Evaluation of Long-distance Transmission Characteristics in a 60 GHz Band Millimeter-wave Wireless Communication Module in a Real Propagation Environment

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The 60 GHz band has wide frequency channels, making it suitable for high-speed, large-capacity communications. It is expected to be applied in areas such as high-definition and low-latency video transmission. To help users assess the applicability of 60 GHz band wireless communications, this paper presents the results of transmission characteristics evaluations conducted in actual outdoor environments. The evaluations were carried out using 60 GHz band millimeter-wave wireless communication modules developed by Fujikura, which have obtained technical compliance certification.

1. Introduction

High-speed, large-capacity wireless communication systems are increasingly needed in various fields to make society smarter. Although 5G/Private 5G wireless communication systems require a license, a 60 GHz band millimeter-wave system does not, making it possible to easily construct high-speed networks at low cost. This system is ideal for various types of applications, including construction sites, work sites, smart commercial and industrial facilities, and high-definition, low-latency video transmission. We have developed an embedded 60 GHz band millimeter-wave communication wireless module that can be used in 60 GHz band wireless communication systems. This module has been certified as compliant with technical standards by a certification body[1)2)]. Figure 1 shows the appearance of the 60 GHz band millimeter-wave wireless communication module. Using this module, which has already obtained a technical conformity certificate, equipment manufacturers can quickly and affordably create communications and industrial equipment using the 60 GHz band.

Fig. 1. 60 GHz millimeter-wave wireless communication module.

Despite these advantages, the 60 GHz band is generally considered to be less suitable for long-distance communications because it is known that oxygen absorption in the atmosphere and rainfall can cause significant propagation attenuation[3)]. However, there have been few quantitative evaluations of the long-distance transmission characteristics of 60 GHz band wireless communication devices with technical standards compliance in the usage environment, and their performance has not been made clear.

In this paper, we report on the distance characteristics of communication performance in a real environment evaluated using a device that incorporates the developed module.

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2 : Millimeter-wave Systems Development Department
3 : Electronic Technologies R&D Center

Abbreviations, Acronyms, and Terms.

technical standards compliance—A certificate that proves that specified radio equipment (small-scale radio equipment such as mobile phones and wireless LAN devices, as defined by the Ministry of Internal Affairs and Communications) conforms to the technical standards of the Radio Law.

5G—5th generation mobile networks
The latest mobile communication system in widespread use today.

Private 5G—A privately-run 5G network installed in a specific area by a business other than a telecommunications carrier, such as a corporation or local government.

NPU—Network Processing Unit
A computer specialized in network processing.

PCP/AP—PBSS central point/Access point
Terminal on the control side of Wi-Fi

STA—Station
Terminal on the client side of Wi-Fi

P2P—Point-to-Point
A configuration in which one station is located at each access point

Throughput—The amount of information transmitted within a certain period of time in communication

TCP/IP—Transmission Control Protocol/Internet Protocol
Transport Layer (L4) protocol. A method of transmitting data after confirming that a connection has been established.

MCS—Modulation and Coding Scheme
An index of the combination of modulation method and coding rate

Physical layer—Layer 1 of the OSI reference model. Responsible for the physical transmission of data

IP layer—Also known as the network layer (L3), it is responsible for functions such as sending and receiving data packets, packet routing, forwarding, fragmentation (dividing and reconstructing packets), and error detection and correction.

channel—Medium for conveying information

EIRP—Equivalent Isotropic Radiated Power
This indicates the strength of the transmission power of radio waves radiated in a specific direction from a directional antenna. In some cases, it indicates the maximum power of radio waves radiated in all directions.

Fig. 2. Outdoor evaluation kit.

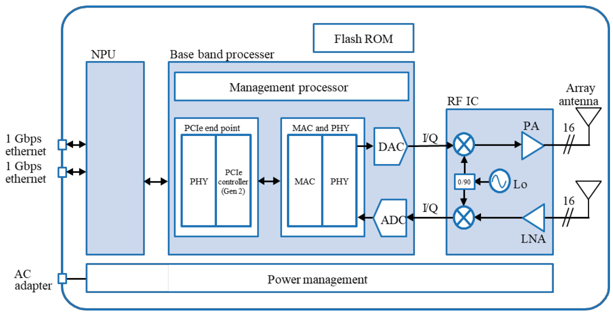

Fig. 3. Functional block diagram of the outdoor evaluation kit

Table 1. Major specifications of outdoor evaluation kit.

Frequency band	57-65 GHz (CH1-CH4)
EIRP	40 dBm (Max)
Horizontal Beamforming	±45 deg
Interface	GbE × 2 ports

Fig. 4. Overview of the field trial.

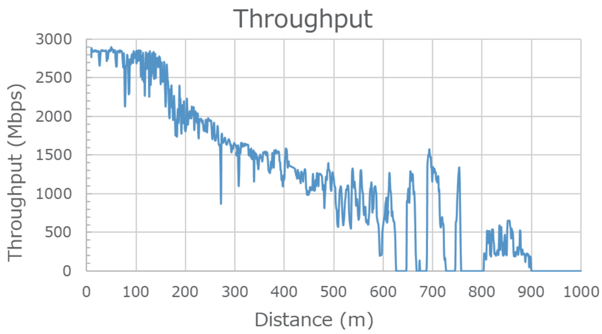

Fig. 5(a). Dependence of throughput on module facing distance

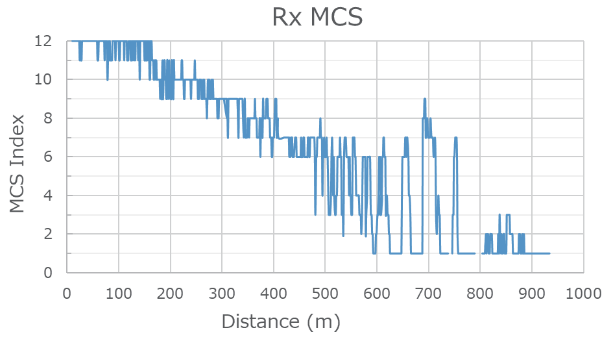

Fig. 5(b). Dependence of received MCS on module facing distance

2. Evaluation device

To evaluate the communication quality of the 60 GHz band millimeter-wave wireless communication module, we constructed a system in which the module and Network Processing Unit (NPU) are installed for communication with an external network. Figure 2 shows the external appearance and Fig. 3 shows the functional block diagram of the outdoor evaluation kit, which is the system equipped with this module. The size of the outdoor evaluation kit is 155 mm wide, 299 mm high, and 109 mm long. The kit is equipped with a 60 GHz band millimeter-wave wireless communication module, an NPU, and a power supply. The kit also has two Gigabit Ethernet (GbE) communication interfaces. Table 1 shows the major specifications of the outdoor evaluation kit.

3. Performance evaluation

In order to determine the communication quality required for real-world applications, we evaluated the performance of the 60 GHz millimeter-wave wireless communication module. In environments such as factories and construction sites, transmission distances of several hundred meters are required, but communication quality is affected by factors such as installation height, distance and rainfall. We evaluated the long-range characteristics of the communication quality, the effect of installation height, and the effect of rain attenuation. These evaluations were conducted in an open area with no obstacles, except for the rainfall attenuation test, in order to observe general trends excluding specific environmental conditions such as the presence of buildings.

3.1 Long-distance characteristics

The evaluation of the communication system was performed by constructing a Point-to-Point (P2P) network with a PBSS central point/Access point (PCP/AP) and Station (STA) using the outdoor evaluation kit. In order to avoid limitations on communication speed (maximum 1 Gbps) due to the GbE interface standard, traffic was generated by the NPU inside the outdoor evaluation kit, not from an external network, using the Transmission Control Protocol/Internet Protocol (TCP/IP). The frequency channel was channel 4 (63.72–65.88 GHz). The height of the antennas was 3.9 m, and evaluation was conducted in an outdoor environment as shown in Fig. 4. Figure 5 shows the effective communication speed (throughput) and Modulation and Coding Scheme (MCS) at the IP layer versus the facing distance between the PCP/AP and the STA. MCS is an index that combines modulation and coding rate. Table 2 shows the physical layer communication speed for each MCS value.[4] The throughput was about 1.0 Gbps at 500 m, confirming that communication is possible at distances up to 900 m. At distances beyond 400 m, the MCS tends to increase and decrease periodically. This is due to fluctuation in the received power (Rx power) caused

Table 2. Relationship between MCS and physical layer data rate

MCS	PHY Data Rate (Mbps)
1	385
2	770
3	963
4	1155
5	1251
6	1540
7	1925
8	2310
9	2503
10	3080
11	3850
12	4620

by the combination of direct waves and reflected waves from the ground, a phenomenon called fading[5]. A change in the facing distance causes a change in the Rx power of the composite wave since the path difference between the direct wave and the reflected wave changes accordingly. The above results show that the 60 GHz band millimeter-wave wireless communication module is capable of high-speed, large-capacity communications at 1 Gbps or higher over long distances of several hundred meters. Next, we compared our modules with commercially available 60 GHz wireless communication devices made by other manufacturers. Figure 6 shows a comparison of throughput over distance with the competitor's product. Since it was not possible to generate the same traffic inside both devices, traffic was applied from an external terminal connected to the GbE interface of each device. Due to this, the maximum throughput was approximately 1 Gbps. At 450 m, the throughput of the competitor's product was about 20 Mbps, while our product achieved 900 Mbps. Note that the increase and decrease in throughput beyond 700 m are due to fading.

3.2 Effects of rainfall attenuation

The 60 GHz band millimeter-wave communication channel is highly attenuated by rainfall, which may cause communication breakdowns when used outdoors depending on the amount of rainfall and communication distance. To evaluate the effect of rainfall on the 60 GHz millimeter-wave communication channel, the outdoor evaluation kit was installed on the roof of an outdoor building, and the amount of rainfall and Rx power were measured. The communication distance was 200 m, and the height of the evaluation kit was about 18 m from the ground on the receiving side and about 28 m on the transmitting side. Channel 3 (61.56–63.72 GHz) was used as the frequency channel. Figure 7 shows the relationship between the amount of rainfall and received power, and between the amount of rainfall and throughput measured during a two-month period. Although the Rx power varied depending on the temperature at the time of measurement, a decrease in Rx power with an increase in rainfall was observed. A linear approximation of the Rx power measurement results, as shown in Fig. 7, indicates that the effect of attenuation due to rainfall at 200 m from the receiver was about 0.1 dBm/mm/h. In addition, even when the rainfall was 30 mm/h, the throughput was 1500 Mbps. Although this was approximately 1000 Mbps lower than on a sunny day, it was still sufficient to achieve a high-speed connection.

3.3 Effect of installation height

As shown in Figs. 5 and 6, fading causes periodic fluctuations in the communication state depending on the distance. This fluctuation also occurs when the installation height is changed. This is called the height pattern and is an important factor when installing communication devices. The cycle of this pattern depends on variables such as the distance, frequency, and antenna configuration. In order to understand the height pattern of the 60 GHz band millimeter-wave wireless communication module, we changed the installation height of the outdoor evaluation kit on the receiving side as shown in Fig. 8 and measured the Rx power and throughput. The height of the transmitter was fixed at 4 m, and the distance conditions were 500 m and 1000 m. Figure 9 shows the measurement results of the Rx power, and Fig. 10 shows the measurement results of the throughput. At 500 m, the Rx power fluctuated within 2 dBm, whereas at 1000 m, the Rx power fluctuated periodically depending on the height of the receiver from a maximum of -57 dBm to -63 dBm or less at which

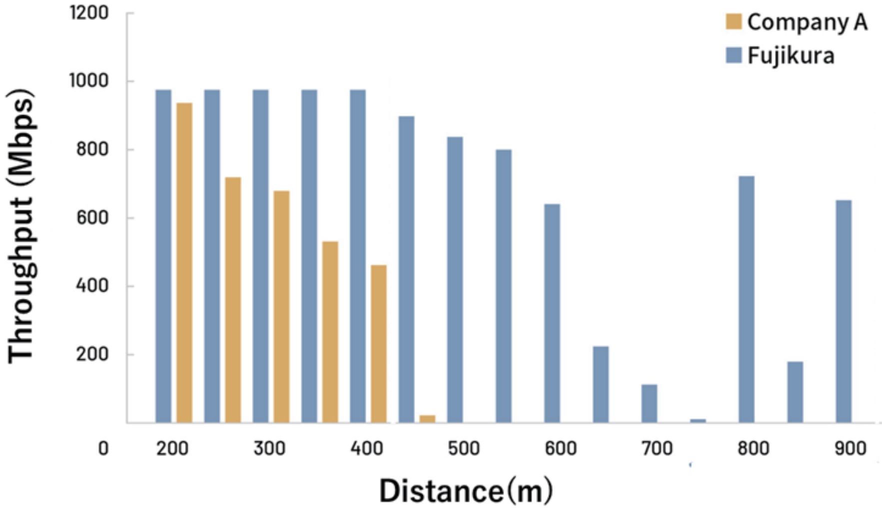

Fig. 6. Throughput comparison with a competitor product

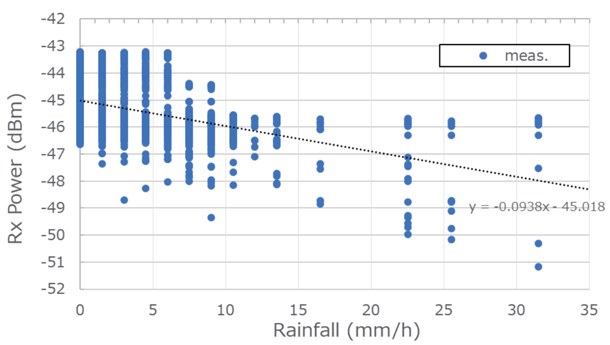

Fig. 7(a). Relationship between Rx power and rainfall

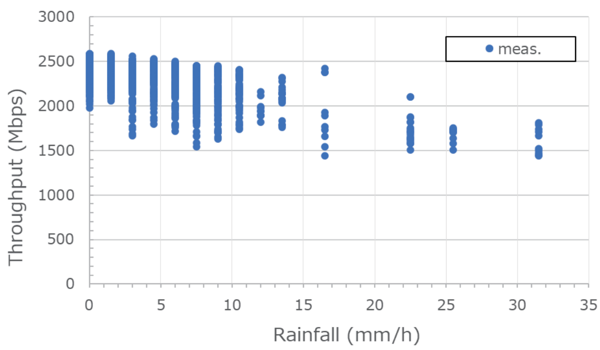

Fig. 7(b). Relationship between throughput and rainfall

Fig. 8. Overview of the height pattern measurement

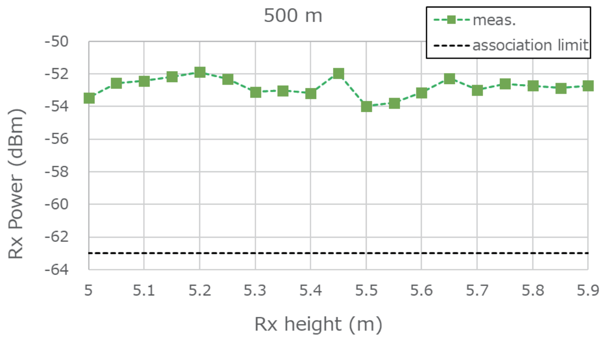

Fig. 9(a). Height pattern of Rx power at 500 m

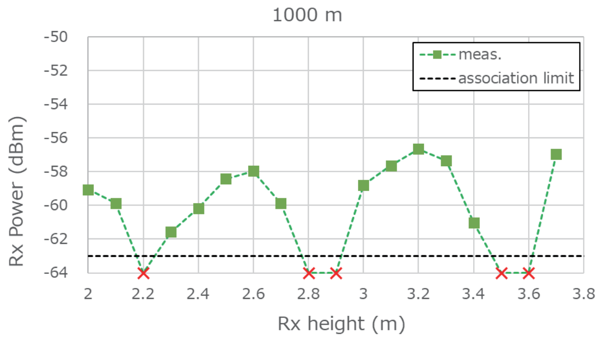

Fig. 9(b). Height pattern of rx power at 1000 m

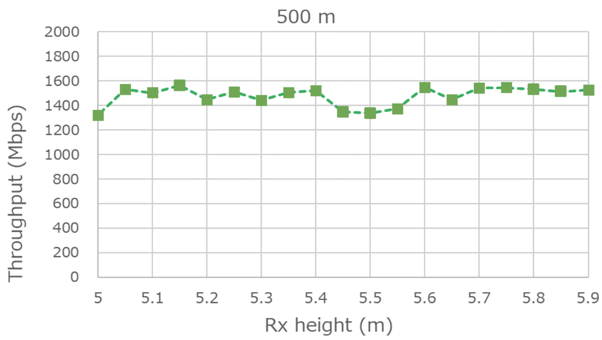

Fig. 10(a). Height pattern of throughput at 500 m

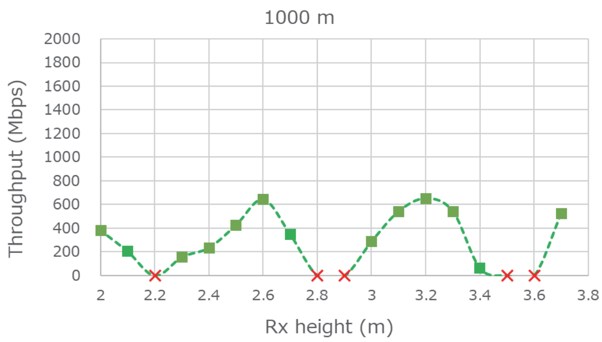

Fig. 10(b). Height pattern of throughput at 1000 m

communication was cut off. The fluctuation cycle was about 0.6 m. These results suggest that communication conditions can be improved by adjusting the installation height according to distance, and that a maximum throughput of about 600 Mbps can be achieved at 1000 m.

4. Conclusion

This paper presents the results of performance evaluations of a 60 GHz band millimeter-wave wireless communication module in a real environment. The findings show the excellent communication performance of the 60 GHz band millimeter-wave wireless communication module over long distances, its resistance to rainfall, and the effect of installation height on communication quality. Based on these results, we aim to provide solutions using 60 GHz band millimeter-wave communication module to our customers.

Reference

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