Technology Reports | 5G | Millimeter Wave | Long-distance Field Transmission Tests

Special Articles on Demonstration of New Technologies for 5G

5G Field Testing of Ultra-high-speed, Long-distance Transmission Using Millimeter-wave Signals

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NTT DOCOMO is conducting R&D on 5th Generation mobile communications systems (5G) with the goal of providing services by the year 2020. In addition to conventional frequency bands, 5G will use higher frequencies in the millimeter-wave band to achieve dramatic increases in communication speed and capacity. This article gives an overview of 5G field tests done in collaboration with Tobu Railway and Huawei Technologies. The tests used ultra-high-gain beam forming transmission technology to achieve high-speed communication over distances exceeding 1 km with millimeter waves, which are difficult to transmit over long distances due to rapid attenuation.

1. Introduction

Mobile communication traffic has increased by a factor of 1.6 each year since 2010 [1], and it is predicted to increase to more than 1000 times volumes when LTE was introduced in 2010, by the 2020s if this continues. 5G mobile communication systems will increase performance of networking systems in various ways. Capacity will increase to handle this rapid increase in traffic at the lowest cost and power consumption possible, but the system will also support ultra-high-speed communication over 10 Gbps, even lower latency, and connectivity for large numbers of terminals, as required due to the spread of the Internet of Things (IoT).

A major feature of 5G is that it will achieve dramatic increases in communication speed and capacity by using millimeter band frequencies (30 GHz and higher)* in addition to frequencies currently used for mobile communications (below 4 GHz). However,

* In the mobile communications industry, the 28 GHz band is in the range customarily called millimeter waves, so the term will be used in this article.

a characteristic of millimeter waves and other high-frequency bands is high attenuation with distance, so they are difficult to use over long distances. NTT DOCOMO has proposed a 5G technology concept called phantom cell*1/dual connectivity*2 [2], which combines these high-frequency bands with lower bands suitable for wide-area coverage to realize both stable communication and increased speed and capacity. On the other hand, it is important to provide as wide of coverage as possible, even with millimeter waves and other high-frequency bands, when providing ultra-high-speed communication in more diverse environments beyond urban areas, such as suburbs, the mountains, and other outlying areas.

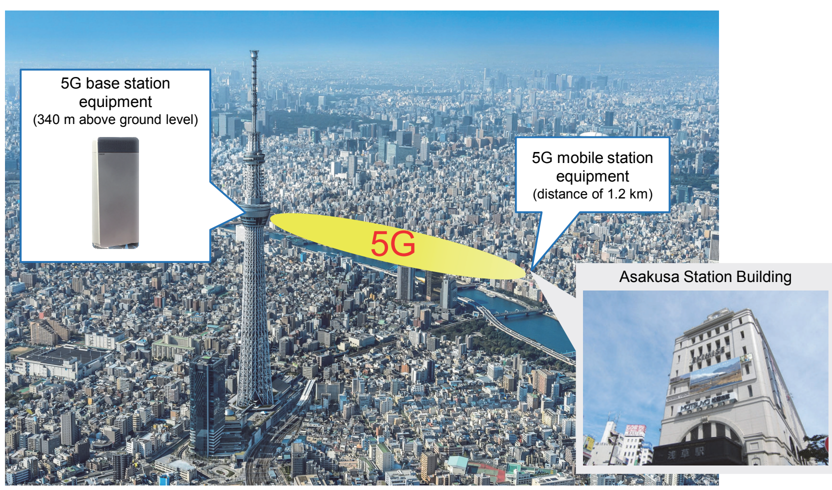
This article gives an overview of 5G radio access field tests done in collaboration with Tobu Railway and Huawei Technologies, implementing long-distance, high-speed transmission exceeding 1 km in a macrocell*3 environment with millimeter waves. This was achieved using an ultra-high-gain beamforming*4 transmission technology to resolve technical issues applying millimeter waves for mobile communications.

2. 5G Long-distance Transmission Tests between TOKYO SKYTREE and Asakusa Using the 28 GHz Band

In December 2017, we conducted long-distance transmission tests in collaboration with Tobu Railway and Huawei Technologies. Transmissions exceeding 1 km, between the TOKYO SKYTREE®*5 observation deck and Asakusa Ward, were done using the 28 GHz band, which is one of the frequency bands that is promising for use in 5G implementations [3].

2.1 Test Overview

The test environment is shown in **Figure 1**. These tests were done at a 5G Trial Site built by



Test station representing base station: Oshiage, Sumida, Tokyo (TOKYO SKYTREE TEMBO DECK, Floor340)
Test station representing mobile terminal: Hanakawado, Taito, Tokyo ((Roof of Tobu Railway Asakusa Station Building), 28 GHz band (800 MHz))

Figure 1　Test environment (TOKYO SKYTREE area)

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*1 **Phantom cell**: The advanced small-cell system being promoted by NTT DOCOMO.

*2 **Dual connectivity**: A technology that achieves wider bandwidths by connecting two base stations in a master/slave relationship and performing transmission and reception using multiple component carriers supported by those base stations.

*3 **Macrocell**: In mobile communications systems, a cell is the area covered by a single base station antenna. A macrocell covers a relatively large area with radius of 500 m or more.

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

NTT DOCOMO in collaboration with Tobu Railway Uplink and downlink communication was between a test base station installed in the TOKYO SKYTREE TEMBO DECK®, Floor340 (**Photo 1**(a)), and a mobile phone approximately 1.2 km from the base station, represented by a mobile station installed on the roof of the Tobu Railway Asakusa Station building (Photo 1(b)).

The center frequency for the tests was 27.9 GHz. An Orthogonal Frequency Division Multiplexing (OFDM)*6 subcarrier*7 interval of 60 kHz and system bandwidth of 700 MHz (100 MHz per

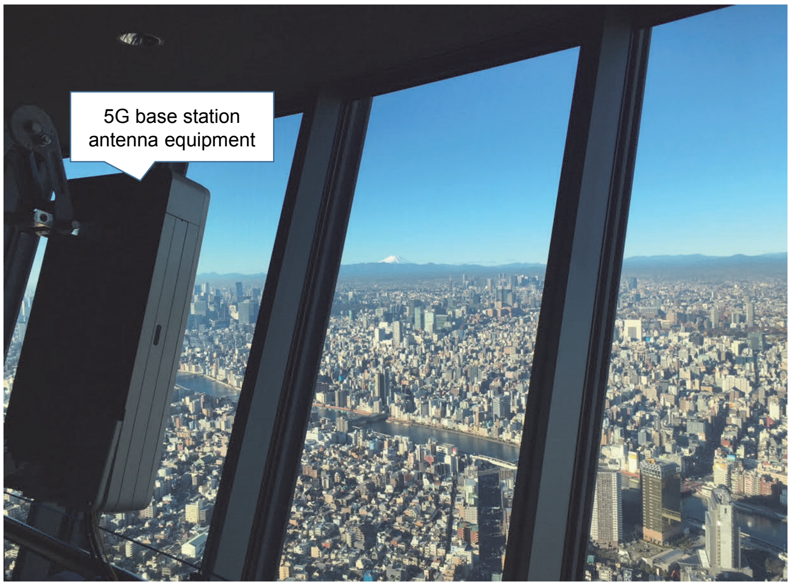


Photo 1(a) 5G base station installation (TOKYO SKYTREE TEMBO DECK)

Photo 1(b) 5G mobile station equipment (roof of Tobu Railway Asakusa Station Building)

*5 TOKYO SKYTREE®: "TOKYO SKYTREE," "TOKYO SKYTREE TEMBO (Observation) DECK," "TOKYO SKYTREE TOWN" are registered trademarks of Tobu Railway Co., Ltd. and Tobu Tower Skytree Co., Ltd.

*6 OFDM: A digital modulation method where the information is divided into multiple orthogonal carrier waves and sent in parallel. It allows transmission at high frequency usage rates.

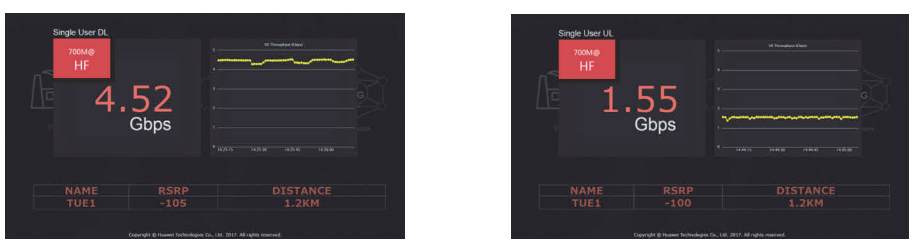
*7 Subcarrier: Each carrier in a multi-carrier modulation system that transmits bits of information in parallel over multiple carriers.

Component Carrier (CC)[*8] × 7) was used.

In these tests, beam forming between TOKYO SKYTREE and Asakusa station was done using Massive Multiple-Input Multiple-Output (MIMO)[*9], a key 5G technology that utilizes many antenna elements. Massive MIMO is able to form a tight beam at the 5G high frequencies by using 100 or more antenna elements to strengthen the signal in the direction of the mobile terminal.

2.2 Test Results and Demonstrations

In these tests, we applied the optimal Time Division Duplex (TDD)[*10] slot ratios on both the downlink (from base station to mobile station) and the uplink (from mobile station to base station), and measured the throughput characteristics under conditions where the mobile station is stationary. The results in **Figure 2** show that communication speeds of up to 4.52 Gbps on the downlink and 1.55 Gbps on the uplink were achieved at a distance of approximately 1.2 km from the base station, despite using the high-frequency 28 GHz band. These tests were done together with two demonstrations using the large outdoor screen on the Asakusa Station Building (sponsored by Tobu Railway Co.). The first provided coverage of the “docomo 5G Trial Site” event held on December 8 to 10, 2017, in Space 634 on the 5th floor of TOKYO Solamachi®[*11], and the second covered the “TOKYO SKYTREE Christmas Love Song Live” event held on December 8 on the TOKYO SKYTREE TEMBO DECK. The docomo 5G Trial Site event demonstrated a new concept of communication for the future as shown in **Photo 2**. Using a head-mounted display and Augmented Reality (AR)[*12] technology, a person in the Asakusa Station Building, some distance from the TOKYO SKYTREE TOWN® event venue, was able to hold a conversation in real time and with low-latency, with a person who was not actually there but appeared to float above a chair. For the event on the evening of December 8, uninterrupted communication speeds over 3 Gbps were achieved even though the part of TOKYO SKYTREE above the observation deck was largely invisible due to rain, as shown in **Photo 3**. The demonstration successfully covered the event on the Asakusa Station Building outdoor screen.



Downlink　　Uplink

Figure 2　Communication speed achieved (downlink/uplink)

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*8　CC: Term denoting each of the carriers used in Carrier Aggregation.

*9　MIMO: A radio communication format in which transmitted data is divided into multiple signals (streams) and then transmitted and received with the same frequency band using multiple antennas at both the transmitter and the receiver.

*10　TDD: A bidirectional transmit/receive system. This system achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions on the same frequency.

*11　TOKYO Solamachi: A registered trademark of the Tobu Railway Co., Ltd.

Photo 2　Demonstration at 5G event

Photo 3　Test environment in rainy weather (roof of Asakusa Station Building)

3. 5G Long-distance Transmission Tests in the Yokohama Minato Mirai District Using the 39 GHz Band

In these tests done jointly with Huawei Technologies, long-distance 5G transmissions using the even higher-frequency 39 GHz band were attempted, anticipating ongoing development of 5G after 2020 [4].

3.1 Overview of Technology Used

The frequency band from 39.5 to 40.9 GHz was used in these tests. The OFDM signal subcarrier interval was 120 kHz, and the system bandwidth was 1,400 MHz (200 MHz/CC × 7).

To achieve long-distance transmission exceeding 1 km at high frequencies in the 39 GHz band, meta-materials*13 were used to create a lens antenna*14 able to achieve beamforming with ultra-high-gain (31 dBi (deciBel isotropic)*15), more than 1,000 times that of a non-directional antenna. Meta-materials are used in the lens antenna to form a specific distribution of dielectric constants, which focuses the signal emitted from the antenna in a particular direction similarly to beamforming using Massive MIMO, but with a smaller antenna. By having multiple emitters in the antenna, the direction of the transmitted beam can also be changed by switching among them. In the trials, the optimal beam for each polarization was selected from among 64 candidates, eight horizontally and eight vertically, as shown in **Figure 3**. The half-power beam width*16 of each candidate beam was approximately 3.5°. Signal reception quality can be improved by measuring reception quality for each combination of base station and mobile station beams and selecting the best one.

The radio frame*17 structure used in these tests is shown in **Figure 4**. The radio frame length was 10 ms, and the slot length was 0.125 ms, so each radio frame contained 80 slots. Using a radio frame structure with very short slot interval allowed the time needed to find the optimal beams on the base

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*12 AR: Technology for superposing digital information on real-world video in such a way that it appears to the user to be an actual part of that scene.

*13 Meta-material: An artificial material that behaves with respect to electromagnetic waves in ways not found in natural materials.

*14 Lens antenna: An antenna able to focus radio waves sharply in a particular direction, much like an optical lens. A lens antenna can be used to emit radio waves emitted broadly from the emitter, tightly in a particular direction, by refracting and aligning the phase of the radio waves.

*15 deciBel isotropic: A unit that describes antenna gain using a hypothetical isotropic antenna as the standard.

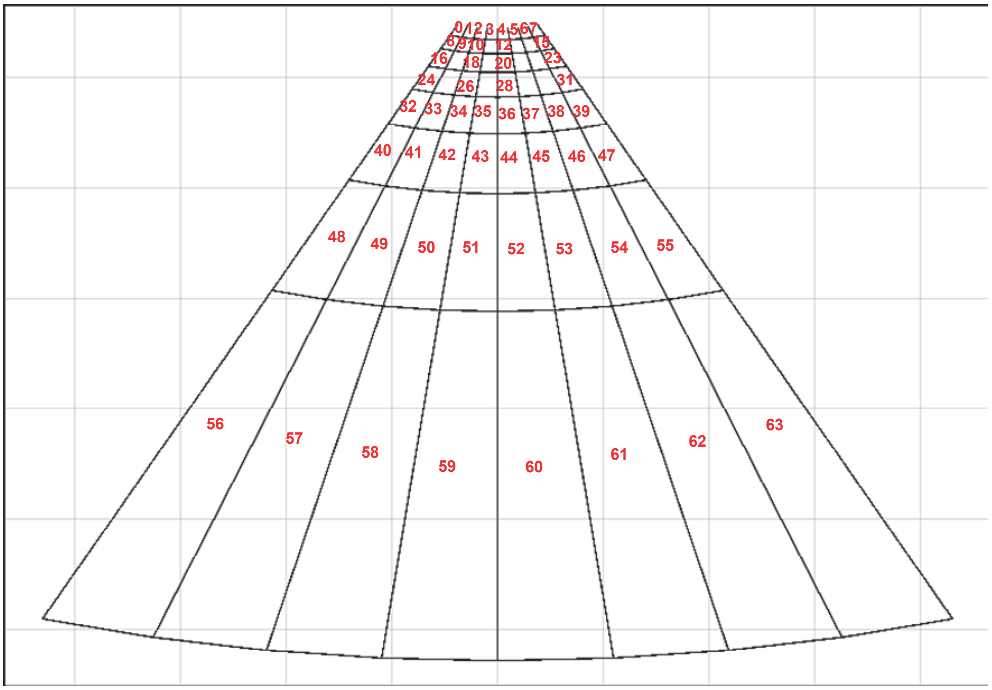

Figure 3 All 64 candidate beams

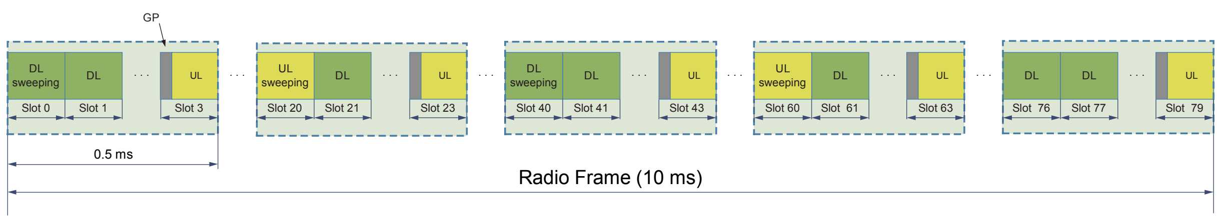

Figure 4 Radio frame structure

station and mobile station to be minimized. The following four types of slots are used in a single radio frame.

(1) DownLink (DL) beamsweeping slot: A slot for performing beam sweeps using a downlink reference signal (e.g.: Fig. 4 (Slot #0)).

(2) DL slot: A slot used to send data on the downlink, including data and control signals (e.g.: Fig. 4 (Slot #1)).

(3) UpLink (UL) slot: A slot used to send data on the uplink, including Guard Period (GP), data, and control signals (e.g.: Fig. 4 (Slot #3)).

(4) UL beam sweeping slot: A slot for performing beam sweeps using an uplink reference signal (e.g.: Fig. 4 (Slot #20)).

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*16 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.

*17 Radio frame: The smallest unit used for signal processing (encoding, decoding). A single radio frame is composed of multiple slots (or subframes) along the time axis, and each slot is composed of multiple symbols along the time axis.

To control beam sweeping and tracking, the reception quality was measured for each beam combination using reference signals in the DL and UL beam sweeping slots. Beam sweeping slots were sent every 2.5 ms, alternating on the up and downlinks, so that all beam combinations (64 (base station) × 64 (mobile station) = 4,096) were scanned in 160 ms. This enabled the optimal beams for transmission and reception at both base station and mobile station to be updated dynamically, according to motion of the mobile station and fluctuations in the radio channel.

The test equipment supported Quadrature Phase Shift Keying (QPSK)*18, 16 Quadrature Amplitude Modulation (16QAM)*19, and 64QAM*20 with adaptive modulation. Large delay Cyclic Delay Diversity (CDD)*21 and vertical/horizontal-polarization 2×2 MIMO transmission were also used.

3.2 Test Results

Testing was conducted in November 2017 in the Minato Mirai District of Yokohama City, in Kanagawa Prefecture. The transmission test equipment is shown in **Photo 4**, and the test environment is shown in **Figure 5**.

Table 1 shows the results of measuring throughput to the mobile terminal using the test equipment and in a real, outdoor radio environment under the various conditions shown in Fig. 5. The results show that ultra-high-speed communication was achieved between a Huawei 5G base station installed in the Yokohama Media Tower and mobile station approximately 1.5 km distant, receiving at up to 2.02 Gbps while moving at approximately 20 km/h, and up to 3.35 Gbps while stationary. Even at a distance of approximately 1.8 km from the 5G base station, reception rates up to 2.14 Gbps while stationary were achieved, and reception at rates up to 5.63 Gbps were achieved at a distance of approximately 0.3 km from the 5G base station. It is generally thought to be difficult to maintain coverage when using millimeter-band signals for mobile communication or long-distance transmission. In spite of this, we achieved throughput characteristics of 2 Gbps and greater over areas spanning 1 km or more with this transmission test equipment, which uses

5G base station equipment

5G mobile station equipment (in a monitoring vehicle)

Photo 4 Base station and mobile station equipment

*18 QPSK: A digital modulation method that allows transmission of 2 bits of information at the same time by assigning one value to each of four phases.

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

*20 64QAM: A digital modulation method that enables the simultaneous transmission of 6 bits of information by assigning one value to each of 64 different combinations of phase and amplitude.

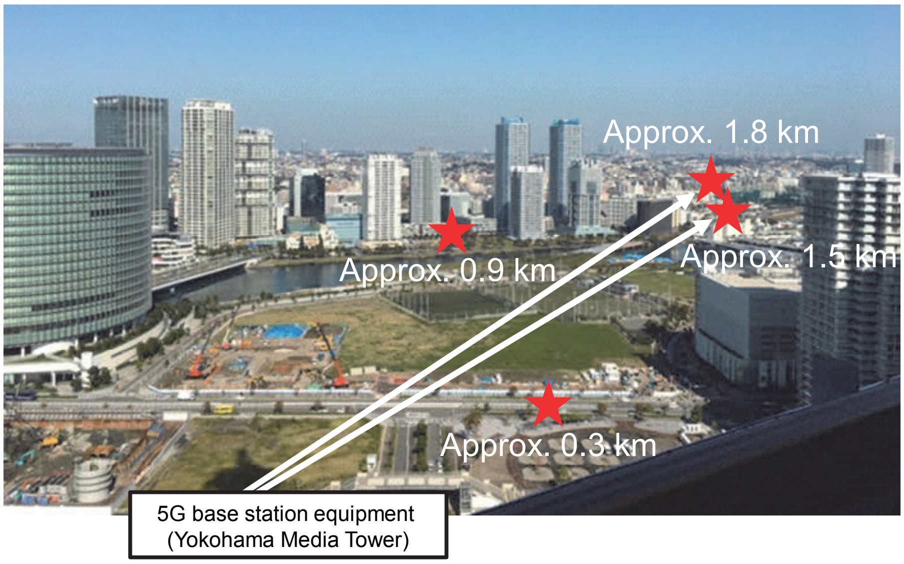

Figure 5 Test environment (Yokohama Media Tower area)

Table 1 Distance from base station vs. throughput characteristics

Mobile station conditions	Distance from base station (km)	Maximum Throughput (Gbps)
Speed (approx. 20 km/h)	1.5	2.02
When stationary		3.35
	1.8	2.14
	0.9	3.78
	0.3	5.63

high-speed beam switching and tracking technology and produces high beamforming gain. Although there was some deterioration in throughput characteristics while the UE was moving compared to when stationary, we were able to maintain throughput of 2 Gbps or greater.

4. Conclusion

This article has given an outline and results of long-distance field transmission tests done with 5G radio access transmission test equipment at millimeter-band frequencies (28 GHz and 39 GHz bands). As a result, high throughput of several Gbps was

*21 Large delay CDD: A type of transmit diversity technology, in which relatively large, differing amounts of cyclic delay are assigned to the same data signal between transmit antennas, producing frequency diversity while avoiding inter-symbol interference.

achieved transmitting over distances of 1 km and greater from the base station. These results demonstrate that technology using high-frequency-band radio signals, which attenuate quickly and have been considered difficult to use for propagation over long distances, can be used in more diverse environments that require transmission over distances relatively longer than in urban areas, such as suburbs, the countryside, and mountainous areas. In the future we plan to conduct further field testing to expand the coverage achievable using millimeter-band signals, in non-line-of-sight and other situations.

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