# 2-3 Study on Propagation Model for Advanced Utilization of Millimeter- and Terahertz-Waves

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To realize high speed wireless communication systems using millimeter-wave and terahertz-wave are expecting, and a study of radio-wave propagation is on-going for introduction of these future radio systems. In this report, the recent results of radio propagation research on millimeter-wave and terahertz-wave bands are described.

## 1 Introduction

With the rapid increase of wireless applications, typically in mobile phones and wireless LAN, frequency resource depletion is a serious issue. As allocation of wide signal bandwidth is required for future high-speed communications, utilization of millimeter-wave and terahertz-waves is under considering. Conventionally, these frequency bands have been considered unsuitable for mobile communication use because the optical nature of the waves (strong tendency of straightness) becomes more apparent as the frequency goes up. However, owing to many innovations in recent wireless technology, it is expected that millimeter and terahertz waves will open new possibilities in mobile communications. In accordance with this trend, Agenda Items (AI) related to these frequency bands will be discussed in World Radiocommunication Conference 2019 (WRC-19)[1], for example: identification of candidate frequency bands in the range 24.25–86 GHz to be added to the International Mobile Telecommunications (IMT) band; and frequency band identification in the range 275–450 GHz to be used for land-mobile and fixed services applications. For further investigation into the practical use of these frequency ranges, the propagation properties need to be characterized for link budget design of wireless systems and interference evaluation of frequency sharing. In this report, we describe the current status of millimeter and terahertz wave propagation research now underway in NICT.

## 2 Research on millimeter wave propagation

As a part of the research on millimeter-wave wireless applications in the wireless systems laboratory of NICT, the characterization of propagation properties is currently focusing on two areas: railway radiocommunication systems between train and trackside, and mobile communications in urban environment. These two areas relate to AI 1.11 and AI 1.13 will be discussed in WRC-19: the former intends to consider a possible global or regional harmonized frequency band to support railway radiocommunication systems between train and trackside, and the latter intends to identify frequency bands for future development of IMT. This section describes key points of propagation characteristics and the development of propagation models for these areas.

### 2.1 Propagation characteristics for railway radiocommunication systems between train and trackside [2]

In preparation for the discussions held in WRC-19, plans toward establishing a worldwide or regional harmonized frequency identification, in frequency bands which are already allocated in mobile services, are under review in ITU-R (ITU Radiocommunication sector). In Japan, studies of the millimeter wave range for railway radiocommunication started in around 1980, and in recent years, attention has focused on the use of millimeter wave in the 40 and 90 GHz bands between train and trackside radiocommunication. The use of the 90 GHz band for this purpose is attracting attention relatively recently in connection with AI 1.11. In the research and development toward harmonized use, characterization of propagation properties and interference evaluation are actively underway in view of the fact that a wide portion of frequencies in the 90 GHz range has already been allocated for mobile services. NICT has conducted, in collaboration with affiliate companies, 90 GHz band propagation experiments in various railway environments including a viaduct and tunnel.

The experiment on propagation measurement in the viaduct environment was conducted using a maglev test line in Miyazaki, Japan. In millimeter wave based train-trackside radiocommunication, it is generally assumed to implement a set of communication areas along the train line. In this experiment, directional antennas were installed and they are directed to the train line (see Fig.1). Figure 2 shows the schematic diagram of the propagation measurement system used in the experiment, and Figure 3 shows the results of propagation loss measurement (path loss vs. transmission distance) and estimated regression curves. In this experiment, transmitter (Tx) and receiver (Rx) antennas were installed at the same height (1 m or 2 m), and the transmitter signal was vertically-polarized. For reference, a theoretical free space loss (path loss coefficient $n$ = 2) by calculating equations (1) and (2) is also plotted in the figure.


**Fig. 1** Propagation measurement in viaduct environment
(Copyright(C)2017 IEICE, [2] Fig. 4)

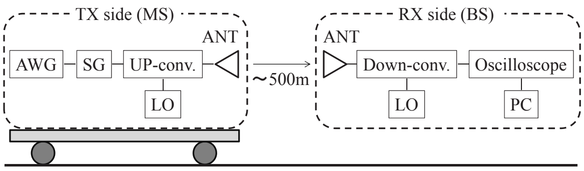



**Fig. 2** Propagation measurement system in 90 GHz band
(Copyright(C)2017 IEICE, [2] Fig. 4)

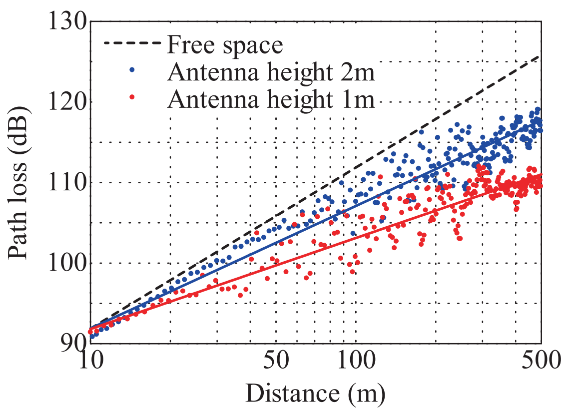



**Fig. 3** Path loss characteristics in 90 GHz band (Measured with vertical polarized signal)
(Copyright(C)2017 IEICE, [2] Fig. 5)

$$PL = L_0 + 10n\log_{10}\frac{d}{d_0} \quad [\text{dB}] \tag{1}$$

$$L_0 = 20\log_{10} f - 8 \quad [\text{dB}] \tag{2}$$

where, the reference distance $d_0$ is 10 m, and the frequency $f$ is in MHz.

Path loss coefficients of regression lines were calculated from the propagation loss data using the least squares method assuming the reference distance $d_0$ = 10 m. The estimated coefficients are: $n$ = 1.52 (for antenna height 2 m) and $n$ = 1.13 (for antenna height 1 m). These results clearly indicate that the pass loss coefficient becomes smaller as the antenna height becomes lower.

The experiment also included path loss measurements using differently polarized signal and power delay profile measurements using modulated waves. By analyzing these results, the authors proposed propagation models and delay spread models to ITU-R SG3 Working Party 3K (WP3K).

### 2.2 Millimeter waves propagation characteristics for mobile communication use in urban environment[3]

Frequency identification in the millimeter wave band (24.25–86 GHz) to be added to the IMT band is scheduled to be discussed as AI 1.13 in WRC-19. A new specification of suitable frequencies involves frequency sharing analysis, requiring the development of a propagation model. The authors conducted experiments using each of the candidate millimeter band frequencies to characterize their propagation properties in an urban environment. This section outlines the results from these experiments.

Measurement items of the experiment include: ① Propagation loss measurement — development of a path loss model to be used in link budget design and interference evaluation, ② power delay profile measurement — to be used for the development of a channel model (impulse response model) that helps in the evaluation of the physi-

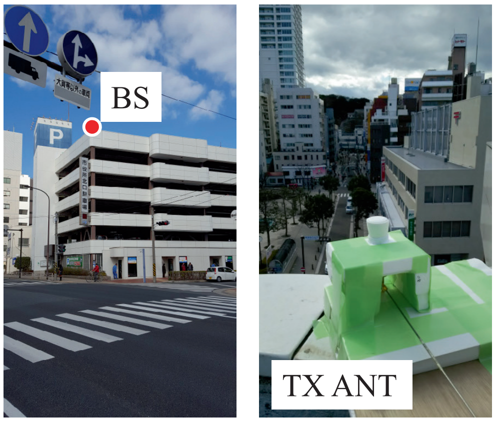
(a)  (b)


**Fig. 4** TX base station
(a) View of building (b) TX antenna
(Copyright(C)2017 IEICE, [3] Fig.4)

(a) (b) 


**Fig. 5** RX mobile station
(a) RX antenna (b) Mobile measurement car
(Copyright(C)2017 IEICE, [3] Fig. 8)

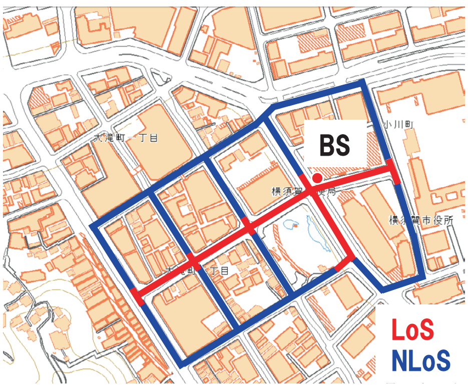



**Fig. 6** Measurement route of MS
(Copyright(C)2017 IEICE, [3] Fig. 9)

cal layer specifications for radiocommunication devices. The authors constructed a propagation measurement system to address these objectives.

The propagation measurements were conducted in the urban environment of Yokosuka city (Kanagawa prefecture). Figures 4 and 5 illustrate the fixed and mobile station, respectively. The mobile station ran along the solid lines shown in Fig.6 (both stations were in line-of-sight while it ran along the red line, and non-line-of-sight along the blue lines). Figures 7 and 8 show propagation loss against transmission distance: the former plots line-of-sight environment data, and the latter non-line-of-sight. To obtain insight for the development of a propagation loss model applicable for each frequency, least-square regression lines were calculated (overlaid in the figures).

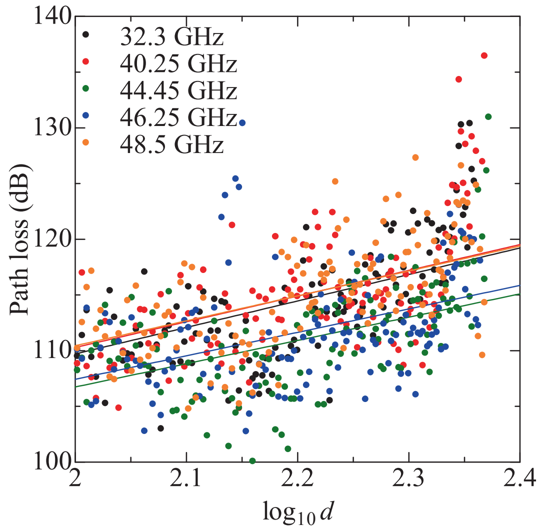



**Fig. 7** Path loss measurement results in LoS urban environment
(Copyright(C)2017 IEICE, [3] Fig. 10)

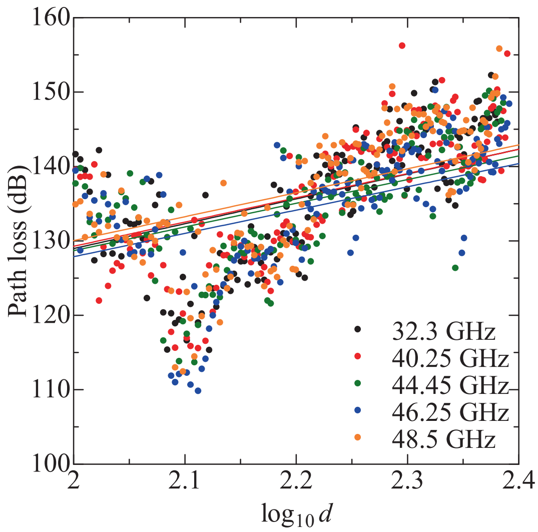



**Fig. 8** Path loss measurement results in NLoS urban environment
(Copyright(C)2017 IEICE, [3] Fig. 10)

$$PL = L_0 + 10n\log_{10}\frac{d}{d_0} \quad [\mathrm{dB}] \tag{1}$$

$$L_0 = 20\log_{10} f - 28 \quad [\text{dB}] \qquad (2)$$

Where; $L_0$ represents the propagation loss at reference distance $d_0$ = 1 m; $n$ represents the pass loss coefficient (a model parameter); $d$ defines the inter-antenna distance between the transmitter and receiver; and $f$ represents frequency in MHz.

The calculated path loss coefficients in the line-of-sight (LoS) situation showed slightly greater values ($n$ = 2.1 ~2.4) as compared to the free space path loss ($n$ = 2). They become larger in the non-line-of-sight (NLoS) situation ($n$ = 3.1~3.3). It was confirmed that contributing factors in the NLoS situation — reflection from building walls and diffraction from rooftops — were a significant portion to the received signal. The authors are planning to utilize these results in the future development of radiocommunication devices, typically for link budget design and interference evaluation. A part of the results, short-distance outdoor propagation models, was submitted as a proposal to the corresponding group 3K-6 in WP3K of ITU-R SG3.

## 3 Research on terahertz wave propagation[4][5]

NICT is now promoting research on characterization of propagation properties in the 300 GHz band with the goal of realizing a radio communication system that uses the 275–325 GHz band. The objectives of the research are related to AI 1.15 of WRC-19, i.e. Studies towards an identification for use by administrations for LMS and FS applications operating in the frequency range 275–450 GHz. This section describes indoor propagation characteristics in the 300 GHz band and the propagation model applicable to this band.

Server-to-server high speed data communication inside a data center is under review as one of the candidate applications of broadband wireless communication systems that can take advantage of the frequencies at and around 300 GHz. The relation between propagation loss and transmission distance was investigated within a server room environment (Fig. 9), where the transmitter and receiver were assumed to be installed on top of the server chassis. The metallic server chassis are basically arranged in a straight line, however, their installation intervals are

**Fig. 9** Data center environment
(Copyright(C)2017 IEICE, [4] Fig.1)

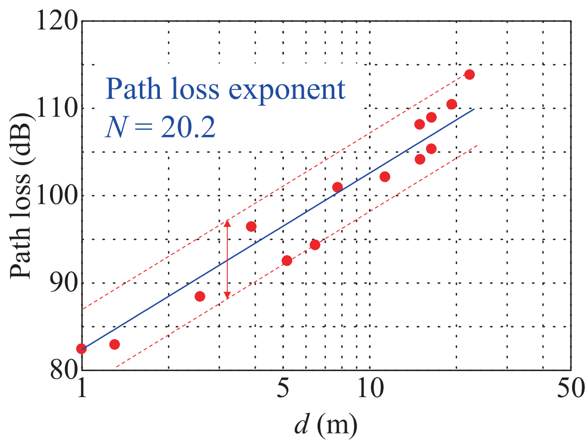



**Fig. 11** Path loss measurement results in data center environment
(Copyright(C)2017 IEICE, [4] Fig. 5)

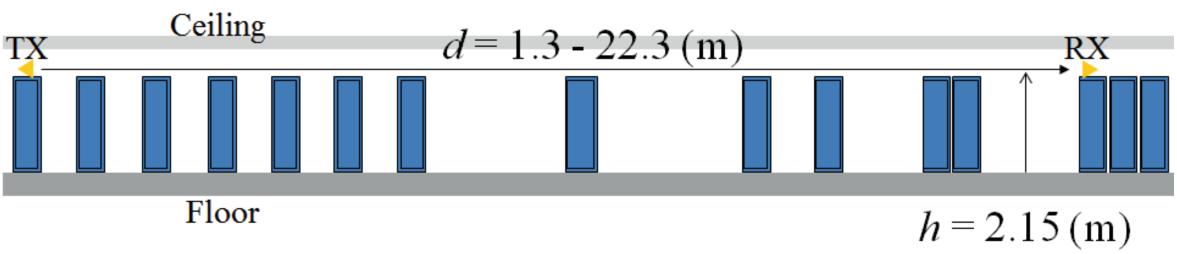



**Fig. 10** Positions of metallic server
(Copyright(C)2017 IEICE, [4] Fig. 2)

not uniform as shown in Fig.10. A 300 GHz-band signal generator was used to transmit an unmodulated continuous wave, and a spectrum analyzer received the signal for propagation loss analysis. The communication distance was changed by relocating the Rx station against the fixed Tx station, and the receiving power was measured up to 22 m away.

Two horn antennas (gain 25 dBi, beam-width 10°) were used at TX and RX, and the TX output power was set to -15 dBm. Both antennas were installed at a height of 215 cm from the floor. Figure 11 shows the plots of measured path loss characteristics by calculating from received power. A straight-line approximation is also overlaid in the figure. The path loss model used in this approximation is based on the model of ITU-R P.1238. Assuming theoretical propagation loss $L_0$ = 82 dB at the reference distance 1 m, the least-squares regression line of the data resulted in a pass loss coefficient value of $N$=20.2, which is slightly larger than the free space path loss ($N$=20). In some TX and RX spatial arrangements, measured data points were away from the straight-line approximation. This was indicating the effect of reflection especially in the configurations in which both the transmitter and receiver are located near a server chassis. To examine the variations of propagation loss (or height pattern characteristics) more closely, the TX and RX antennas were positioned in two different spatial arrangements as shown in Fig.12: one with a server chassis positioned on the specular reflection point, and the other off the point. The results showed clear difference between the two cases: the one in which the receiver received the direct path only, and the other in which the receiver received waves reflected from the server chassis in addition to the direct path. This indicates the importance of two parameters — i.e. distances between the server chassis and height of the antennas — for the optimum design of inter-server wireless communication. Numerical calculation using the ray-tracing method also made clear that the cause of different behavior can be ascribed to the reflected waves from the server chassis. The authors conducted additional propagation measurements in office and corridor environments, and combined all the results into a contribution document, which was submitted to ITU-R SG3 WP3K for review. The proposed model was approved in the working group and has been included in ITU-R Recommendation P.1238 (prediction and evaluation method for indoor, short-distance propagation loss).

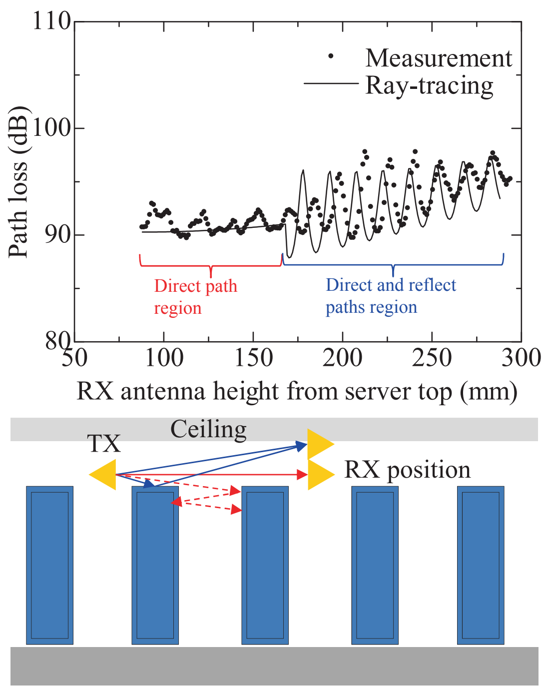



**Fig. 12** Validation of measurement result by ray-tracing method



## 4 Summary

For designing wireless applications using millimeter-wave and terahertz-wave, the first step is to know the radio propagation characteristics. To clarify the radio propagation characteristics contributes to the further development of radio communication, and it is a part of our mission. Developed propagation models will be a useful tool for designing specific future radio communication systems.

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