# Technologies to Enhance 5G Communication Network Capacity

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**With its commercialization envisaged for 2020 and later, the fifth-generation mobile communication system (5G) is expected to make communication networks evolve further through significant improvement of performance enabling communication capacity, low latency, high reliability, and simultaneous connections with massive numbers of devices. The 5G system may be used, for example, to transmit monitoring camera data, watch real-time free-viewpoint video in a stadium, or control manufacturing robots in a factory. To increase network capacity in order to accommodate such services, technologies such as small cells and beam multiplexing technology are being considered. However, it is necessary to solve the problem of communication quality degradation caused by inter-cell and inter-beam interference. To address this problem, Fujitsu has developed two technologies. One is dynamic virtual cell control using the centralized baseband unit (C-BBU) to reduce inter-cell interference. The other is configuring interleaved beamforming with inter-subarray coding to minimize inter-beam interference by antenna configuration and inter-subarray coding. This paper describes the merits of these technologies, application scenarios, and evaluation results through simulations and experiments.**

## 1. Introduction

Data traffic of the world's mobile terminals is predicted to increase at an average annual growth rate of 46% between 2017 and 2022, expanding seven-fold over this 5-year period.[1] Further, communication functions can now be found in various kinds of machines and sensors, the number of IoT devices connected to networks is increasing at an average annual growth rate of 15%, and is expected to reach 40 billion by 2020.[2]

In response, R&D of the fifth generation mobile communications system (5G), which is expected to come into service possibly as soon as 2020, is actively being carried out. 5G is expected to give rise to new services that take advantage of the evolution of communication networks, with merits such as low latency, high reliability, and simultaneous connection of a massive number of devices,[3] besides increased communication capacity through dramatic performance improvement.

5G, with its large capacity, may for example be used to accommodate the use of mobile terminals by a huge number of users in crowded urban areas, or transmit videos from monitoring cameras in a shopping mall or product inspection cameras in a factory. The low latency and large capacity of 5G may also be used to watch real-time free-viewpoint video during sporting events at stadiums. Furthermore, its high reliability and low latency may be used to control robots in a factory. The implementation of such services will require the following measures.

1) Cell density increase (small cell deployment)

Small cell deployment means reducing the size of the geographical area covered by the radio waves of a base station. By downsizing cells and increasing the number of transmission points (TPs) per unit area, it is possible to increase capacity per unit area as the number of users per TP decreases. Moreover, since 5G uses radio waves in a higher frequency band than 4G (LTE), these radio waves are difficult to diffract, and radio wave penetration loss from outdoor to indoors is high. As a result, dead zones tend to occur in non-line-of-sight (NLOS) areas where obstacles exist between TPs and users and in indoor areas where there is no straight path of radio wave propagation. Small cell deployment is also effective for such cases.

2) Expansion of frequency bandwidth

Since the system capacity, which is the accommodatable data traffic volume, is proportional to the frequency bandwidth to be used, it can be increased by expanding the frequency bandwidth. The UHF band (300 MHz to 3 GHz), which has been conventionally used for mobile communication, is overcrowded and more bandwidth is needed. Therefore, use of the SHF band (3 GHz to 30 GHz) or the EHF band (30 GHz to 300 GHz), which are higher frequency than conventional frequency bands, is also being considered for 5G. Since these high frequency bands are hardly used as of now, it is easy to secure wide bandwidth for new applications. Further, in April 2019, Japan decided to allocate the 3.7 GHz, 4.5 GHz, and 28 GHz frequency bands to existing carriers. Moreover, 4.5 GHz and 28 GHz band allocations for private mobile networks are also being considered. This envisions expansion of the traditional allocation of band licenses beyond the major carriers to include also municipalities and companies for business and other uses.[4)]

We have been working since FY2015 on research and development of an ultra-high-density distributed antenna system for the application of small cell deployment to 5G.[5), 6)]

This paper introduces dynamic virtual cell control technology as a countermeasure against the inter-cell interference that accompanies small cell deployment in the low SHF band of 6 GHz or less. Next, it describes inter-subarray coding interleaved beamforming technology using a high SHF band of 6 GHz or higher that can secure a wide frequency band.

## 2. Dynamic virtual cell control technology

### 2.1 Characteristics of conventional small cells and massive MIMO

Conventional small cell configurations have high TP density, which increases interference to users from nearby TPs. This inter-cell interference reduces the beneficial effect of improving system capacity through small cell deployment. Moreover, as shown in **Figure 1(a)**, this interference invariably causes cell boundary areas with poor reception quality. For these reasons, massive MIMO (multiple input multiple output), which concentrates many antennas in one place instead of

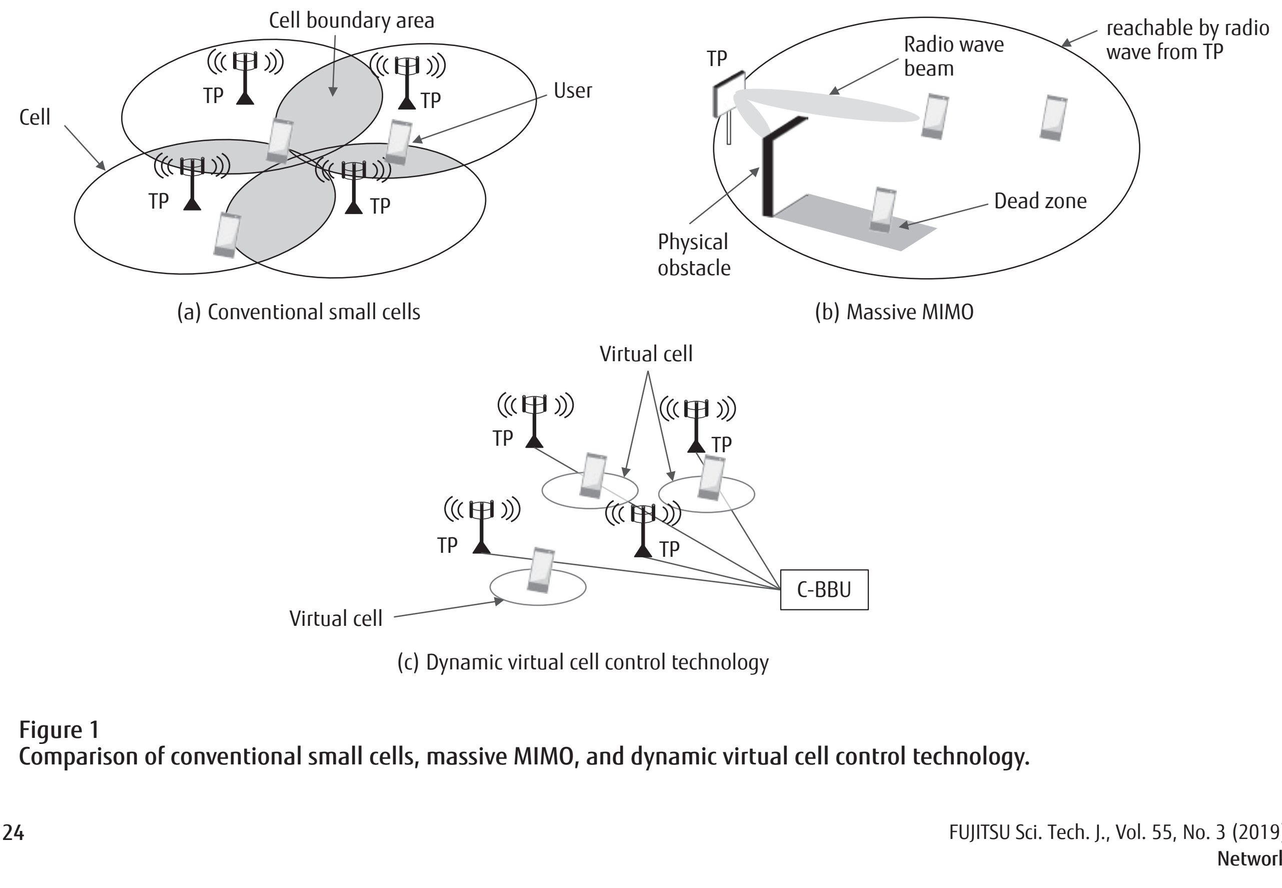



**Figure 1**
**Comparison of conventional small cells, massive MIMO, and dynamic virtual cell control technology.**

dividing the antennas TPs to form small cells, is also being considered.

However, in environments with many NLOS spots where obstacles obstruct straight paths between TPs and users, radio waves have poor reach and as a result, dead zones occur, as shown in **Figure 1(b)**. Furthermore, the size of antenna elements for low-SHF bands is larger than that for high-SHF bands. Use of multiple such antennas for massive MIMO in low-SHF bands will result in larger equipment size, which may be problematic in terms of esthetics in some environments such as indoors.

## 2.2 Advantages of dynamic virtual cell control technology

Against this backdrop, we have been studying dynamic virtual cell control as a way to improve signal quality while reducing interference among multiple TPs. Dynamic virtual cell control technology forms virtual cells by narrowing down with beams the area reached by radio waves. This technology allows the shape of cells to be changed instantly, and the cell boundaries to change dynamically. As shown in **Figure 1(c)**, this allows adjustments to ensure that each user can be at the center of a virtual cell with good reception quality.

Concretely, through a centralized baseband unit (C-BBU) to which TPs are connected, the amplitude and phase of the transmission signal are adjusted so that the data of individual users transmitted at the same time do not interfere with one another.[5] In the case of conventional small cells, the signals from nearby TPs are also received as interference, causing reduction of throughput. By contrast, in the case of dynamic virtual cell control technology, virtual forming of propagation paths of independent radio waves makes it possible to achieve communication without inter-cell interference. This makes dynamic virtual cell control technology a very effective method in cases of ultra-high-density placement of TPs, which are sources of interference.

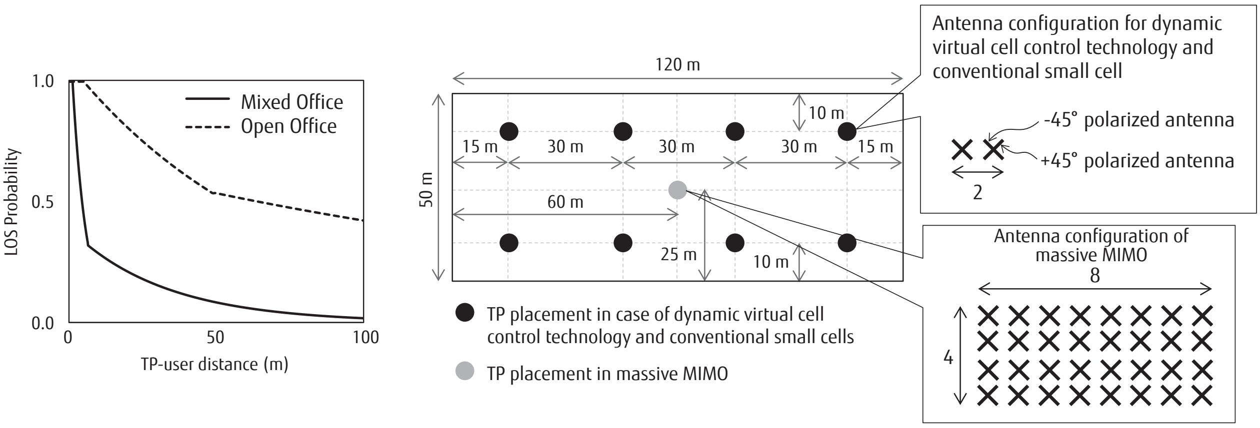
## 2.3 Simulation using the Indoor Mixed Office model

Dynamic virtual cell control technology increases the probability of securing a straight unobstructed path, line of sight (LOS), between any one of the TPs arranged at a very high density and the user. Thus, environments that present many obstructions that impede the transmission of radio waves are ideal for demonstrating the capabilities of dynamic virtual cell control technology. Such environments include indoor environments such as shopping malls, as previously mentioned, and factories housing various production equipment, as well as ultra-dense urban environments crowded with buildings.

As an example, the evaluation results of a simulation using the Indoor Mixed Office model[7] simulating a complicated indoor structure as defined by the 3rd Generation Partnership Project (3GPP), which is developing the 5G standard, are presented. The Indoor Mixed Office model is a statistical model that probabilistically determines LOS or NLOS conditions between a given TP and user according to distance.

As shown in **Figure 2(a)**, in this model, the probability of LOS conditions is lower than in the case of a model that simulates an open space, since simulated environment is one in which radio wave propagation is poor. As shown in **Figure 2(b)**, in the case of dynamic virtual cell control technology and conventional small cells, eight TPs, compared with just one in the case of massive MIMO, are placed on the ceiling (height: 3 m). Further, as regards the antenna configurations, in the case of dynamic virtual cell control technology and conventional small cells, two cross polarized antenna pairs arranged in the lateral direction are used for each TP. In the case of massive MIMO, four cross polarized antenna pairs in the longitudinal direction and eight cross polarized antenna pairs in the lateral direction are arranged.

**Table 1** shows the total throughput of all users and the 5% CDF (cumulative distribution function) throughput, which is the lower 5% value of the cumulative distribution of each user, when 30 users are randomly placed. Dynamic virtual cell control technology and massive MIMO had total throughput approximately 1.8 times and 1.6 times greater, respectively, than that of conventional small cells. Looking at the 5% CDF throughput, dynamic virtual cell control technology has throughput approximately 13 and 2.2 times greater than conventional small cells and massive MIMO, respectively. These results confirm that this technology is capable of achieving both high total throughput and high 5% CDF throughput by increasing the probability of a TP being near the user.




(a) Relationship between TP-user distance and LOS probability

(b) TP placement of 3GPP Indoor Mixed Office model evaluation

**Figure 2**
**Evaluation conditions for 3GPP Indoor Mixed Office model.**

**Table 1**
**Evaluation results of 3GPP Indoor Mixed Office model.**

| | Total throughput (Mbps) | 5% CDF throughput (Mbps) |
|---|---|---|
| Dynamic virtual cell control technology | 5,920 | 184 |
| Massive MIMO | 5,113 | 83 |
| Conventional small cells | 3,269 | 14 |

## 2.4 Indoor demonstration experiment using real-time transmission equipment

We conducted an experiment to demonstrate the practicality of dynamic virtual cell control technology in the lobby area of Fujitsu Shinkawasaki Technology Square.

In this experiment, four TPs (with two antennas each) were placed at the four corners of the area, and the directivity of each antenna was adjusted so that the resulting beam was oriented in the directions of the arrows shown in **Figure 3**. Directivity as used here refers to the transmission direction with the highest gain of the antenna element. In the case of conventional small cells, user #0 (not shown in the figure) communicates with the TP with the highest reception power, and dummy signals are transmitted from the other TPs to simulate interference. On the other hand, in the case of dynamic virtual cell control technology, one receiving antenna is arranged on each user terminal, and all the TPs communicate with all the users (#0 to 3) simultaneously. Measurement was performed with the location of users #1-3 fixed and that of user #0 variable.

The respective heat maps as shown in Figure 3. It can be clearly seen that in the case of conventional small cells, the locations with good throughput are limited to the vicinity of TPs due to inter-cell interference. On the other hand, it was found that, in the case of dynamic virtual cell control technology, high throughput can be maintained at any location since cell boundaries do not occur.

# 3. Inter-subarray coding interleave beamforming technology

## 3.1 Beam forming (BF) method

In the high SHF band typified by 28 GHz, since a wide bandwidth of several hundred MHz to several GHz can be secured, system capacity is dramatically improved. For this reason, 5G is expected to be used for mobile broadband (MBB). Compared with the low-SHF band, in the high-SHF band wavelengths are short and the antenna elements can be made more compact, making it possible to control the directivity of the beam,

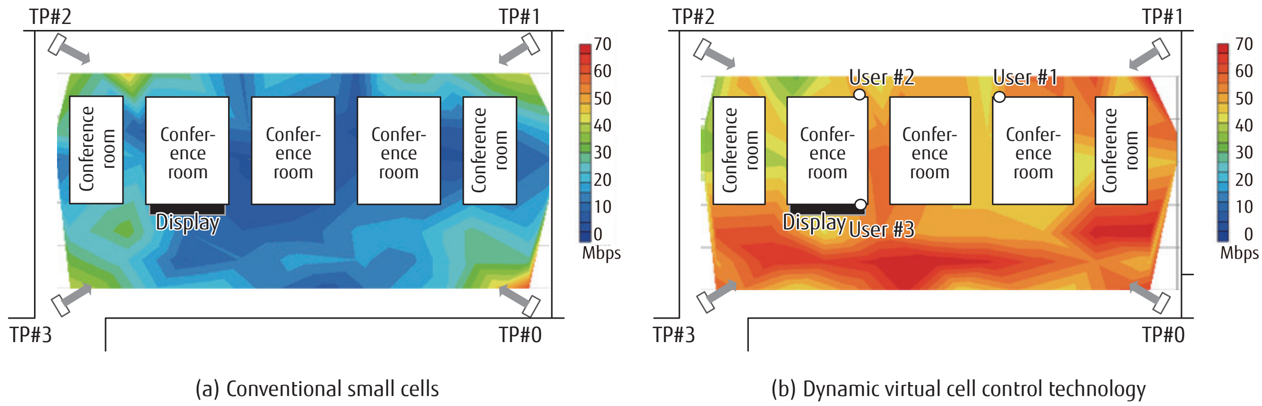



**Figure 3**
**Comparison of throughput.**

that is, the radio wave, with massive-element antennas to transmit radio waves in the desired direction. Beam multiplexing, a technology capable of increasing system capacity by generating multiple beams with a massive-element antenna that simultaneously transmits and receives signals in the multiple required directions, is attracting attention. The characteristics of the conventional methods using beam multiplexing technology (digital BF method and localized subarray type hybrid BF method), and the inter-subarray coding interleave BF method devised by Fujitsu Laboratories are described below.

1) Conventional method

The digital BF method is shown in **Figure 4(a)**. In this method, beam control is performed only with digital circuits, and the number of frequency converters and DACs (digital-to-analog converters) and ADCs (analog-to-digital converters) must be the same as the number of antenna elements, resulting in enormous power consumption.

Hence, hybrid beamforming that uses phase shifters (PSs), which are analog circuit for beam control, has been attracting attention. In this configuration, the number of DACs, ADCs, and frequency converters can be reduced to the number of beams generated by the antenna elements, thereby greatly reducing power consumption.

One hybrid BF method is the localized subarray type hybrid BF method, which groups antennas into subarrays corresponding to the number of beams to be generated, and controls beams in different directions using the respective subarrays as shown in **Figure 4(b)**. However, to generate the same beams as the digital BF method by this method, it is necessary to make the antenna size per beam the same as for the digital BF method. As a result, antenna size is proportional to the number of beams, meaning larger equipment, which is an issue in its own right.

2) Inter-subarray coding interleave BF method

As a solution, the authors devised the inter-subarray coding interleave BF method, which reduces power consumption as well as antenna size as shown in **Figure 4(c)**. This method consists in forming beams by distributing multiple data to alternately arranged subarrays. Since the antenna interval of each subarray is several times longer than one wavelength, grating lobes, which are unnecessary beams in directions other than the desired direction, are generated. This problem is dealt with by mixing multiple data in an inter-beam coding unit beforehand and then radiating each data from all the antennas, allowing the space between antennas to be reduced equivalently.

Although each beam is fixed at a fixed angular interval, the beam azimuth can be freely controlled by the PS installed in each antenna. In areas of dense user demand for large-capacity communications, such as spectator stands in stadiums and downtown areas, there are almost no disadvantages in the beam interval being fixed, and inter-subarray coding interleaving technology is very effective.

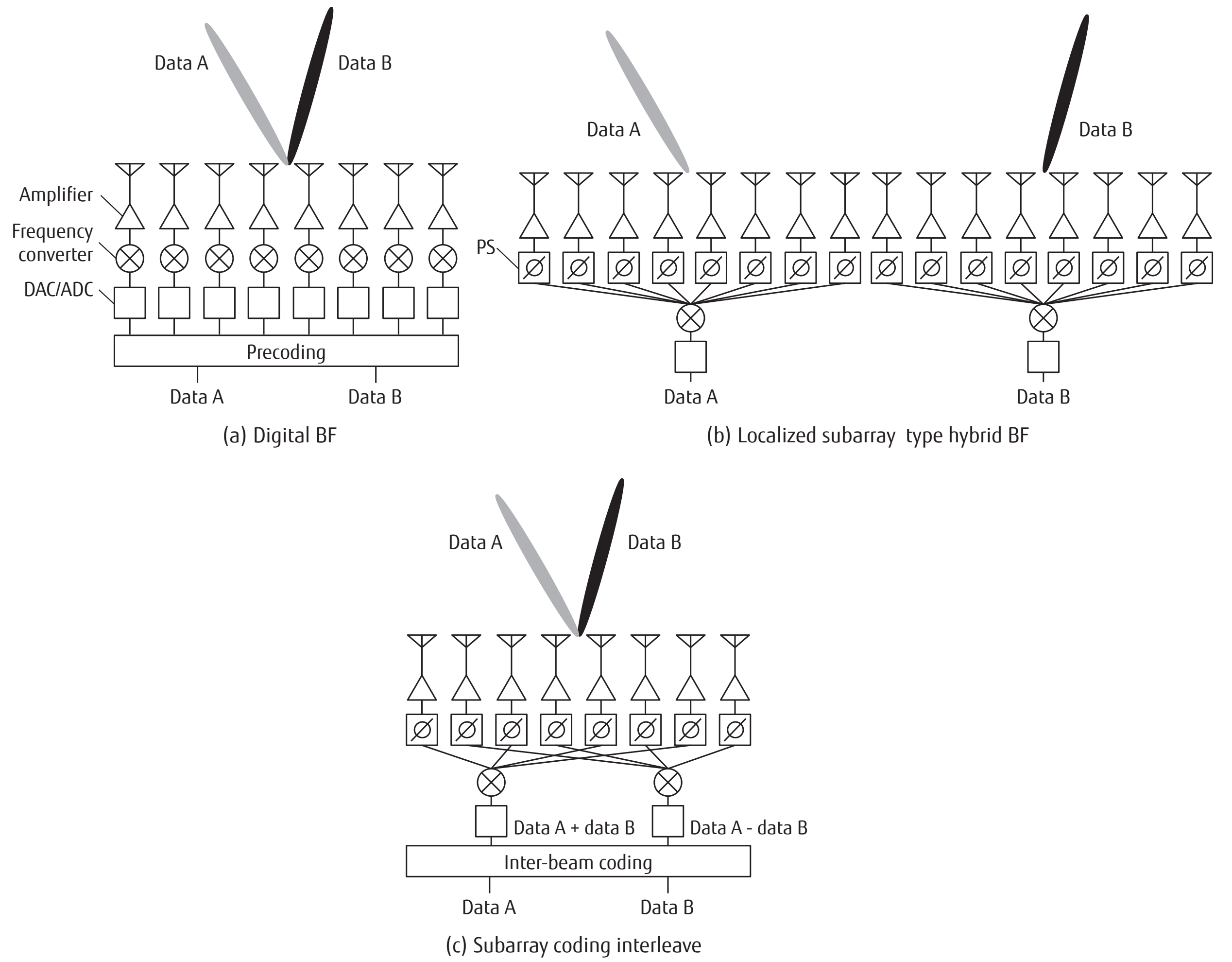



**Figure 4**
**BF method configurations**

## 3.2 Demonstration experiment

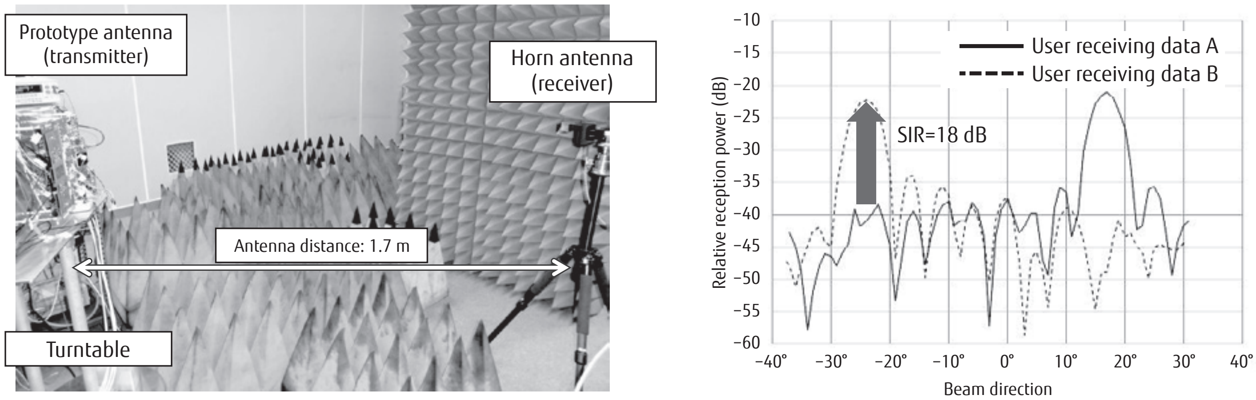
To verify the principle of the inter-subarray coding interleave BF method, a demonstration experiment was carried out using frequencies in 60 GHz band, which is an unlicensed band. A total of 128 antennas were manufactured on a trial basis for carrying out the demonstration experiment, and they were arranged 16 across and 8 deep. Using these antennas, the system was set up to generate beams into two directions differing by 45 degrees.

The actual test environment is shown in **Figure 5(a)**. The signal was transmitted using the prototype antennas and it was received by a horn antenna while turning the transmitting side by using a turntable. Then, measurement of the power of the signal yielded the beam pattern. The measured beam patterns are shown in **Figure 5(b)**.

In this experiment, beam multiplexing using the inter-subarray coding interleave BF method was realized by securing the signal-to-interference power ratio (SIR) of 18 dB or more by directing the beams to the user receiving data A and the user receiving data B respectively. Further, as the result of generating beams in four different directions using two prototype antennas, it was possible to achieve throughput of 2.5 Gbps per beam and 10 Gbps in total.

## 4. Conclusion

This paper described improvements to conventional small cells and inter-beam interference with a view to expanding system capacity to meet the traffic capacity requirements for 5G commercialization.




(a) Experimental setup

(b) Beam pattern measurement results

**Figure 5**
**Experimental setup and results.**

For the low-SHF band, dynamic virtual cell control technology that can realize homogeneous throughput regardless of the location of users was described. Further, for the high-SHF band, inter-subarray coding interleave BF technology using massive-element antenna was described as being applicable. Going forward, we plan to raise the number of users who can communicate simultaneously.

This paper includes some of the achievements of the "The research and development project for realization of the fifth-generation mobile communications systems," we were commissioned to carry out by the Ministry of Internal Affairs and Communications.

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