5G Trials | Trial Collaboration | High Frequency Band

Technology Reports

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5G Trials with Major Global Vendors

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5G has many requirements beyond just higher speed and greater capacity, such as supporting huge numbers of devices and transmitting with even less delay. Satisfying these requirements involves many technical elements and requires supporting broad bandwidths. As such, to verify technologies efficiently, we have built relationships to collaborate on 5G trials with many influential vendors. This article gives an overview of 5G transmission trials done in collaboration with major vendors in the world, focusing on verifying multi-antenna transmission technologies for utilizing high frequency bands. It also introduces results obtained from collaborative trials done with these companies.

1. Introduction

5G*1 is aiming to increase system capacity dramatically, to more than 1,000 times that of LTE. To achieve this, technical development is being done to actively use high frequency bands for mobile communications, including ultra wideband transmission exceeding 1 GHz and targeting bands up to the Extremely High Frequency (EHF)*2 band. There are also much more diverse system requirements beyond increased capacity, such as supporting connections from very large numbers of devices, and transmission with even less delay, and technical elements to implement these are diverse. Also, to implement 5G services by 2020, it will be necessary to begin practical technical verification early and accelerate technical study, so there may not be enough time for NTT DOCOMO to complete the wide range of technical validations as it has done in the past. As such, NTT DOCOMO is conducting trials in cooperation with major global vendors, to verify key elemental radio access technologies for 5G, in order to quickly establish a 5G ecosystem*3 and implement efficient and effective technical verification. As of the end of December, 2015, it had agreed on collaborative trials with 13 companies, and some vendors had started field trials as of the beginning of 2015 [1] [2].

This article gives an overview of these 5G trials and introduces the results obtained in cooperative experiments with each vendor, focusing on

*1 **5G:** A next-generation mobile communication system, the successor to 4th generation mobile communications systems.

*2 **EHF:** Radio waves in the range from 30 to 300 GHz. Also called millimeter waves.

experimental results related to multi-antenna transmission technologies for high frequency bands.

2. Overview of 5G Trial Collaboration

Current 5G trial efforts being conducted in cooperation with vendors can be categorized into the following topics: (1) Technologies to improve spectral efficiency that can be applied to a broad range of frequency bands, including the current cellular bands, (2) Utilization of high frequency bands including the EHF band, (3) Key devices (chipsets*4) for studying 5G terminal devices, and (4) Measurement technologies for evaluating performance of 5G radio access technologies and radio equipment in the ultra-high frequency bands (**Table 1**).

(1) Deals with validating various elemental technologies to increase system capacity in very densely arranged optical-feed

Table 1　5G Trials overview

	Collaborating vendor	Trial overview
(1) Experiments on technology for improving spectral efficiency over a wide range of frequency bands to which it can be applied	Alcatel Lucent (France)	· Experiments on new signal waveform candidates suitable for broadband communication and M2M communication
	Fujitsu (Japan)	· Experiments on coordinated radio resource scheduling for super dense base stations using RRH
	Huawei (China)	· Experiments on MU-MIMO using TDD channel reciprocity, new signal waveforms, and advanced multiple access
	NEC (Japan)	· Experiments on a beamforming technology that controls directivity in the time domain using very-many-element antennas to increase system capacity per unit area in small cells
	Panasonic (Japan)	· Experiments on system control technologies for efficient communication combining multiple frequencies, such as high frequency bands and wireless LAN frequency bands, and system solutions applying advanced imaging to 5G communications technology
(2) Experiments that focus on development of high frequency bands	Ericsson (Sweden) (Sec. 3.1)	· Experiments on a new radio interface concept, for use with high frequency bands, and a Massive MIMO technology combining spatial multiplexing and beamforming
	Samsung Electronics (South Korea) (Sec. 3.2)	· Experiments on hybrid beamforming, combining digital and analog techniques to realize stable, ultra-wideband transmission in high frequency bands as well as a beam control technology for tracking mobile stations
	Mitsubishi Electric (Japan) (Sec. 3.3)	· Basic experiments on a multi-beam, multiplexing technology using virtual arrangements of massive numbers of antenna elements, which will realize ultra-high speeds in high frequency bands
	Nokia Networks (Finland) (Sec. 3.4)	· Experiments on ultra-wideband radio transmission, assuming use for efficient EHF band mobile communication
(3) Experiments on 5G terminal devices	Intel (USA)	· Experiments involving compact, low-power chipset prototypes for mobile terminals, such as smartphones and tablets that will realize the 5G concept of high-speed, high-capacity and high reliability.
	Qualcomm (USA)	· Collaboration on study and testing for compact, low-power 5G device implementations to enable provision of mobile broadband extended to peak data rates of several Gbps
(4) Evaluation of performance of radio equipment for ultra-high frequency bands	Keysight Technologies (Japan)	· Study of communication performance measurement technology for base stations and terminals, for ultra-wideband communication in high frequency bands · Experiments on antenna performance measurement technology for Massive MIMO · Measuring and analysis of radio propagation characteristics in high frequency bands and generation and analysis of signal waveforms
	Rodhe & Schwarz (Germany)	· Study of antenna performance and evaluation technology for base station communications performance for schemes such as Massive MIMO, which use ultra-wide bandwidths in high frequency bands · Measuring and analysis of radio propagation characteristics in high frequency bands, generation and analysis of signal waveforms

*3 **Ecosystem:** A mechanism in which a number of companies partner across their specialties and include consumers and society in their business activities to stimulate each others' technologies and assets, from R&D through to sales, advertising and consumption, to enable coexistence and co-prosperity.

*4 **Chipset:** Devices that control mobile terminal software and various hardware processing. Devices such as the CPUs and control circuits are collectively referred to as "the chipset."

small cells*5 using transmission methods and signal waveforms suited to particular usage scenarios such as broadband or Machine-to-Machine (M2M)*6 communication and to further improve spectral efficiency with Multiple Input Multiple Output (MIMO)*7 transmission [3]–[7].

(2) Deals with broadband mobile communications technology with radio interfaces for effective use of frequencies higher than those currently in use, including frequencies over 6 GHz. Specific examples include ultra-high-speed, high-capacity transmission technologies using MIMO with large numbers of antennas (Massive MIMO*8) to effectively compensate for radio propagation losses in the high frequency bands, and elemental technologies that can be applied in EHF-band mobile communications.

(3) Deals with key-device prototypes for implementing compact, low-power 5G devices.

(4) Deals with elucidating radio propagation in the EHF band and evaluating radio performance of active antenna systems composed of large numbers of antennas.

3. 5G Experimental Trials

This section describes some of the 5G experimental trials mentioned above, emphasizing cultivation of high frequency bands in (2), which will be essential to realizing high speed and increased capacity in the medium and long term.

3.1 Trials of 5G Radio Access in the 15 GHz Band

An overview of verification of a 5G radio interface concept using the 15 GHz band, done in cooperation with Ericsson, is given below [8]–[10].

1) Trial Overview

The major specifications of the 15 GHz band 5G testbed are given in **Table 2**, and the base station and mobile station are shown in **Figure 1**. Four Component Carriers (CC)*9 of bandwidth of 100 MHz and of successive frequencies were combined with carrier aggregation*10, resulting in a system bandwidth of 400 MHz. Base stations and mobile stations have four antennas for transmitting and receiving and use four-stream*11 MIMO transmission. Use of high frequency bands for small cell areas is being studied for 5G, and this testbed was used in a 15 GHz band trial, to verify radio signal transmission performance in various small cell environments, in the YRP area in Yokosuka City in Kanagawa Prefecture. Experiments were done in four small cell environments: (a) a lobby (indoor), (b) a courtyard (outdoor and indoor-outdoor), (c) between buildings, and (d) a parking lot (outdoor).

2) Experimental Results

Throughput measurement results are shown together in **Figure 2**. Throughput of up to 4.3 Gbps was obtained in (a) the lobby when standing still. However, throughput dropped when in the shadow of a pillar, confirming that the direct signal is dominant at 15 GHz. In (b) the courtyard, the maximum through-

Table 2 Test equipment basic specifications

Radio access	OFDMA
Duplexing	TDD (Uplink/Downlink ratio = 2 : 48)
Carrier frequency	14.9 GHz
System bandwidth	400 MHz
Output power	Base station: 2.14 W (33.3 dBm) Mobile station: 2.24 W (33.5 dBm)
No. of transmit/receive antennas	4
No. of CCs	4
Subcarrier spacing	75 kHz
Subframe length	0.2 ms
Symbol duration	13.3 μsec + CP 0.94 μsec
Data modulation	QPSK, 16QAM, 64QAM

OFDMA: Orthogonal Frequency Division Multiple Access
TDD: Time Division Duplex
QPSK: Quadrature Phase Shift Keying

*5 **Small cell:** A generic term for cells transmitting with low power and covering areas relatively small compared to macrocells.

*6 **M2M:** A generic term for machine communication without intervention from a human operator.

*7 **MIMO:** A signal transmission technology that uses multiple antennas for transmission and reception to improve communications quality and spectral efficiency.

*8 **Massive MIMO:** A generic term for MIMO transmission technologies using very large numbers of antennas.

*9 **CC:** A term used to refer to the carriers bundled together when using carrier aggregation (See *10).

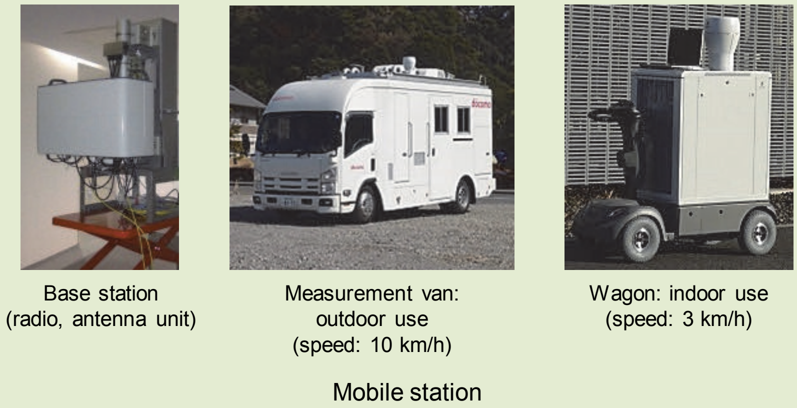

Figure 1 5G test equipment

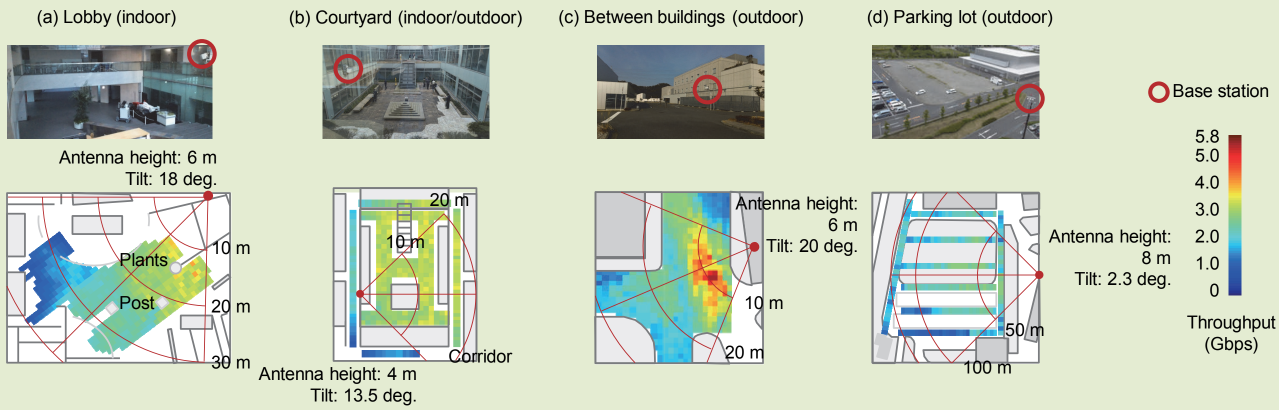

Figure 2 Transmission test environment and throughput characteristics

put was 3.6 Gbps, and the throughput was similar in the courtyard (outdoor) and in the corridor separated by a glass window (outdoor-indoor). In the corridor, the throughput decreases since the received signal power dropped due to the glass window separating it, while channel correlation*12 is low. On the other hand, despite the stronger received signal, the throughput decreases in both lobby and courtyard due to high channel correlation caused by the dominant direct signal path. Based on this, in measurements in (c), between buildings, throughput up to 5.5 Gbps was achieved by reducing channel correlation with increased separation between base station antenna elements, from 5 λ to 21.5 λ. Finally, (d), the parking lot, was a line-of-sight environment so channel correlation was very high, and maximum throughput was 2.8 Gbps. However, even at distances of 100 m or more from the base station, throughputs averaging 2 Gbps were achieved.

Indoor and outdoor 5G experiments were done using the 15 GHz band as above, achieving 5 Gbps by setting the outdoor base station antenna spacing to 21.5 λ. We also confirmed propagation losses and increased channel correlation due to propagation characteristics particular to high frequency bands. To resolve these issues in the future, we will validate technologies for coordinated

*10 **Carrier aggregation:** A technology for increasing bandwidth while maintaining backward compatibility with LTE, by using multiple component carriers and transmitting and receiving them simultaneously.

*11 **Stream:** A data sequence transmitted or received over a propagation channel using MIMO transmission.

*12 **Channel correlation:** An index indicating the similarity among multiple signals, with values near 1 (one) indicating similarity (correlation) and values near 0 (zero) indicating dissimilarity.

multi-point transmission*13, distributed MIMO*14, and beamforming*15.

3.2 Trials of 5G Radio Access in 28 GHz Band

An overview of verification of broadband transmission in the 28 GHz band, done in collaboration with Samsung Electronics, is described below [11] [12].

1) Test Overview

Various specifications of the trial test equipment are shown in **Table 3**, and the test equipment is shown in **Figure 3**. Broadband transmission was performed using a carrier frequency of 27.925 GHz and a bandwidth of 800 MHz. The base station antennas consisted of two 48-element planar array antennas*16 and the mobile station had two four-element linear array antennas. Each array antenna produced one beam, enabling beam multiplexed transmission of up to two streams. Both base station and mobile station featured beamforming capabilities, enabling them to achieve higher beam gain*17. Base station and mobile station select the combination of beams that maximize received power from among multiple beam candidates. To verify the beamforming effects of using Massive MIMO with high frequency bands, transmission field trials were conducted at Samsung Digital City in Suwon, Korea.

Table 3 Test equipment specifications

Specification	Base station	Mobile station
Access method	OFDMA	
Modulation	QPSK, 16QAM, 64QAM	
Duplexing	TDD	
Carrier frequency	27.925 GHz	
Bandwidth	800 MHz	
No. of antenna elements per array	8 × 6 (= 48)	4
No. of antenna arrays	2	
Array gain	21 dBi	7 dBi
Beam width	10°	Horizontally: 20° Vertically: 60°
MIMO configuration	Up to two-streams multiplexing	

dBi: deciBel isotropic

2) Experimental Results

Figure 4 shows the experimental environment and results for downlink throughput. For these trials, one stream was transmitted using adaptive modulation and coding*18 with up to 16 Quadrature Amplitude Modulation (16QAM)*19, for a maximum throughput of 1.27 Gbps. The base station was located on the roof of a 23.5 m building, and throughput was measured while the mobile station moved at 3 km/h along a roadway approximately 200 m from the base station.

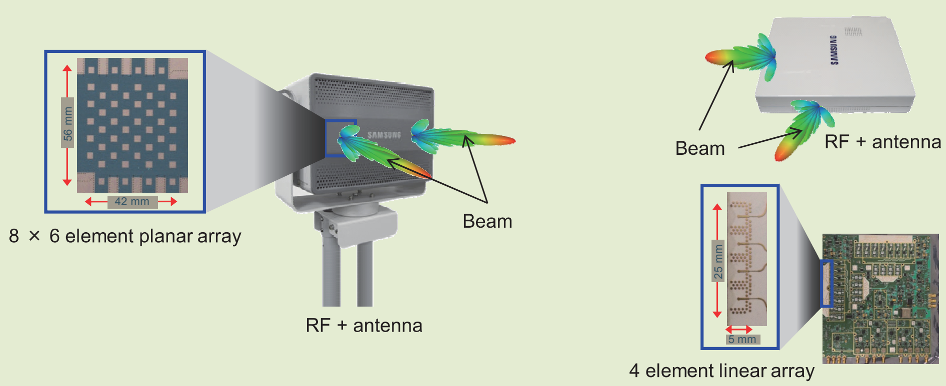

Figure 3 Test equipment appearance

*13 **Coordinated multi-point transmission:** Technology which sends and receives signals from multiple sectors or cells to a given UE. By coordinating transmission among multiple cells, interference from other cells can be reduced and the power of the desired signal can be increased.

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

*15 **Beamforming:** 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 with the antennas.

*16 **Array antenna:** An antenna consisting of an array of multiple elements.

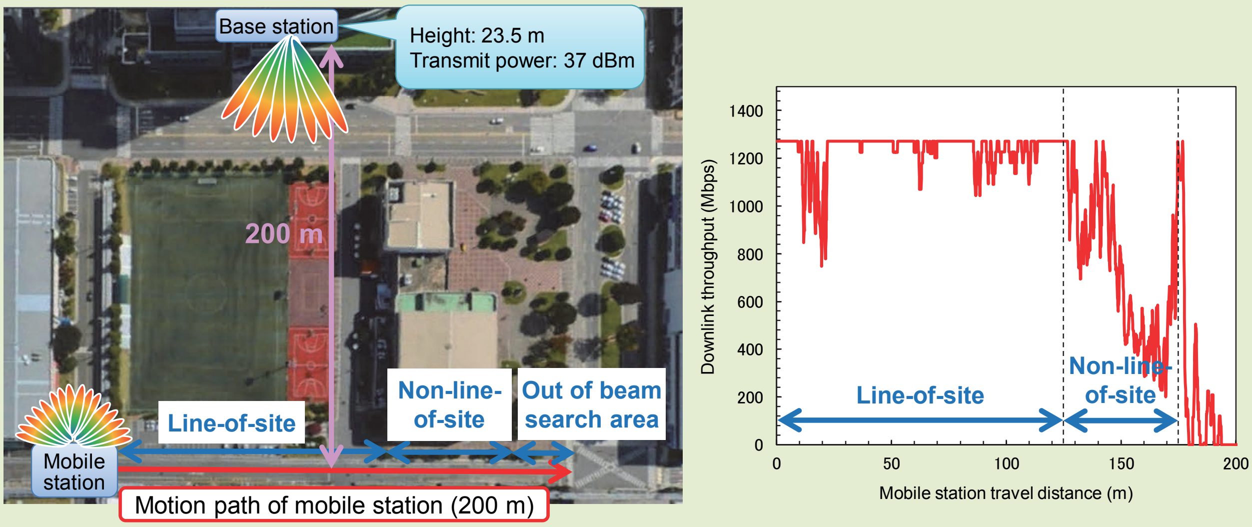

Figure 4 Outdoor transmission tests

Results showed that maximum throughput of almost 1.2 Gbps was possible even at points more than 200 m from the base station in line-of-sight environments, due to the effects of beamforming. On the other hand, in non-line-of-sight environments obstructed by buildings, throughput dropped due to shadowing losses*20. However, even in this sort of non-line-of-sight environment, continuous communication was possible and relatively high throughputs of around 300 Mbps were achievable. This was because even though the direct signal from the base station could not be received, beam selection enabled reception of signals reflected from the buildings.

These trials showed the potential for broadband transmission using beamforming with Massive MIMO in the 28 GHz band. Future trials will verify high-speed transmission with stream multiplexing and beam tracking performance for movement of mobile stations at high speeds.

3.3 Basic Trials of Multi-beam Multiplexing in 44 GHz Band

Basic trials of multi-beam multiplexing technology in the 44 GHz band, done in collaboration with Mitsubishi Electric, are described below [13]–[15]. Trials focused on multi-beam multiplexing using Massive MIMO to compensate for radio propagation losses in high frequency bands and realize dramatic increases in frequency utilization. An overview of the basic field trials and simulation studies using measured data to verify the potential of multi-beam multiplexing technology in the 44 GHz band is given.

1) APAA-MIMO

These trials examined a hybrid beamforming configuration called APAA-MIMO, which combines analog beamforming using Active Phased-Array Antennas (APAA)*21 with MIMO pre-coding using digital signal processing. To achieve the high-capacity transmission required for 5G, both the bandwidth and the frequency utilization must be increased, so MIMO spatial multiplexing of more streams using multiple beams generated by APAA is needed. With APAA-MIMO, interference generated between multiple beams can be controlled with pre-coding.

2) Trial Overview

To verify multi-beam multiplexing technology using APAA-MIMO, basic field trials were done using APAA in

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*17 **Gain:** One of the radiation characteristics of an antenna. An indicator of how many times larger the radiation strength in the antenna's direction of peak radiation is, relative to a standard antenna.

*18 **Adaptive modulation and coding:** A method of modifying the modulation and coding schemes according to radio propagation path conditions. Modulation and coding schemes are modified to increase reliability when the propagation environment is poor, and to increase throughput when it is good.

*19 **16QAM:** A digital modulation method that allows transmission of 4 bits of information simultaneously by assigning one value to each of 16 different combinations of amplitude and phase.

the 44 GHz band as shown in **Figure 5**. Specifications of test equipment used are shown in **Table 4**. The APAA was a planar array of 8 × 6 (48) elements and a single beam was generated using all elements. To verify the feasibility of multi-beam multiplexing, the APAA was moved using a positioner as shown in Fig. 5, and 16-beam multiplexing performance was evaluated using a simulated array of 48 × 16 (768) elements. First, a basic trial was done in the factory of Mitsubishi Electric in Amagasaki City in Hyogo Prefecture, measuring outdoor propagation with APAA analog beamforming. These results were then used as a basis for simulating 16-user multiplexing to evaluate propagation performance.

3) Experimental Results

Experimental results are shown in **Figure 6**. High throughput was achieved, with users near the base station obtaining roughly 2 Gbps and users at 100 m from the base station obtaining roughly 1 Gbps. All users obtained a total throughput of 21.1 Gbps.

In the future, we will conduct further transmission trials and combine them with simulation to study issues including optimizations of APAA-MIMO antennas and circuit configurations, the maximum number of beams that can be multiplexed, the analog beamforming beam search interval and range, precoding optimizations, and user multiplexing control.

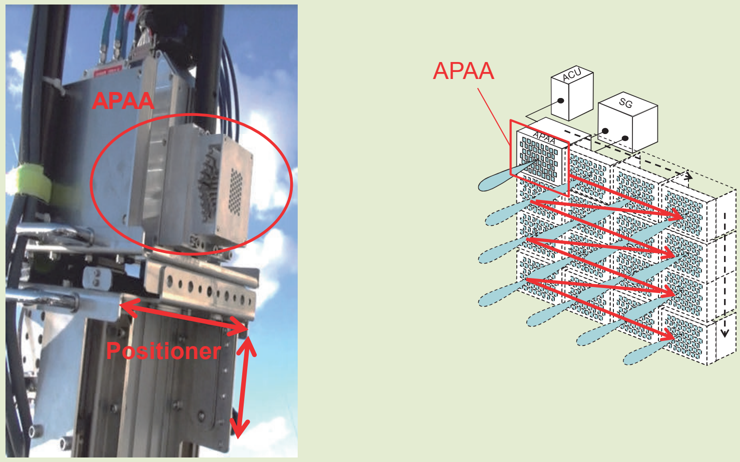


Figure 5 APAA base station equipment and virtual beam multiplexed APAA-MIMO

Table 4 Test equipment specifications

Carrier frequency	44 GHz	
Base station antenna	APAA	
	No. of antenna elements	8 × 6 (= 48)
	Antenna gain	17.2 dBi
Receiver antenna	Horn antenna	
	Receiver antenna gain	20.4 dBi

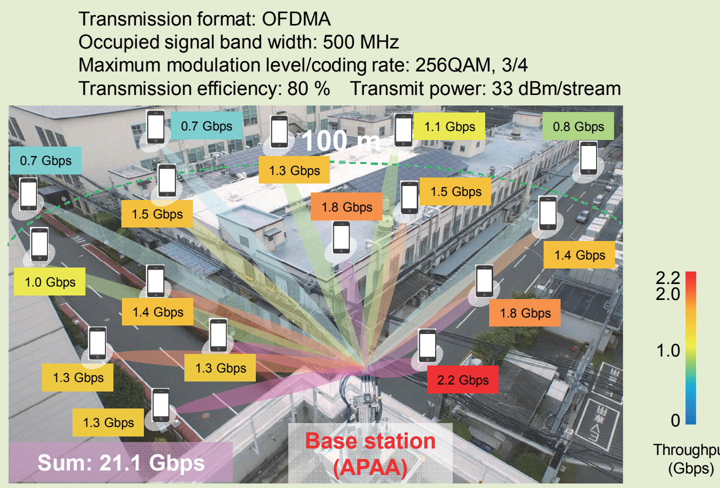


Figure 6 Evaluation of 16-beam multiplexed-transmission characteristics by simulation based on transmission measurements

*20 **Shadowing losses:** Shadowing refers to when reception power drops because a mobile terminal enters the shadow of a building or other object and losses refers to decreases in reception power in general.

*21 **APAA:** An array antenna with amplifiers and phase shifters for each antenna element and capable of controlling radio wave directivity (beam) electronically.

3.4 Trials of 5G Radio Access in the 70 GHz Millimeter-wave Band

Trials done in collaboration with Nokia Networks to verify beamforming technology for 70 GHz band millimeter wave transmission are described below [16] [17]. These trials validated beamforming technology anticipated for use in applications such as small cells and indoor hotspots*22 to improve coverage and mobility.

1) Trial Overview

Specifications of the testbed are shown in **Table 5** and the base station and mobile station are shown in **Figure 7**. The center frequency of the equipment was 73.5 GHz and the system bandwidth was 1 GHz. The base station controls a beam with half-power beam width*23 of 3° over a range of ±17.5° horizontally and ±4.0° vertically. The base station has a beam tracking mechanism that selects the beam of best mobile station signal quality from among 64 candidates (4 directions vertically and 16 directions horizontally).

Trials were conducted in various small cell environments in the YRP district in Yokosuka City, Kanagawa Prefecture, to evaluate millimeter wave propagation characteristics and beamforming. **Figure 8** shows photographs of the trial conditions. Here, we give results from testing in three environments: (a) A courtyard (outdoor, line-of-site), (b) A lobby (indoor line-of-site and non-line-of-site), and (c) An underground parking lot (indoor line-of-site and non-line-of-site). The distances from the base station to the courses in each environment were roughly 20 m in (a), 20 m and 35 m in (b), and 40 m and 60 m in (c). The mobile terminal moved at a speed of 4 km/h, assuming a walking speed. As the mobile terminal moved along the course, the best beam changed, and the base station beam followed this appropriately.

2) Experimental Results

Cumulative Distribution Functions (CDF)*24 for throughput in each of the environments are shown in **Figure 9**. The CDFs confirm the throughput distribution ratios on each course. For each of the courses, the locations where the maximum transmission throughput of

Table 5 Testbed specifications

Radio access	NCP-SC
Multiplexing	TDD (uplink/downlink ratio = 12 : 188)
Center frequency	73.5 GHz
System bandwidth	1 GHz
Transmitting power	23.6 dBm (0.229 W)
No. of transmission/reception antennas	1
TTI length	100 μsec
Data modulation	BPSK, QPSK, 16QAM

BPSK: Binary Phase Shift Keying
NCP-SC: Null Cyclic Prefix Single Carrier

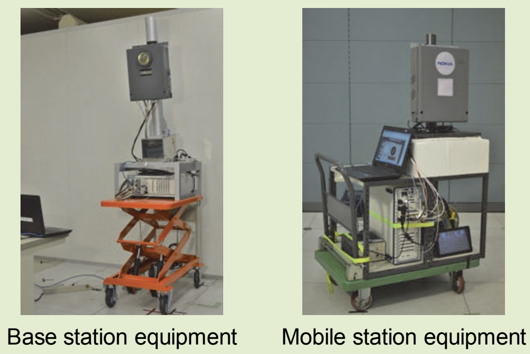


Figure 7 Testbed appearance

*22 **Hotspot:** A place where traffic is generated in concentrated form such as a plaza or square in front of a train station.

*23 **Half-power beam width:** The angular range from the maximum power emitted from an antenna to the half of that value. Indicates the sharpness of the antenna pattern.

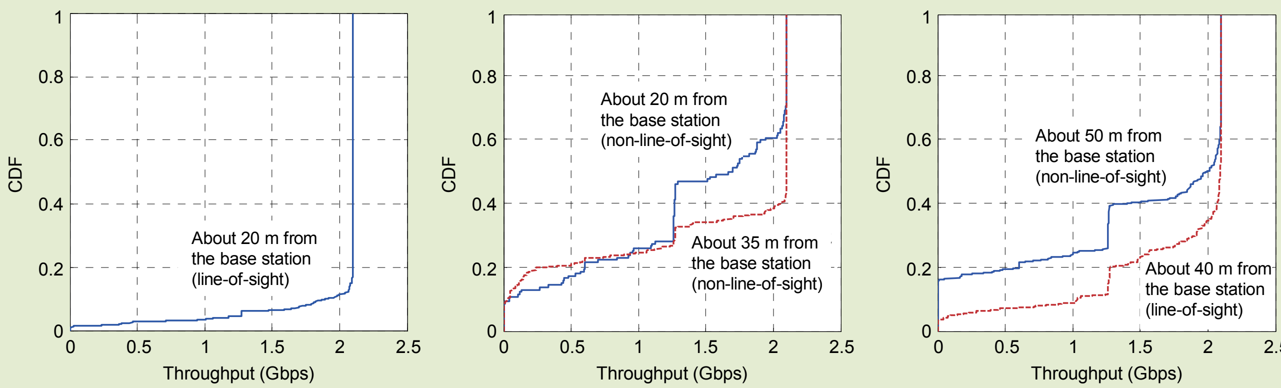
*24 **CDF:** A function that represents the probability that a random variable will take on a value less than or equal to a certain value.

(a) Courtyard: Cell radius 20 m (outdoor line-of-site)

(b) Lobby: Cell radius 35 m (indoor, line-of-site and non-line-of-site)

(c) Underground parking garage: Cell radius 60 m (Indoor, line-of-site and non-line-of-site)

Figure 8 Trial environments



(a) Courtyard

(b) Lobby

(c) Underground parking garage

Figure 9 Throughput characteristics

the equipment, which is over 2 Gbps, is achieved and the proportion of each course where this maximum throughput is achieved varies due to differences in the courses. In particular, for line-of-site environments, the maximum throughput was achieved over most of the courses.

Currently we are developing a system for visualizing beam state as shown in **Figure 10**, and explaining millimeter wave propagation characteristics. We are also conducting trials in urban environments that are closer to actual-use environments. In the future, we also plan to test multi-site transmission with multiple base stations that can reduce non-line-of-site conditions.

4. Conclusion

This article has given an overview of 5G trials being done by NTT DOCOMO in collaboration with major vendors and introduced experiments focused on verifying elemental technologies for utilizing high frequency bands. The test results obtained will be used as verification of the 5G concepts advocated by NTT DOCOMO and to contribute to discussion at research organizations and international conferences around the world related to 5G and in 5G standardization activities, which will begin in earnest in 2016. They will also be used in study to create more advanced technologies.

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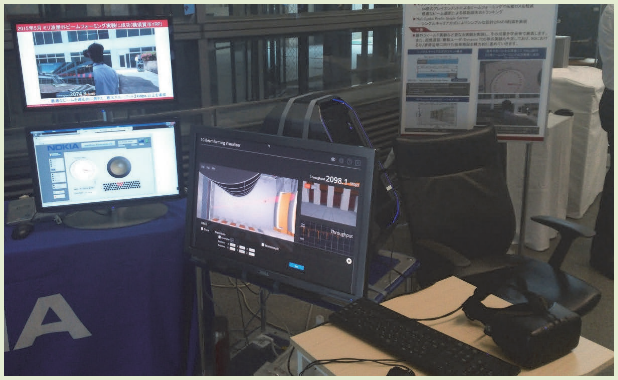

Figure 10 Beam state visualization system

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