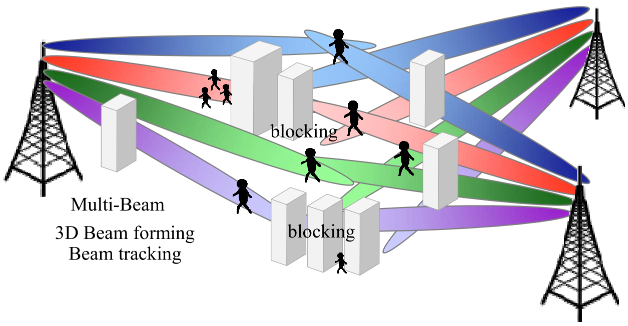


Fig. 7 Massive MIMO & multi-site.

Table 1 Examples of massive MIMO implementation to testbeds.

Reference	[29]	[30]	[31]	[32]	[33]
Frequency band [GHz]	28	28	2.6	2.6	4.5
Bandwidth [MHz]	800	800	20	20	200
Total number of elements	96	128	64	64	192
Number of digital Ports	2	2	64	64	64
Maximum number of MIMO layers	2	2	4	8	24

multiplexing effect. Instead of conventional sectors and omnidirectional base station antennas, "massive MIMO" antennas are expected in high frequency band for high throughput and large capacity systems.

Massive MIMO has been researched and developed widely from various aspects such as hardware design, signal processing, beam management mechanism, field trials, and so on [15]–[17]. In the urban area, to make the capacity of the system larger, the number of base stations is very large. When base stations of sector/omni beam antenna are arranged at a high density, interference in the system due to cell overlapping becomes large, so that the capacity and the performance are deteriorated. Although it is intended to reduce interference with larger tilt angle, there is a limit to high density. Recently massive MIMO is beginning to be deployed in commercial 4G network for enhancing system capacity [18], and it is expected to be deployed on a full scale in 5G-era for further enhanced system capacity and coverage extension.

Using massive MIMO, however, cannot improve blocking loss in NLOS environment in high frequency bands. By using a high gain base station antenna even in a high frequency band, the range of coverage can be large in the LOS environment. In urban areas, the probability of being an LOS environment, that is, the visibility is extremely small. On the other hand, in urban areas, base stations are arranged at extremely high density. Taking these factors into consideration, it is expected to improve the visibility and the system capacity with "multi-site technology" where multiple base stations communicate to one UE as shown in Fig. 7. Technologies that integrate massive MIMO and "multi-site", such as "cooperated beamforming (BF)" [19], are expected.

4. System Trials

Numerous development and testing of 5G systems has been done and planned all over the world [20]–[25]. In addition to 28 GHz, the frequency band used for testing includes 15 GHz band, 3.5 GHz band, etc. In many cases, massive MIMO is the key technology, and various functions such as BF and Beam-tracking are implemented and tested.

BF methodologies in massive MIMO can be classified into 3 categories, by its hardware architecture, i.e. analog, digital and hybrid BF [26], [27]. Hardware for analog BF is much simpler than that of digital BF, which equipped with a lot of RF chains, and ADC/DACs. Meanwhile, the capability of multiplexing UEs with MU-MIMO depends on the number of subarrays or digital ports in digital or hybrid BF.

Currently, various massive MIMO antennas with various number of elements and subarrays for each candidate frequency bands have been employed in 5G testbeds [28]. Table 1 summarizes typical examples of massive MIMO to the testbeds. Most of testbeds for higher frequency bands such as 28 GHz employs analog or hybrid BF with relatively few number of digital ports and it mainly focusses on compensation of large path-loss by analog BF gain [29], [30]. The testbeds for below 6 GHz tends to employ full digital or hybrid BF with comparatively large number of digital ports more than 32 for multiplexing large number of UEs [31]–[33].

Field tests that handover is performed between multiple massive MIMO base stations have been carried out [22]. Beam tracking and hand-over have also been demonstrated in a high-speed mobile environment at a speed of 200 km/h [23]. Field test of high-speed transmission has also been carried out many times, and it depends on bandwidth and moving speed, but downlink throughput of 10 Gbps class has been verified. Examination aimed at URLLC has also been conducted, and "a transmission success rate of 99.999% or more, a delay of 1ms or less in radio section" has been verified [20].

It is not easy from the viewpoint of coverage area to provide 5G service alone in a high frequency band like 28 GHz. Therefore, multi-band operation complementarily building areas in combination with lower frequency bands below 6 GHz will be effective. Multi-band 5G testing is also proceeding [34]. In the case of multi-band, radio system would be more stable if the control channel is handled in a lower frequency band. Considering that coverage is small at the beginning of 5G deployment, it is considered that the dual-connectivity would be effective, where 4G LTE handles control channel and 5G handles user data channel only. And field verification of dual-connectivity is being advanced [35].

5. Use Case Trials

Mobile Internet using smartphone has been the main usage style in 4G era. As mentioned in Sect. 1, 5G is designed to assume various usage scenarios such as URLLC and mMTC in addition to eMBB. What kind of new usage scenes and applications can be considered taking advantage of the super high speed transmission such as 1Gbps and 10Gbps in eMBB? In parallel with development of the system infrastructure, verification of usage scenes and applications is extremely important for considering appropriate system configuration and device specifications. It is also expected that various vertical markets will use 5G. For this reason, a large number of verifications for service and application are conducted worldwide, with telecommunications operators, equipment vendors and users in unison.

In Japan MIC (The Ministry Internal Affairs and Communications) reported nine different fields where vertical industries are categorized as the utilization field of 5G services [36]. The "5G System Integration Verification Test Program" led by MIC is ongoing [37]. The specific implementation are detailed in the report of the 5G Trial Promotion Group (5G-TPG) in 5GMF [38].

Table 2 shows the PoC trials of use cases that have been or are scheduled around the world. In relation to eMBB, there are many high-definition 4K/8K video applications and combination with VR, AR and free viewpoint video such as sending 4-channels of 8K video to the UE and viewing it as free view video on the UE side. There are opinions that 4K/8K video are meaningless for mobile services due to small size display of mobile devices. However, it is clearly understood that it is important that high-definition original video are sent through such application demonstration.

There are many trials relating "connected car" and "remote construction machine" for URLLC scenario. It is expected to utilize 5G in usage scenes different from the 4G era such as support for automatic driving and remote construction at dangerous places.

Table 2 Examples of use case trial.

Usage Scene	Application	Main Feature	Reference
Remote Area	4K/8K video, VR, Telemedicine	eMBB	[39] [56]
Stadium	4K/8K live video, VR, AR, Free View point	eMBB	[40] [44] [48] [57]
Connected Car	Auto-driving, Remote control, Monitoring, V2X, Convoy, 4K video	URLLC eMBB mMTC	[41] [43] [45] [47] [49] [50] [51]
Construction	Remote construction, Monitoring, 4K video	URLLC eMBB mMTC	[46] [55]
Security	4K uplink	eMBB	[39] [54]
Robot	Remote control, Monitoring	URLLC eMBB	[42]
Railway	4K/8K video	eMBB	[39] [52]
On-site broadcasting	FPU, 8K live	eMBB	[53]

6. Expectation for Antennas & Propagation

Key system features of 5G are summarized below.

(1) Capacity

a. Higher frequency (u-wave, mm-wave)
b. Wider bandwidth
c. Spatial multiplexing

(2) Connectivity

a. Multi-band
b. 4G/5G Dual connectivity

(3) Low latency

a. Short frame
b. High speed algorism

(4) Cost effective

a. Global eco-system
b. Backward & Forward compatibility
c. Power consumption

Wide bandwidth are necessary to provide throughput of 10Gbps more and huge system capacity. Inevitably, 5G uses higher frequency (μ-wave, mm-wave) bands. In addition, introduction of spatial multiplexing is also indispensable. Multi-band and 4G/5G dual connectivity would also be essential for efficient and stable communication using high frequencies bands. It is necessary to use short frame and a high-speed signal processing algorithm for URLLC scenario.

From the above, further development of Antennas & Propagation technologies for 5G era are expected. Examples of major technical items to be expected are shown below. Note that the index shows the key feature of the system listed above.

□ Propagation

- Channel modeling
- Wider band channel estimation (1)-b
- MIMO channel estimation (1)-c
- Quick & accurate channel estimation (1), (3)

□ BS Antenna

- Wider band, Multi band (1)-a b, (2)-a
- Scanning beam (1)-a c
- Tracking beam (1)-a c
- Adaptive BF (1)-c
- Multi-system support (2)-b
- High speed processing (3)
- Low power consumption processing (4)
- Optimal analog/digital splitting (4)

□ UE Antenna

- Multiple small antennas (1)-c

- More bands (1)-a, (2)-a
- More band-width (1)-b
- More adaptation (1)
- Interference cancellation (1)

Research on radio wave propagation requires two perspectives. The first is a radio wave propagation model for the system simulator which is necessary for 5G system and area design [58], [59]. Especially, models for higher frequency bands and narrow antenna beam are important subjects. In higher frequency bands, the propagation characteristics tends to be more sight and situation specific such with the geographical property, alignment of the buildings and their materials, foliage, and surrounding blockages like human or vehicles. Hence, adequate modeling and its proper use suitable for each evaluation purpose are further required.

The second is the knowledge of the propagation required to process propagation channel estimation at high speed in base stations and devices. Especially for MU-MIMO, accuracy of channel estimation is very critical for precise pre-coder design to suppress inter-user interference [60]. Further quick and accurate estimation algorithm is expected. In addition, accurate RF calibration to compensate reciprocity of uplink and downlink under the asymmetric RF circuits between BS and UE is also required for BS to design pre-coder.

Massive MIMO antenna technologies are the most important key technologies of 5G [17], [21], [26], [61]. Under the constraints of complexity, weight and cost, antenna design and development suitable for expansion of system capacity and flexible operation are major themes. In addition, it is necessary to solve the regulatory issues how to handle massive MIMO antennas, such as definition of transmitting power and how to perform radio equipment conformity certification test. In the ITU-R, studies on the advanced antenna system (AAS) pattern model for use in sharing and compatibility studies between mobile systems and systems in other services have started [62].

How to mount a large number of antennas in devices so that MIMO gain can be secured is an important issue. Antenna design considering the influence of human body in high frequency band and antenna design of small IoT device are also expected [63], [64].

7. Conclusion

The paper overviewed the outline of the next generation mobile system "5G" from the viewpoint of using a relatively high frequency band. In order to realize and disseminate the 5G system, it mentioned that further development of antenna and propagation related technology is quite essential. It is expected that 5G will become popular as a global eco service in the 2020s.

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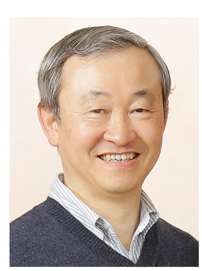

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