Technology Reports (Special Articles) 6G 100 GHz Band System-level Simulator

Special Articles on 5G evolution & 6G (2)

6G System-level Simulator —Toward 100 GHz Band, 100 Gbps Extreme-high-data-rate Communications—

6G-IOWN Promotion Department Tatsuki Okuyama Satoshi Suyama Nobuhide Nonaka Takahiro Asai

With 6G, the target is to add the 100 – 300 GHz bands to the millimeter-wave band introduced by 5G, which means that we can expect extreme-high-data-rate communications beyond 100 Gbps as a peak data rate using so-called terahertz waves. At NTT DOCOMO, we have already begun research and development toward the use of terahertz waves in 6G with the aim of conducting trials using experimental equipment in the future. However, at this initial stage of study, the possibility of improving system performance using terahertz waves to achieve extreme-high-data-rate communications of 100 Gbps must first be demonstrated through performance evaluations based on simulations. With this in mind, we have developed a real-time system-level simulator using the 100 GHz band and used this simulator to show that a throughput in excess of 100 GHz per user can be achieved in an environment with multiple users for two types of indoor scenarios. This article describes these simulations in detail.

1. Introduction

The commercial deployment of the 5th Generation mobile communications system (5G) has been progressing throughout the world, but the penetration of 5G services in society has uncovered issues with

5G and generated expectations of further evolution. In 5G, services have been rolled out using the Sub6*1 band and the 28 GHz millimeter-wave*2 band. With regard to the latter, a 400 MHz wide bandwidth has been allocated in Japan, which can provide a high data rate compared with the 100 MHz bandwidth of the Sub6 band.

At the same time, opportunities for using high-frequency bands toward the 6th Generation mobile communications system (6G) have recently been increasing. For example, the Federal Communications Commission (FCC) in the United States is opening up the 95 GHz – 3 THz frequency bands higher than the millimeter-wave bands for 6G trials. The study of wireless technologies and the development of devices toward the use of such high-frequency bands are moving forward [1] – [3]. However, to achieve this objective, the possibility of improving system performance through the use of high-frequency bands must be clarified early and performance evaluations in real environments using experimental equipment must be performed as research and development advances. However, equipment development takes time, so it is not that easy to perform evaluations in real environments at the initial study stage. It is therefore necessary to demonstrate performance by simulations to determine, for example, the level of communication speeds that can be achieved by using terahertz waves*3. To this end, NTT DOCOMO has developed a system-level simulator*4 for the purpose of clarifying the feasibility of extreme-high-data-rate communications by 6G in near-real-world environments. With this simulator, we targeted two types of scenarios, namely, a shopping mall and factory, each featuring both stationary and moving Mobile Stations (MSs). We evaluated, in particular, the downlink throughput per MS using the 100 GHz band taken from the 95 GHz – 3 THz frequency bands mentioned above.

In this article, we show by simulations that a throughput of 100 Gbps per MS can be achieved by ultra-broadband*5 transmission (bandwidth = 8 GHz), which marks a step toward the practical use of 6G. We also describe how using multiple units of a drone Base Station (BS) and Intelligent Reflecting Surface (IRS)*6 enables the number of MSs capable of 100 Gbps throughput to be increased while compensating for high propagation loss*7 in the 100 GHz band.

2. Adoption of High-frequency Bands toward 6G and New Wireless Communication Technologies

In 6G, we can envision new combinations of requirements beyond the high-data-rate/high-capacity, low-latency, and massive-connectivity features of 5G as well as use cases that require extreme performance difficult to achieve in 5G [3]. Specifically, this will mean improving communication speeds even further in 6G through “extreme-high-data-rate and high-capacity communications” beyond 100 Gbps to achieve new sensory services that are comparable or even superior to the quality of experiences achieved through the five human senses. We can also expect “extreme coverage extension” that will cover areas such as the sky, sea, and space not

*1 Sub6: A division of the frequency band. A radio signal with a frequency between 3.6 GHz and 6 GHz.

*2 Millimeter waves: A division of the frequency band. A radio signal with a frequency between 30 GHz and 300 GHz.

*3 Terahertz waves: Electromagnetic waves with a frequency of around 1 THz. Often used to refer to frequencies ranging from 100 GHz to 10 THz.

*4 System-level simulator: In contrast to link-level simulation that simulates the behavior between base stations and terminals, system-level simulation is an evaluation method that, within an environment containing multiple base stations and terminals, incorporates quality control based on the selection of communication terminals and on the radio-wave propagation environment.

*5 Ultra broadband: Bandwidth of 100 MHz or greater. In Japan, 400 MHz of bandwidth has been assigned in the 28 GHz band for 5G radio communications.

*6 IRS: A reflecting surface that can arbitrarily design the direction of reflected waves and beam shape by a two-dimensional arrangement of structures called metamaterial that are microscopically small with respect to wavelength.

presently covered by current mobile communications systems, "extreme low power consumption and cost reduction" per bit in the future adoption of millimeter waves and terahertz waves, "extreme low latency" achieving End-to-End (E2E) communications under 1 ms, and "extreme reliable communication" for achieving high reliability and high security. We can also envision "extreme massive connectivity" of 10 million devices per square kilometer and the provision of functions for sensing the real world as in ultra-high-accuracy positioning of MSs on the order of centimeters using radio waves of mobile communications [4].

In 6G, moreover, the use of terahertz waves will enable signal bandwidths dramatically wider than those of 5G, so there are expectations of extreme-high-data-rate communications in excess of 100 Gbps. On the other hand, terahertz waves have strong straight-line propagation properties and large propagation loss compared with conventional millimeter waves, which prevents long-distance transmission. This is a technical problem that needs to be addressed. It is therefore important to clarify and model signal propagation characteristics*8 in terahertz waves, establish 6G radio access technologies based on those characteristics, and develop wireless device technologies for these high-frequency bands.

It is common in current mobile communications networks to use a fixed network topology that provides area coverage with BSs installed by a telecommunications carrier. In 6G, however, securing coverage in high-frequency bands and improving connectivity will require an even more advanced network configuration called New Radio Network Topology that will include optimal path selection through the cooperation of multiple access points in the vicinity of a MS as well as diversity*9 transmission and reception [3]. However, to achieve New Radio Network Topology, a variety of studies still need to be made. These include the use of existing objects such as streetlamps and traffic lights for mounting communication antennas, the development of advanced radio relay technologies such as Integrated Access and Backhaul (IAB)*10 and repeater*11 equipment for high-frequency bands, IRSs that can dynamically control reflection intensity and directivity*12, inter-MS linking, and moving BSs. In 6G, the development of advanced Massive Multiple Input Multiple Output (Massive MIMO)*13 is an important technology area. Here, the use of even more antenna elements and an increase in the number of streams (many-layer scheme) are progressing, and the use of Massive MIMO in a distributed antenna arrangement called Distributed MIMO*14 in combination with New Radio Network Topology shows promise.

3. 6G System-level Simulator toward Use of High-frequency Bands

3.1 Simulator Overview

To demonstrate the 6G requirements and technical concepts described in an NTT DOCOMO white paper and special article in this journal [3] [4] and to present the possibilities of terahertz waves, it is important, in the end, to perform evaluations in real environments using real equipment.

*7 Propagation loss: The amount of attenuation in the power of the signal emitted from the transmitting station till it arrives at the reception point.

*8 Signal propagation characteristics: Refers to characteristics such as propagation losses, power and delay profiles, and angular profiles.

*9 Diversity: A general name for technologies designed to improve the quality and reliability of communications using MIMO antennas. In particular, non-closed loop types.

*10 IAB: Technology that aims to achieve high-data-rate/high-capacity services over a wide area by applying 5G wireless communications to even backhaul communications and by achieving flexible and low-cost network design and rollout.

*11 Repeater: Relay equipment on the physical layer for amplifying downlink signals received from a base station and forwarding them to a terminal.

*12 Directivity: An antenna radiation characteristic indicating the directional characteristics of radiation strength (or reception sensitivity) from the antenna.

However, the maturing of wireless device technology and equipment development takes time. At the same time, the possibilities that terahertz waves can bring should be tested early, so it is important to evaluate the possibility of achieving extreme-high-data-rate communications in excess of 100 Gbps by computer simulations. In this regard, it has already been shown by link-level simulation*15 that throughputs of 100 Gbps and greater in the 100 GHz band can be achieved [5]. However, to verify the utility of terahertz waves in near-real-world environments, we developed a 6G system-level simulator in the 100 GHz band and used it to evaluate transmission performance.

This simulator applies terahertz waves under the constraints that antenna size is equivalent to that of the 28 GHz band and transmission power is the same as that of 5G. The use of terahertz waves makes it possible to significantly increase the number of antenna elements (hereinafter referred to as "number of elements"), which means that high BeamForming (BF)*16 gain can be obtained. This, in turn, should compensate for the high propagation loss of terahertz waves, which is what the simulator will test. It also implements IRSs and moving BSs to test New Radio Network Topology mentioned above so that any improvement effects with respect to loss caused by shadowing and blocking can be verified.

In this article, we evaluate user throughput and the feasibility of achieving throughput in excess of 100 Gbps in a shopping mall scenario and factory scenario as two examples of indoor environments.

3.2 Simulator Functions

This simulator compares performance between 5G using a millimeter-wave band and 6G using the 100 GHz band. For the two indoor scenarios described above, performance was evaluated by installing multiple fixed BSs at locations determined beforehand. Furthermore, for the 6G performance evaluation, communications by these fixed BSs were supplemented by drone BSs and small-vehicle-type BSs moving along specific paths. Moreover, in addition to communication by personal devices that have been the mainstay up to now, both people and robots were arranged as MSs envisioning the provisioning of services by advanced robots in the future. It was also assumed that a mixture of stationary MSs and MSs moving at walking speed would be present.

Terahertz waves are greatly affected by propagation loss and blocking that are significantly higher than that of millimeter waves. Taking this into consideration, this simulator first calculates propagation loss and attenuation by blocking according to the positional relationship between BSs and MSs and whether blocking exists between those BSs and MSs. It then determines the received power of each MS and uses that received power to determine the MSs communicating with each BS (fixed, drone, moving, IRS). When using an IRS, the simulator calculates attenuation by blocking using the path lengths from BS to IRS and from IRS to MS. Here, to simplify evaluations, the simulator assumes reflection direction by an IRS to be ideally controlled and performs BF by treating the IRS as a virtual fixed BS. Additionally,

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*13 Massive MIMO: MIMO systems transmit radio signals overlapping in space by using multiple antenna elements for transmission and reception. Massive MIMO systems aim to achieve high-speed data communications with greater numbers of simultaneous streaming transmissions while securing service areas. They achieve that aim by using antenna elements consisting of super multi-element arrays to create sharply formed radio beams to compensate for the radio path losses that accompany high-frequency band usage.

*14 Distributed MIMO: A MIMO transmission technology that transmits different MIMO streams from multiple base stations to a single mobile station.

*15 Link-level simulation: Modeling of the transmitter, receiver, and the physical behavior of the radio propagation path between them, applied in experiments on functionality and performance from transmitter to receiver.

*16 BF: A technique for increasing or decreasing the gain of antennas in a specific direction by controlling the amplitude and phase of multiple antennas to form a directional pattern of the antennas.

based on received power calculated from the above, the simulator will switch BSs communicating with certain MSs with no delay.

To provide communications to multiple MSs, a BS schedules the allocation of radio resources*17, generates a transmission weight*18, performs rank control*19, and determines the modulation level*20. It performs scheduling by allocating time in slot units and frequency in Resource Block (RB)*21 units based on a Proportional Fairness (PF)*22 algorithm. It also calculates a PF metric*23 for each MS and RB and allocates resources to the MS-and-RB combination having the largest PF metric. This simulator, however, performs no retransmissions, so retransmission control is not used in this metric calculation.

Then, after resource allocation, the BS determines the modulation level according to the average Signal to Interference plus Noise power Ratio (SINR)*24 estimated within that RB. Furthermore, in each time slot, each BS communicates with one MS and transmits a maximum of eight layers according to the number of layers that can be transmitted. Here, to speed up calculations in system-level simulations, we use a transmission weight that averages by rank number the elements in the column direction of the Hermitian transpose*25 of the propagation channel*26.

The MS, meanwhile, estimates the transmission signal based on the Minimum Mean Squared Error (MMSE)*27 weight using the propagation channel [6]. It then calculates the block error rate and received SINR of this estimated signal and calculates throughput.

3.3 Evaluation Scenarios

This article describes system-level simulations for a shopping mall and factory. These simulations construct a propagation environment based on multipath Rayleigh fading*28.

1) Overview of Shopping Mall Scenario

The shopping mall scenario is shown in **Figure 1**. This environment consists of a three-story structure in which shops are lined up on the sides of an atrium-style mall. For the sake of simplification, the shop section is treated as a wall surface. People and any robots or self-driving vehicles that serve as MSs are either stationary or moving on the 1st floor. Fixed BSs are installed on the walls of the 2nd floor ceiling. In addition, the evaluation for 6G included the installation of IRSs and drone BSs. The IRSs were installed on pillars to mitigate blocking effects caused by those pillars or signboards scattered throughout the mall and were positioned to reflect radio waves of a fixed BS in a desired direction. The drone BSs were made to shuttle back and forth in the air in the lower section of the two-story atrium to provide communications to MSs on the 1st floor. In this evaluation, it was assumed that the backhaul*29 for the drone BSs was ideally constructed.

2) Overview of Factory Scenario

The factory scenario is shown in **Figure 2**. In contrast to the shopping mall scenario, this scenario assumes a large box-shaped environment containing conveyor belts for work and a crane for moving packages as well as Automatic Guided Vehicles (AGVs). In this environment, people, robots, and AGVs are taken to be MSs. Fixed BSs

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*17 **Radio resources:** General term for radiocommunication resources (radio transmission power, allocated frequency, etc.).

*18 **Transmission weight:** A transmission weighting factor for forming a directional pattern by controlling the amplitude and phase of multiple antennas and for increasing/decreasing antenna gain in a specific direction.

*19 **Rank control:** A method for adaptively changing the number of spatially multiplexed streams according to propagation channel conditions. Given a propagation environment in which the number of eigenspaces (rank) needed for spatial multiplexing is large, the number of spatially multiplexed streams is made large to obtain high throughput.

*20 **Modulation level:** The number of signal phase points in data modulation. This number is 4 in Quadrature Phase Shift Keying (QPSK) and 16 in 16 Quadrature Amplitude Modulation (16QAM).

*21 **RB:** A unit of frequency to be allocated when scheduling radio resources.

*22 **PF:** A technique for allocating radio resources considering fairness among multiple terminals.

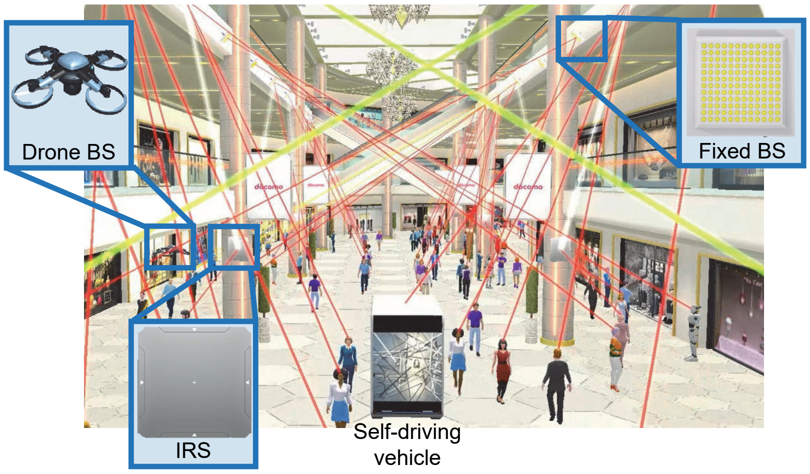

Figure 1 Evaluation environment for shopping mall scenario

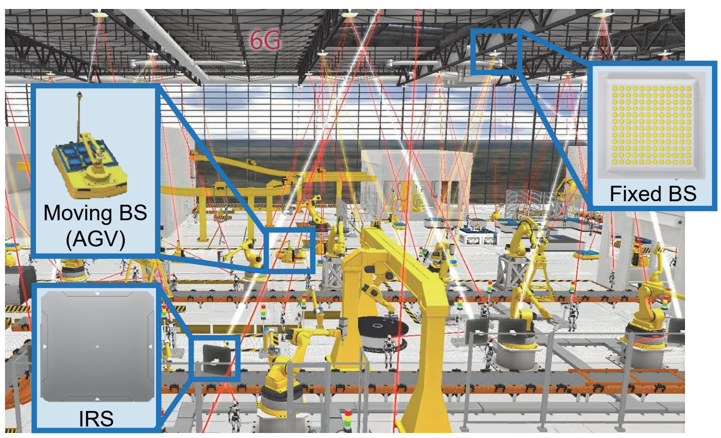

Figure 2 Evaluation environment for factory scenario

are installed on the ceiling and IRSs are installed on walls or pillars so that radio waves can reach MSs positioned at locations that are blocked by the crane or other obstructions. In addition, this environment has no blocking in the ceiling section as in the case of the shopping mall scenario so that radio waves from above are considered to emanate from fixed BSs. Any benefits from drone

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*23 Metric: A numerical index. In the PF algorithm, it is the value obtained by dividing the value of the instantaneous communication quality (received power, etc.) by average communication quality over a certain time period.

*24 SINR: The ratio of desired-signal power to the sum of all other interference-signal power and noise power.

*25 Hermitian transpose: The matrix obtained by transposing each element of a matrix or the rows and columns of a complex matrix containing complex numbers and taking the conjugate of each element.

*26 Propagation channel: An individual communication path in wireless communications. In this article, a communication path between transmit/receive antennas.

*27 MMSE: A method for signal computation that minimizes mean square error.

*28 Multipath Rayleigh fading: A phenomenon by which radio signals emitted from a transmit point traverse multiple transmission paths (multi-path transmission) and combine at a moving receive point resulting in severely fluctuating receive levels. It is known that this statistical fluctuation distribution approximates a Rayleigh distribution especially in a non-line of sight propagation environment.

*29 Backhaul: Indicates the route connecting a wireless base station to the core network.

BSs would therefore be difficult to obtain in this scenario. For this reason, some of the AGVs on the floor are treated as moving BSs. The backhaul for these moving BSs operate ideally the same as that for drone BSs.

4. Performance Evaluation of Throughput in Excess of 100 Gbps Using Terahertz Waves

4.1 Simulation Specifications

Simulation specifications are listed in **Table 1**.

Table 1 Simulation specifications

	Shopping Mall		Factory	
Communication system	5G	6G	5G	6G
Center frequency	28 GHz	100 GHz	28 GHz	100 GHz
Bandwidth	400 MHz	8,000 MHz	400 MHz	8,000 MHz
Number of fixed BS elements (vertical × horizontal × sub-arrays)	392 (7×7×8)	4,608 (24×24×8)	128 (4×4×8)	1,152 (12×12×8)
Number of drone BS elements (vertical × horizontal × sub-arrays)	–	1,024 (8×8×8)	–	–
Number of moving BS elements (vertical × horizontal × sub-arrays)	–	–	–	228 (6×6×8)
Number of BSs	10	Fixed: 10, 20 Drone: 4 IRS: 12	12	Fixed: 12, 25 Moving: 3 IRS: 12
BS total transmission power	30 dBm	Fixed: 30 dBm Drone: 15 dBm	30 dBm	Fixed: 30 dBm Moving: 15 dBm
BS element interval	0.5 λ			
BS element gain	5 dBi			
Number of MS elements	32 (omni-directional antenna)			
Number of MSs	100 (moving: 70, stationary: 30)		100 (moving: 50, stationary: 50)	
MS element gain	0 dBi			
Moving speed	3 km/h			
Channel estimation	Ideal			
Maximum number of layers	8			

For 5G, the center frequency*30 and bandwidth were set to 28 GHz and 400 MHz, respectively, while for 6G, the simulator performed ultra-wideband transmission with a bandwidth of 8,000 MHz at a center frequency of 100 GHz. The element interval was set to 0.5 λ for both 5G and 6G. At this time, the antenna panel size for fixed BSs was assumed to be the same for both 5G and 6G with 6G having approximately 10 times more elements than 5G. In addition, a BS is structured with 8 sub-arrays*31 in one flat array*32 with each sub-array forming one analog beam. Beam direction at each BS was oriented to one MS unit and each BS performed Single User MIMO (SU-MIMO)*33 accommodating only one MS. Transmission power was fixed regardless of the number of elements and set to 30 dBm for fixed BSs and 15 dBm for drone and moving BSs. Each MS used an omni-directional antenna*34 having 32 elements with no gain, and MS gain was taken to be the diversity gain achieved by multiple elements. In addition, 100 MSs were used in the evaluation environment, and among this number, 70 in the shopping mall and 50 in the factory were made to move along a predetermined route at a speed of 3 km/h. As for the number of transmission layers, specifications were set so that the maximum number of transmission layers for each MS could be selected according to the propagation environment from a set of candidates consisting of 1, 2, 3, 4, and 8 layers. Here, it was assumed that throughputs exceeding 100 Gbps could be achieved with 4 or more layers.

4.2 Shopping Mall Scenario

1) Evaluation Results for 5G

The geometry*35 index when applying 5G and the throughput ratio of each MS are shown in **Figure 3**. For 5G, only 10 fixed BSs were used. The

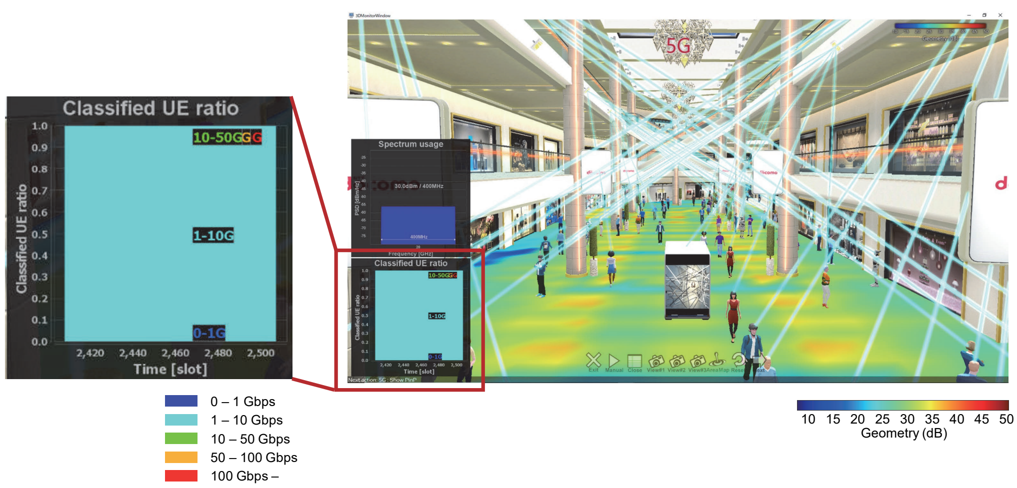

Figure 3 Evaluation results for 5G (shopping mall)

*30 **Center frequency:** The frequency within a frequency band at the center of the range used for communication.

*31 **Sub-arrays:** When generating L beams in Massive MIMO having N antenna elements, a full-array configuration generates L beams while sharing those N elements. In contrast, a sub-array generates a single beam using N/L elements. Sub-arrays are used to reduce the scale of circuitry.

*32 **Flat array:** An array structure featuring a two-dimensional arrangement of many elements in a Massive MIMO antenna.

*33 **SU-MIMO:** A technology for transmitting and multiplexing multiple signal streams by multiple antennas between a base station and terminal with one user as target.

*34 **Omni-directional antenna:** An antenna for which radio-wave intensity is equal in all directions. Also called a non-directional antenna.

*35 **Geometry:** An index indicating area quality using received power distribution, etc.

geometry is displayed on the screen in a range of 10 – 50 dB. The throughput ratios are shown by the graph at the lower left of the figure. In this graph, five different colors represent throughput values in the ranges of 0 – 1 Gbps, 1 – 10 Gbps, 10 – 50 Gbps, 50 – 100 Gbps, and 100 Gbps and greater and the horizontal axis and vertical axis represent time and throughput ratio, respectively. In addition, the colors of the lines connecting the BSs and MSs in the figure correspond to those throughput colors. It can be seen from the figure that propagation loss in 5G using the 28 GHz band was large compared with that of the Sub6 band. On the other hand, the 1st floor section could be covered in full for the most part with all MSs achieving a throughput over 1 Gbps.

2) Evaluation Results for 6G

Next, **Figure 4** shows the results of increasing the number of BS elements assuming 6G and changing the center frequency to 100 GHz while keeping the fixed BSs at the same positions as in Fig. 3. Geometry and throughput ratios are shown in the figure the same as in Fig. 3. Since the bandwidth in this case is 8,000 MHz, the power spectral density*36 dropped significantly, but since the number of elements could be greatly increased compared with 5G even for a relatively small flat array given its relationship with wavelength, high BF gain could be obtained. As a result, received power near the center of the 1st floor mall was improved by approximately 10 – 15 dB compared with 5G. Due to this wide bandwidth and high BF gain, the throughput of each MS was greatly improved. It was found that approximately 70% of the MSs could achieve a throughput over 100 Gbps while approximately 30% could achieve a throughput over

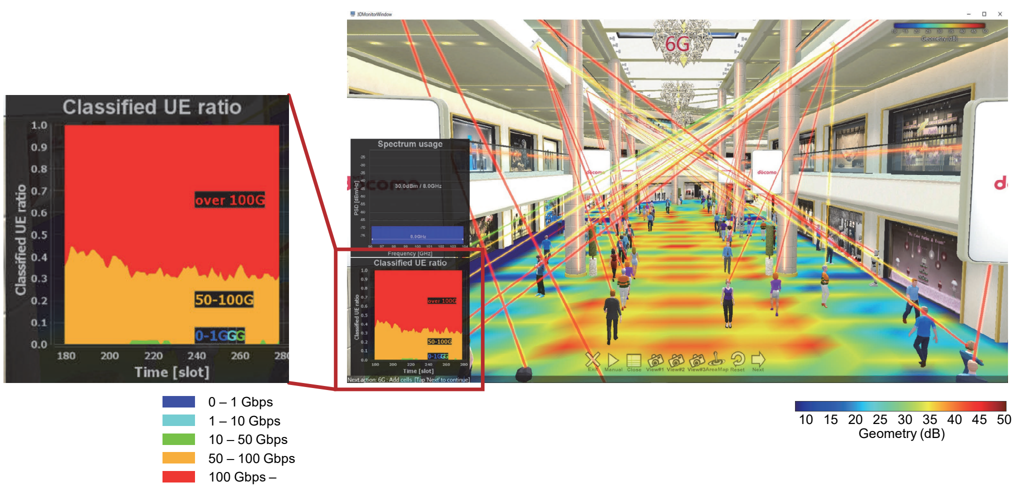

Figure 4　Evaluation results for 6G (shopping mall)

*36　**Power spectral density:** Power per unit frequency (1 Hz).

50 Gbps. In particular, since a single BS could generate multiple beams toward a MS, it can be seen from the colors of the straight lines connecting BSs and MSs that MSs in a Line-Of-Sight (LOS) environment and relatively close to a BS could achieve a throughput over 100 Gbps (4 or 8 layers). On the other hand, given the large propagation loss and strong straight-line propagation properties of radio waves in the 100 GHz band, received power near the walls on the 1st floor deteriorated greatly by as much as 10 dB due to the effects of blocking by the walkway on the 2nd floor. Pillars, as well, produced blocking effects so that, for example, radio waves from a fixed BS installed on a wall on the right side of the mall could not arrive at some sections of the floor on the left side.

3) Evaluation Results when Adding More BSs

Figure 5 shows evaluation results when increasing the number of fixed BSs to 20 units taking the above blocking effects into account. These results show that the increase in BS density could mitigate the effects of pillar blocking and decrease the ratio of MSs with received power less than 20 dB. Based on these results, the ratio of MSs achieving a throughput over 100 Gbps could be improved up to a value of approximately 85%. However, in this figure as well, received power remained low near the 1st floor walls.

4) Evaluation Results when Adding Drone BSs and IRSs

Figure 6 shows evaluation results when adding drone BSs and IRSs taking the above conditions into account. In this evaluation, four drone BSs moved continuously at low speed near the 1st floor walls and two IRSs were attached to each of six pillars. These results show that received power could be greatly increased near the walls of the 1st floor and generally improved by about 20 dB.

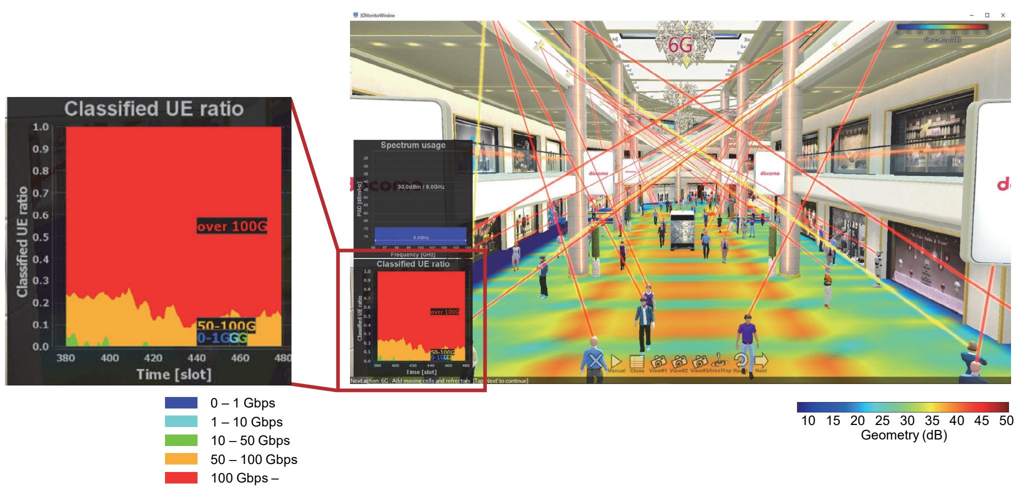

Figure 5　Evaluation results for 6G when adding more fixed BSs (shopping mall)

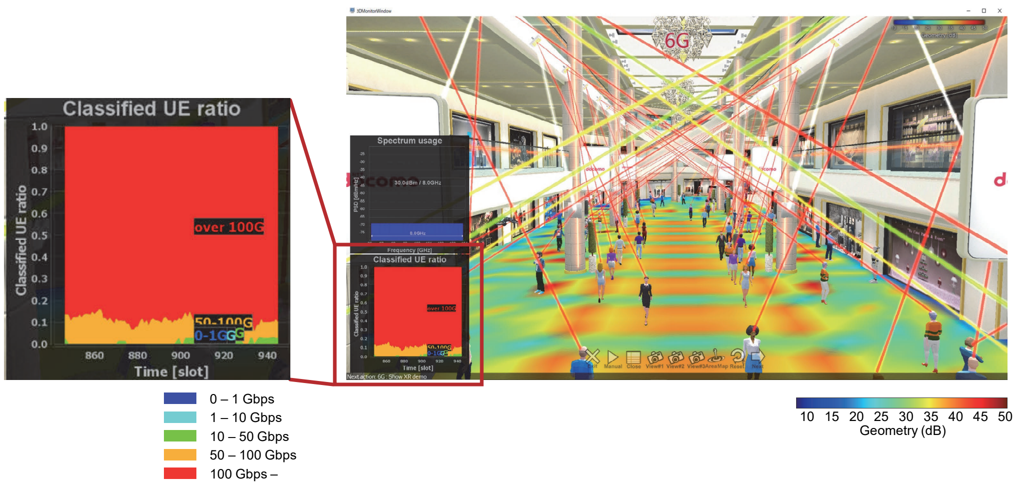

Figure 6 Evaluation results for 6G when adding IRSs and moving BSs (shopping mall)

However, since received power near the center of the mall was already high due to fixed BSs, the effects of the drone BSs and IRSs were thought to be limited to the areas near the walls. For this reason, throughput itself improved only slightly and the ratio of MSs with a throughput over 100 Gbps came to approximately 90%.

The above simulation results for the shopping mall scenario showed that throughputs over 100 Gbps could be achieved when using the 100 GHz band in 6G and that the effects of blocking could be mitigated by the use of drone BSs and IRSs.

4.3 Factory Scenario

Next, we set out to clarify geometry and throughput in the factory scenario.

1) Evaluation Results for 5G

First, evaluation results for the case of 5G are shown in **Figure 7**. For 5G, 12 fixed BSs are installed on the ceiling. In contrast to the shopping mall environment, radio waves radiate from the ceiling with little blocking in the zenith direction. As a result, received power of approximately 35 dB could be achieved in a stable manner in all areas and a throughput of 1 Gbps and higher could be achieved for all MSs.

2) Evaluation Results for 6G

Next, evaluation results when replacing 5G with 6G for the same arrangement and number of fixed BSs as 5G are shown in **Figure 8**. Similar to the shopping mall scenario, received power at locations entering a LOS state due to BF gain could be improved by more than 10 dB compared with 5G. In addition, approximately 30% of MSs could achieve a throughput over 100 Gbps while approximately 60% of MSs could achieve a throughput over 50 Gbps in combination with wideband effects. Additionally, as in the shopping mall scenario, it

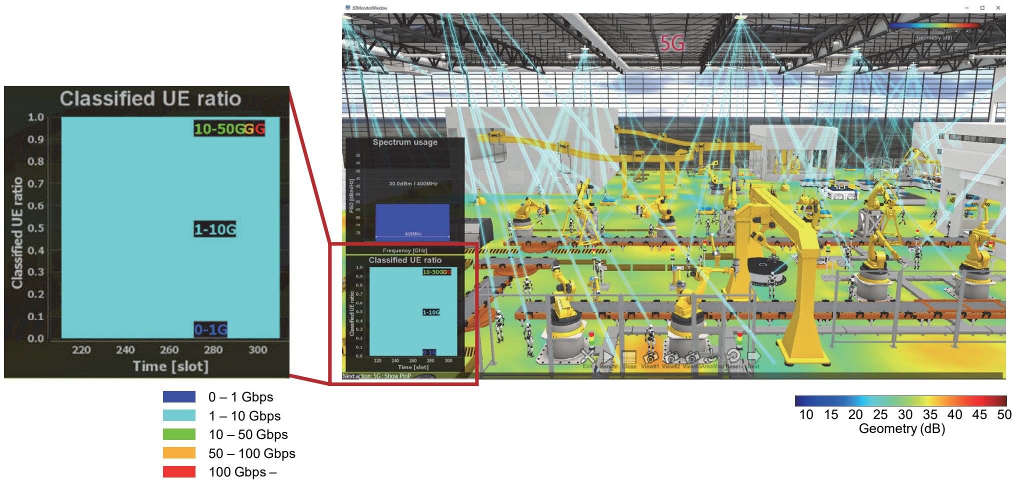

Figure 7 Evaluation results for 5G (factory)

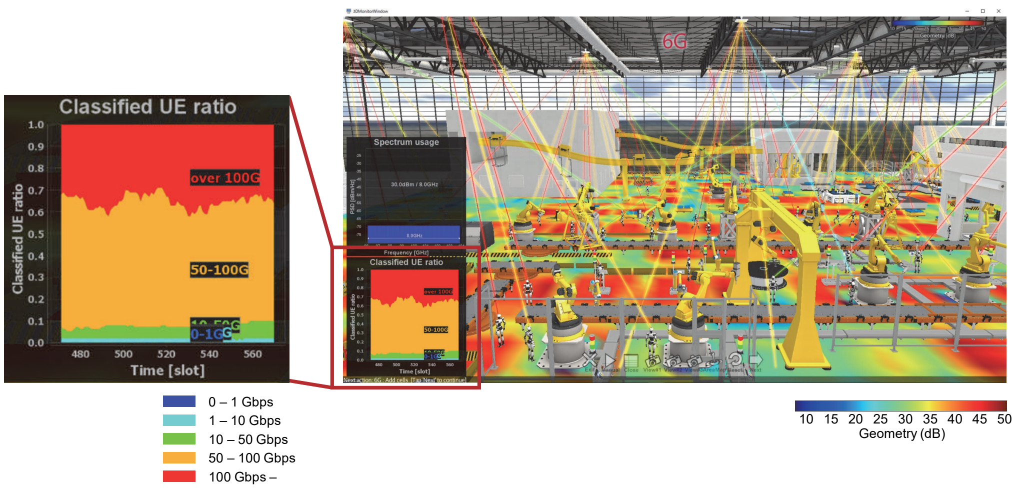

Figure 8 Evaluation results for 6G (factory)

can be seen from the colors of the straight lines connecting BSs and MSs that communications over 100 Gbps (4 or more layers) could be achieved mainly in a LOS environment. However, the factory scenario as well suffered from the effects of blocking caused by the crane or other obstructions in relation to 100 GHz propagation loss and straight-line propagation properties, and received power in some areas came to about 20 dB. As a result, the ratio of user throughput in the range of 10 – 50 Gbps was high compared with the shopping mall scenario.

3) Evaluation Results when Adding More BSs

We increased the number of fixed BSs to 25 units in response to the above blocking effects. Results are shown in **Figure 9**. This increase in the number of BSs shortened the average arrival distance and enabled BF from different fixed BSs to blocked locations. As a result, received power improved over all areas and there were almost no areas with received power less than 30 dB. This had the effect of increasing the ratio of MSs that could achieve a throughput over 100 Gbps to approximately 80% while greatly reducing the ratio of MSs having a throughput in the range of 10 – 50 Gbps.

On the other hand, received power near the structures in the background of Fig. 9 was low, which is thought to be due to the blocking of radio waves from fixed BSs above those structures.

4) Evaluation Results when Adding Moving BSs and IRSs

Taking the above blocking effects into account, we added IRSs near the above structures and near the crane in the foreground of the figure while also adding moving BSs that moved left and right in the center of the figure. Evaluation results in this case are shown in **Figure 10**. These results show that blocking effects could be mitigated and received power improved and that the ratio of MSs with a throughput over 100 Gbps could be improved to approximately 85%.

Based on the above, it was clarified for a factory scenario too that using the 100 GHz band combined with the installation of IRSs could improve received power over all areas and achieve throughputs over 100 Gbps.

5. Conclusion

This article described system-level simulations for two scenarios—a shopping mall and factory—to clarify the feasibility of extreme-high-data-rate

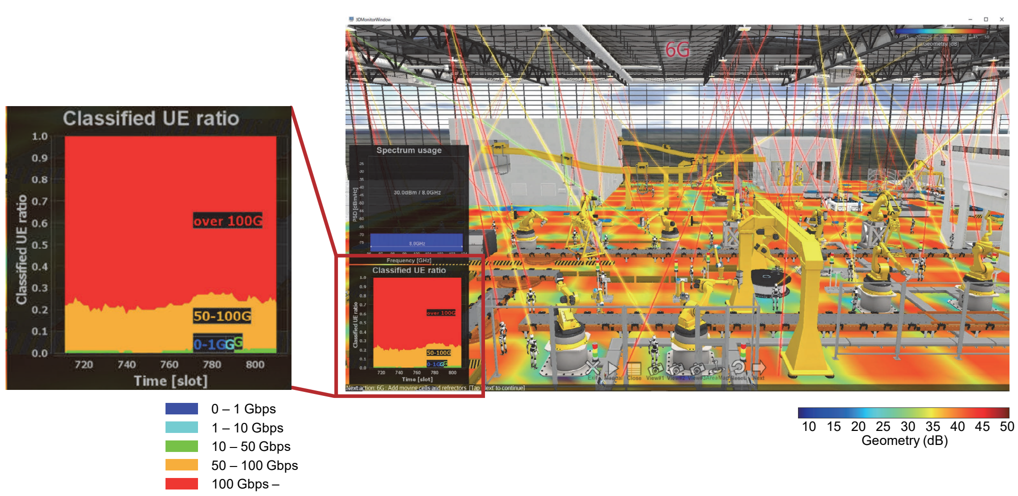

Figure 9 Evaluation results for 6G when adding more fixed BSs (factory)

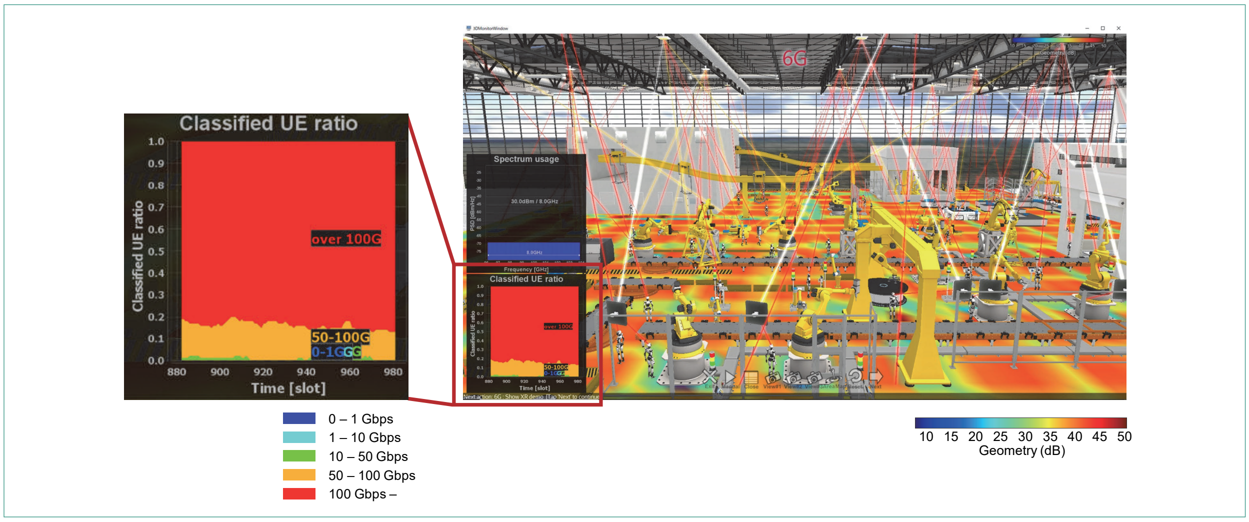

Figure 10 Evaluation results for 6G when adding IRSs and moving BSs (factory)

communications using the 100 GHz band. Going forward, there will be a need to evaluate performance for uplink communications and diverse scenarios to make 6G a reality. In future research, we seek to extend the simulator presented here so that system evaluation and performance of various technical concepts can be visualized and that use cases fitting the 6G era can be experienced in accordance with that performance level.

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