5G | High Frequency Band | Radio Propagation Characteristic

Technology Reports

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Radio Propagation for 5G

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NTT DOCOMO is currently studying a fifth-generation mobile communications system (5G) intensely. This system is expected to use high frequency bands, so clarification of the propagation characteristics in these high frequency bands is the most important issue in radio propagation research for 5G. This article gives an overview of the issues and current state of study in radio propagation, and describes results obtained by NTT DOCOMO in field tests and studies done using radio propagation simulation technology.

1. Introduction

NTT DOCOMO is currently studying the radio access network*1 for a fifth-generation mobile communications system (5G) based on a phantom cell concept*2 as shown in **Figure 1** [1]. This concept assumes an overlay*3 structure with small cells*4 in various shapes arranged within a macrocell*5, and that wider bandwidth will be secured to implement ultra-high-speed transmission, in the Super High Frequency (SHF)*6 band (over 6 GHz) or Extremely High Frequency (EHF)*7 band (mainly 30-100 GHz). In order to decide the carrier frequencies*8 in these high frequency bands, the frequency characteristics for various types of propagation must be known, and this is the most important issue in radio propagation research for 5G. This article first gives an overview of issues and the current state of study of radio propagation together with trends in 5G-related projects. It then introduces some of the results obtained in field testing done by NTT DOCOMO so far, and describes results of studies using radio propagation simulation technology for high frequency bands, which will be needed in the future.

2. Issues and Current Study of Radio Propagation

2.1 Issues with 5G

1) Frequency Bands under Study

Since high frequency bands are expected to be used with 5G, propagation characteristics (propagation losses*9 and multipath*10 characteristics) must be

*1 **Radio access network:** A general term for the wireless access segment of a communications network.

*2 **Phantom cell concept:** A system concept in which small cells are overlaid on macrocells (see *5), and the macrocell base stations are used for control signals, while the small cell (see *4) base stations are used for data signals.

elucidated for the 6 to 100 GHz range. So far, results of several studies on the 20 to 30 GHz and 50 to 70 GHz ranges have been reported by organizations such as New York University (NYU) and the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)*11, although most in the 50 to 70 GHz range have been on the 60 GHz band [2] [3]. On the other hand, there are very few reports on the 10 to 25 GHz and 40 to 55 GHz bands, and these will require study in the future.

2) Factors Affecting Propagation

Figure 2 summarizes factors expected to have a significant effect on propagation characteristics in high frequency bands. Of these, (1) rainfall attenuation and (2) losses due to trees and plants have been clarified in International Telecommunication Union, Radiocommunications Sector (ITU-R) reports [4] [5]. Further, the effects of (3)

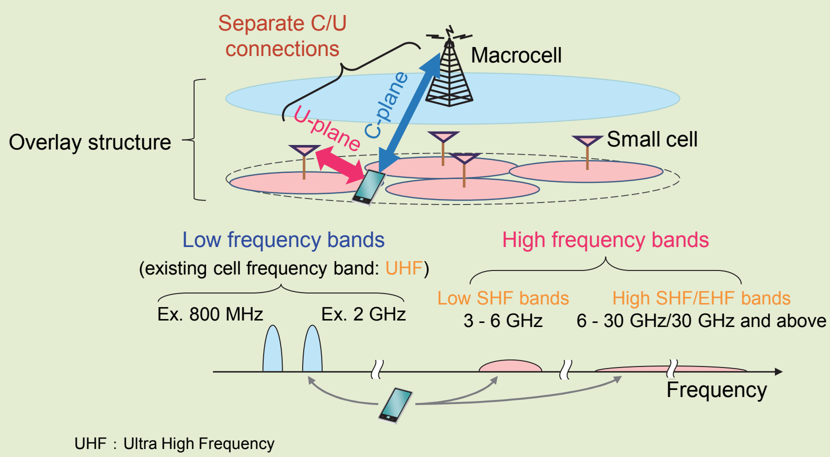


Figure 1 Phantom cell concept

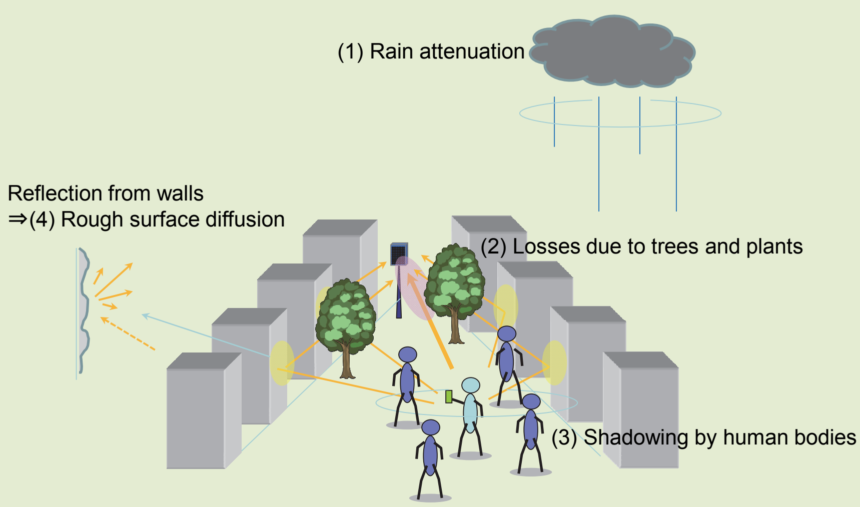


Figure 2 Factors affecting propagation in high frequency bands

*3 **Overlay:** A structure in which small cells (see *4) are arranged within a macrocell (see *5).

*4 **Small cell:** A cell covering a relatively small area of radius less than approximately 500 m. Also called a microcell.

*5 **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.

*6 **SHF:** Radio waves in the range of frequencies from 3 to 30 GHz.

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

*8 **Carrier frequency:** A carrier frequency is a radio wave that is modulated in order to transmit information.

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

*10 **Multipath:** A phenomenon that results in a radio signal transmitted by a transmitter reaching the receiver by multiple paths due to propagation phenomenon such as reflection, diffraction, etc.

shadowing by human bodies has been considered in a channel model*12 proposal [6] from the Millimeter-Wave Evolution for Backhaul and Access (MiWEBA)*13 project. However, this model deals mainly with the 60 GHz band, and further study will be needed to determine it applies to other frequencies. It will also be important to understand the characteristics of (4) rough surface diffusion using ray tracing*14 and other propagation simulation techniques [7].

2.2 Trends in 5G Related Projects

The METIS [2] and MiWEBA [6] research projects in Europe are well known projects related to 5G. The characteristics of studies conducted by these projects are summarized in **Table 1**.

1) METIS

METIS has proposed two channel models, depending on the application. The first is the Geometry-based Stochastic Channel Model (GSCM) generally used by the ITU-R and 3rd Generation Partnership Project (3GPP) for evaluating systems. GSCM gives statistical characteristics to each path based on measured data. It applies to frequencies of 70 GHz and below, but only parameters for generating models for 6 GHz and below are available for urban microcell environments. For indoor environments, only parameters for 6 GHz and under and 50 to 70 GHz bands have been prepared, so the frequency ranges expected for 5G are not adequately covered. The other model is called the Map-based Model, and calculates propagation characteristics using ray tracing. This model applies to frequencies of 100 GHz or less, but few comparisons of results computed by this model with measured data have been done, so verifying the accuracy of these results will be an issue for future work.

2) MiWEBA

MiWEBA has proposed a model called the Quasi-Deterministic Model. This model uses paths computed using ray tracing and considers paths statistically, so it is a hybrid of the GSCM and Map-based Models from METIS. It is being used mainly for the 60 GHz band of frequencies, so care must be taken when applying it to other frequency bands.

Besides those described above, there are other projects that have begun studying channel models for 5G, including the 5G Millimeter Wave Channel Model Alliance [8] formed at the prompting of the National Institute of Standards and Technology (NIST) and the Millimeter-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC) [9] at the 5G Infrastructure Public-Private Partnership (5GPPP).

3. Propagation Characteristics in Real Environments Investigated by NTT DOCOMO

Propagation loss characteristics in urban microcell environments and multipath characteristics in indoor environments, as obtained in propagation field testing by NTT DOCOMO, are explained below.

Table 1 5G related projects

Project	Channel model type	Frequency	Scenarios
METIS	GSCM	70 GHz and below	Urban micro, urban macro, offices, shopping malls, highways, open-air festivals*1, stadiums.
	Map-based Model	100 GHz and below	Urban micro, urban macro, rural macro, offices, shopping malls, highways, open-air festivals
MiWEBA	Quasi–Deterministic Model	57 to 66 GHz	Open areas, street canyons*2, hotel lobbies

*1 Open-air festivals: Scenarios such as outdoor concert venues.

*2 Street canyons: Scenarios in which a street is surrounded by tall buildings and the base station antenna is positioned lower than the surrounding buildings.

*11 **METIS:** A next-generation wireless communications system research project in Europe.

*12 **Channel model:** A model simulating the behavior of radio waves, used for evaluating the performance of wireless communications systems.

*13 **MiWEBA:** A research project in Europe studying application of millimeter wave technologies for mobile communications systems.

*14 **Ray tracing:** A method of simulating propagation characteristics by treating radio waves like light and tracing their paths.

3.1 Propagation Loss Characteristics

1) Overview of Measurements

Measurements were performed in the area around Tokyo Station. The measurement area is shown in **Photo 1**, and the average building height and road width are approximately 20 m and 30 m respectively. For the measurements, a Continuous Wave (CW) , for which it is easy to measure the reception level, was transmitted from a base-station antenna mounted on the basket of a basket-lift truck, the signal was received by a mobile station antenna mounted on the roof of the measurement car, and the received power was recorded. The measurement parameters are shown in **Table 2**. The data was processed, calculating the median over spans of 10 m which were moved in 1 m steps, and these were used to derive propagation losses.

Photo 1 Measured area

2) Measurement Results

The relationship between radio propagation losses and distance is shown in **Figure 3** [10]. These results were calculated by regression formula of measured path loss values using distance and frequency values. The figure shows that for both the line-of-site and non-line-of-site cases, propagation losses increase as the distance increases. Losses also increase as the frequency increases. For example, in the line-of-site case, propagation losses increase by about 30 dB from 0.81 GHz to 37.1 GHz. Propagation losses increase further in the non-line-of-site case, so technology to compensate of propagation losses is particularly important.

3.2 Multipath Characteristics in Indoor Environments

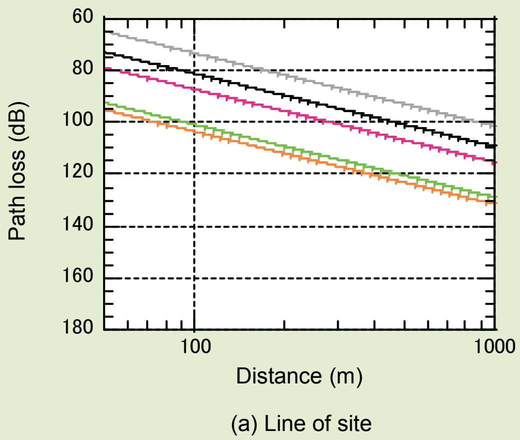
1) Experiment Overview

Here, we describe the characteristics

Table 2 Measurement specifications

Parameter	Value
Center frequency	0.81 GHz, 2.2 GHz, 4.7 GHz, 26.4 GHz, 37.1 GHz
Transmission power	43 dBm (0.81 GHz, 2.2 GHz), 40 dBm (4.7 GHz, 26.4 GHz), 37 dBm (37.1 GHz)
Transmitted signal	Continuous wave
Base station antenna height	1.5 m, 6 m, 10 m
Base station antenna	Sleeve antenna
Mobile station antenna height	2.7 m
Mobile station antenna	Sleeve antenna
Distance between base station and mobile station	56 - 959 m

of radio waves arriving at the base station as obtained in indoor propagation experiments. In order to enable separating multipath in the time direction, in experiments we used delay time measuring equipment to measure multipath delays [11]. The center frequency of the measured signal was 19.85 GHz and the bandwidth was 50 MHz. Experiments were done in an office as shown in **Figure 4**. The office contained desks and chairs of height approximately 1 m, and metal lockers of height approximately 2 m. There were also several meeting rooms, booths containing office equipment and walls with concrete pillars and glass windows. The ceiling was at a height of 2.7 m and was made of plaster board. In measurements, the transmitter was considered to be the mobile station which emitted a signal in all directions using a sleeve antenna*15 at a height of 1.5 m. The receiver was considered to be the indoor base-station



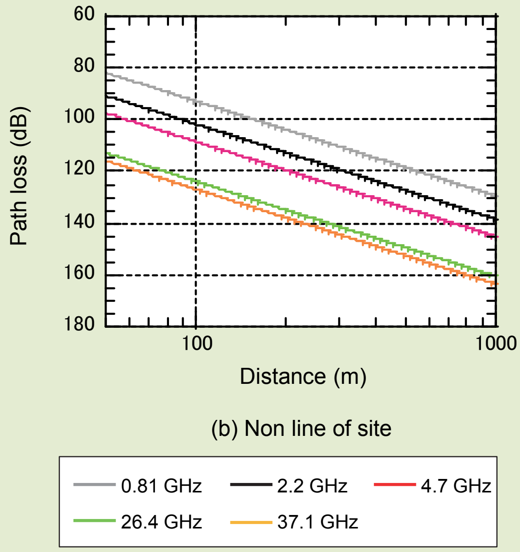


Figure 3 Path loss/distance characteristics

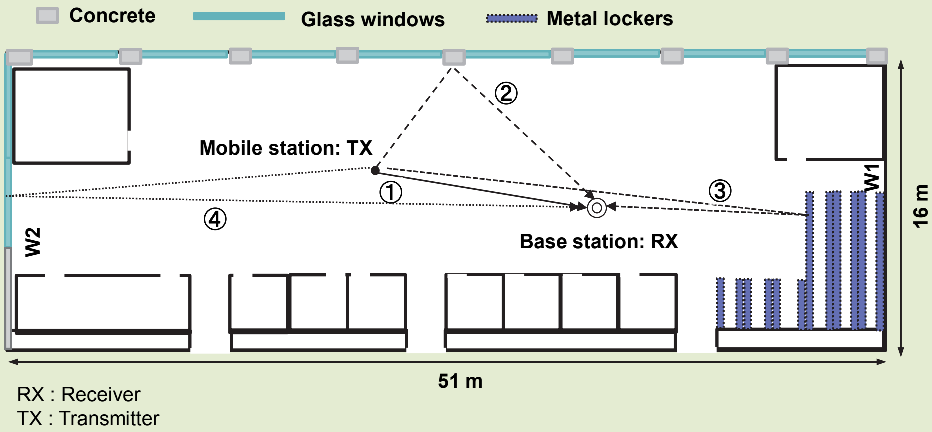


Figure 4 Office measurement area

*15 **Sleeve antenna:** A type of antenna that emits a signal of mostly-uniform intensity in the horizontal plane.

and had an antenna height of 2.3 m. A horn antenna*16 was used for the base station in order to obtain delay profiles*17 and measure arrival directions of radio waves, while varying the azimuth and elevation angles. The antennas were kept within line-of-sight.

2) Measurement Results

The results obtained from measurements are shown in **Figures 5** and **6**. Fig. 5 shows the received power vs. azimuth and elevation angles, while Fig. 6 shows the received power vs. azimuth and delay. The circle marks in each figure represent propagation paths obtained in analysis of the measured results. For elevation, the case when the horn antenna was horizontal was defined as 0°, and positive values indicate positions above horizontal. For azimuth, 0° indicates the horn antenna was par-

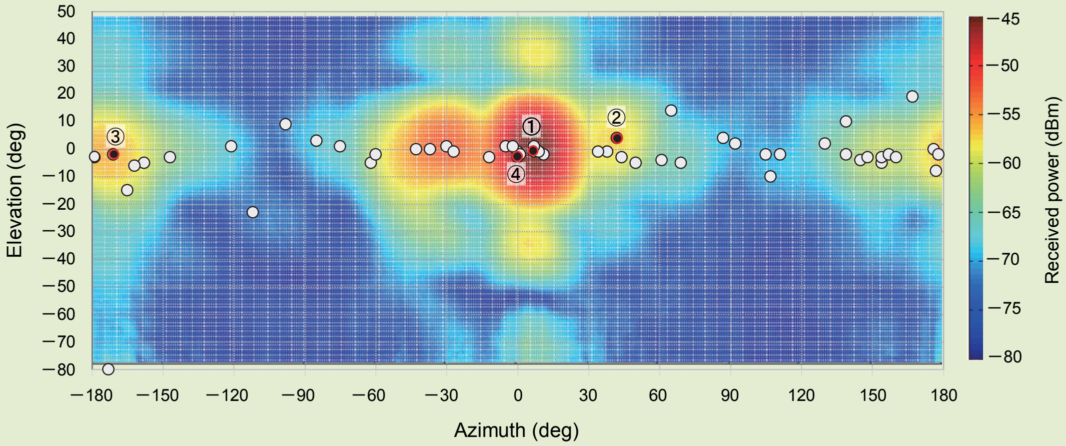


Figure 5　Relation between arrival direction and received power

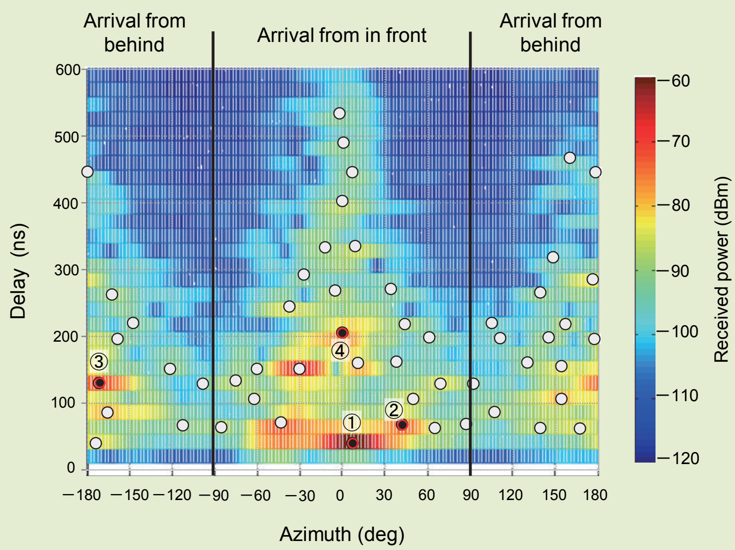


Figure 6　Relation between arrival direction, delay time and reception power

*16 **Horn antenna:** A type of antenna with a cone or pyramid shape, which emits a signal that is strong in a particular direction.

*17 **Delay profiles:** Waveforms that indicate the relationship between received powers and propagation delay times between the signal arriving directly to the receiving station and scattered signals.

allel to the normal vector of wall W2, and positive values correspond to positions of the right side of the normal vector. Fig. 5 and 6 show that there were many paths. These paths were distributed almost uniformly for azimuth angle, and concentrated around 0° for elevation. Results verified that the direct path and the main paths which were reflected regularly by walls (also be shown as Fig. 4, #1 to #4), had strong received power. Note that path #4 is considered to be reflected by the metal frame of the glass window.

4. Propagation Simulation Technology

4.1 Ray Tracing Methods

Ray tracing is a typical technology used to estimate the propagation characteristics in urban areas. Here, street environments often involve tall buildings lining the street, so a propagation model with walls lining the street is often assumed for ray tracing. For this model, many rays emitted from the transmitter and arriving at the receiver must be considered in order to obtain an accurate result, including paths composed of rays arriving at the receiver after reflecting multiple times between buildings on both sides (blue line in **Figure 7**), those reflecting from the edges of buildings on corners (red line in Fig. 7), and reflections from the ground.

4.2 Intersection-building Model

For ray tracing, conventional models assumed square corners at the edges of buildings at intersections. **Figure 8** shows a comparison of results calculated with a conventional model and measured values. The conventional model matched measured values well in (a), for the relatively low frequency of 800 MHz, but in (b) for 37 GHz, the accuracy of the estimate degraded dramatically as distance from the intersection increased. This error will need to be reduced, since use of high frequency bands (6 to 100 GHz) is expected for 5G systems.

However, most real buildings have rounded corners rather than square corners, as shown in Fig. 7. As such, NTT DOCOMO has proposed modeling the edges of buildings at corners with curved surfaces of specified radius, a [12]. As such, the conventional model could be said to use a radius of zero (a = 0). Below, this model using curved surfaces

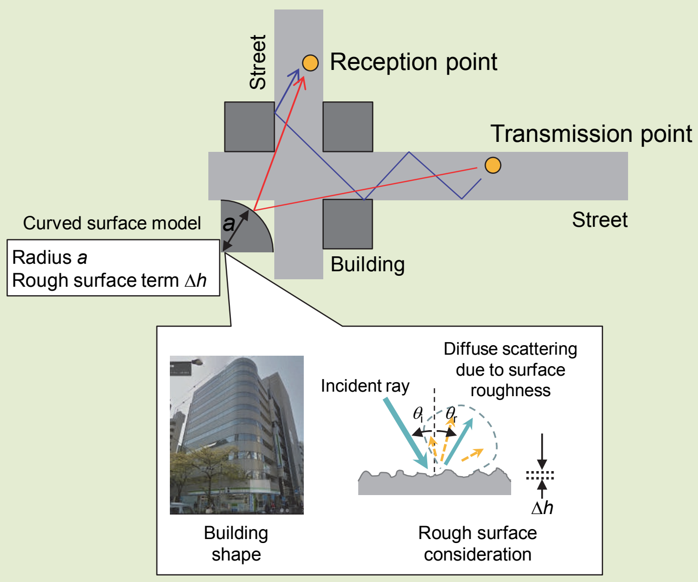


Figure 7 Analysis model

will be referred to as the proposed model.

Conventional models also handled building faces as smooth surfaces, but in the EHF band, with wavelengths of millimeter order, the roughness of building surfaces can no longer be ignored. **Figure 9** shows error characteristics relative to surface roughness, *h* (See Fig. 7). In fact, for ray tracing, the proposed model considering curved surfaces for ray tracing was used (a = 7 m, comparable to real buildings), and an average value of the Root Mean Square (RMS) error*18 difference between calculated and measured values was used. For frequencies below 4.7 GHz, there is almost no variation with surface roughness, but its effects increase dramatical-

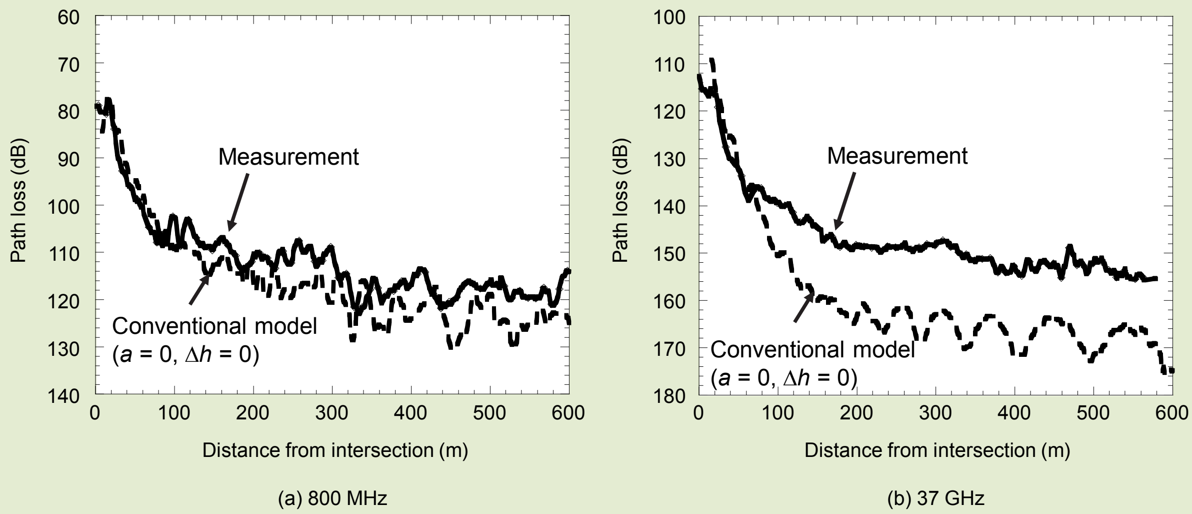


Figure 8　Transmission loss/distance characteristics

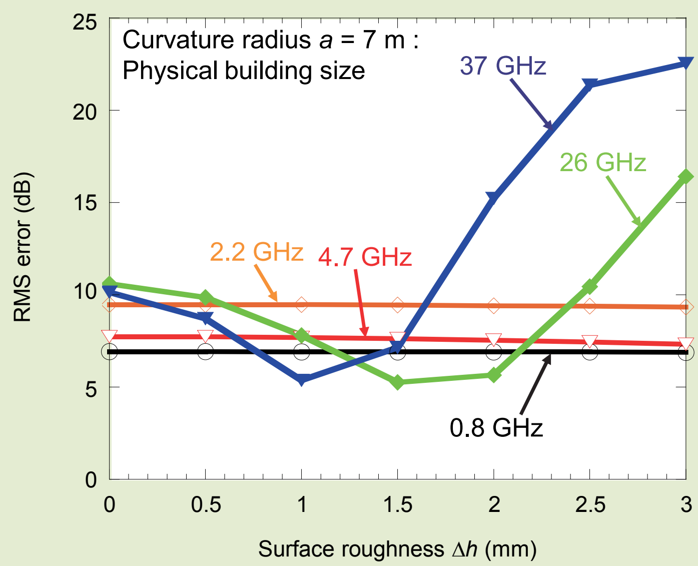


Figure 9　Surface roughness effects

*18 **RMS error:** A value that is the square root of the average of squared error values.

ly for frequencies of 26 GHz and above. These results show that for a surface roughness of approximately 1.5 mm, the error for 26 GHz and above can be reduced.

4.3 Verifying Accuracy

Figure 10 shows the frequency characteristics of RMS error for the conventional model and the proposed model relative to measured values. Note that considering the results above, values of a = 7 m and Δh = 1.5 mm are used for the proposed model. The figure shows that, rather than the error increasing with frequency as indicated by the conventional model, with the proposed model the error can be reduced to 10 dB or less for all frequencies. In other words, for ray tracing, the proposed model can be used to simulate signal propagation for high frequency bands.

5. Conclusion

High frequency bands are expected to be used with 5G, so radio propagation characteristics must be elucidated in order to study 5G systems. This article has described issues related to radio propagation and results obtained in studies done so far. The results discussed here are partial results obtained by NTT DOCOMO. For details of the actual measurements, see references [10] and [11]. For details of the propagation simulation techniques, see reference [12]. In the future, we will perform measurements in a wider range of environments and in frequency bands for which little has been reported.

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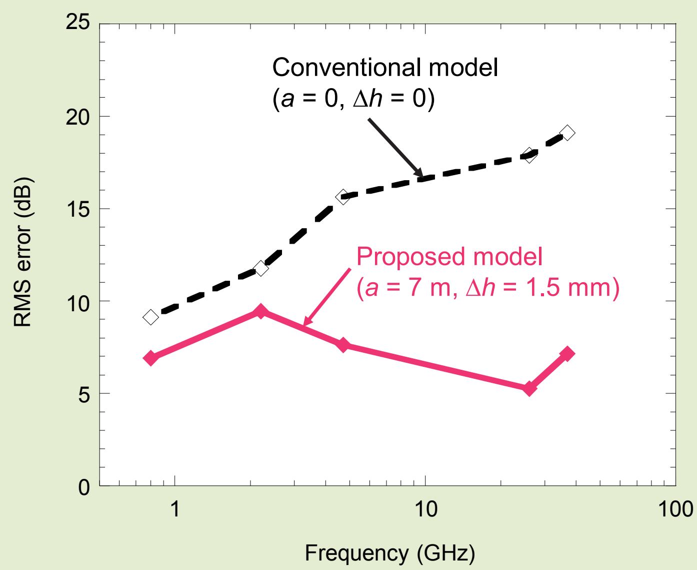

Figure 10 RMS error/frequency characteristics for conventional and proposed models

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