Comparison of SNR and channel capacity with micro and millimeter wave bands based on outdoor propagation measurement

Ryotaro Taniguchi\textsuperscript{a)} and Kentaro Nishimori
Graduate school of Science and Technology, Niigata University
Ikarashi 2-nocho 8050, Nishi-ku Niigata, 950–2181 Japan
\textsuperscript{a)} taniguchi@gis.ie.niigata-u.ac.jp

Abstract: The 5-th generation mobile communication system (5G), which is the next generation communication system, is being developed. In 5G, it is assumed that multiple cells with different frequency bands will be used. The attenuation of signal power due to propagation loss in free space and the reflection of radio waves from buildings, etc., differs depending on the frequency. In this paper, a radio propagation measurement is performed for micro and millimeter waves (5 and 19 GHz bands), which will be used in 5G. The outdoor propagation characteristics of each frequency band based on the measured channel state information are evaluated in terms of the signal to noise ratio and channel capacity.

Keywords: 5G system, micro wave, millimeter wave, outdoor propagation, propagation pathloss, channel capacity

Classification: Antenas and propagation

References


1 Introduction

In recent years, there has been a significant increase in the volume of wireless traffic due to the spread of wireless communication devices such as smart-
phones. In particular, between 2016 and 2021, the total wireless traffic throughout the world is expected to increase sevenfold [1]. It is difficult for the current communication technology to cope with this increase in traffic volume. Therefore, the research and development of wireless communication technology that can realize high speed and high efficiency in a limited frequency band is essential. The 5-th generation mobile communication system (5G), which is the next generation communication system, has been developed in this regard. In 5G, multiple cells with different frequency bands are used to improve frequency utilization efficiency. The propagation loss in free space and the attenuation of signal power due to reflections and refractions on buildings, plants, etc., are different depending on the frequency band.

Until now, experiments have been reported in the 2 to 5 GHz band for 5G [2] [3]. Also, the direction of arrival of the microwave band was indicated in our previous study [4]. In this report, radio propagation measurement is performed for micro and milli-meter waves (5.12 and 19.55 GHz band), which are expected to be used in 5G. The outdoor propagation characteristics of each frequency band based on the measured channel state information (CSI) are evaluated in terms of the signal to noise ratio (SNR) and channel capacity.

2 Device configuration and measurement environment

At the transmitter, first, a PC generates a baseband orthogonal frequency duplex multiplexing (OFDM) signal. Then, the signal is D/A converted, quadrature modulated, and frequency converted to 2.425 GHz (L.O.1). Here, this device can be used even in the 5.12 GHz frequency band. Then, this signal is converted to 19.55 GHz (L.O.2), power amplified, and transmitted from the antennas. Also, by switching the L.O.1 frequency from 2.425 GHz to 5.12 GHz, the device can be operated at 5.12 GHz.

The signal received by the receiver is down converted from 19.55 GHz to 2.425 GHz (L.O.3). Even at the receiving side, evaluation of the 5.12 band is possible by switching the L.O.3 frequency from 2.425 GHz to 5.12 GHz. The signal, which is frequency converted from 2.425 GHz, is configured to be transferred to a PC after quadrature demodulation and A/D conversion.

The OFDM signal used consists of a short preamble and a long preamble. First, the short preamble is used to detect the beginning of the signal by autocorrelation processing. Then, CSI is estimated using the long preamble. Since each antenna has different signal transmission timing, it can obtain 4x4 channel matrix.

The parameters are as follows. The center frequencies are 5.12 GHz and 19.55 GHz, and the four transmitting and receiving antennas are sleeve antennas. The signal band is 20 MHz, the number of bits for A/D conversion and D/A conversion are both 12 bits, and the transmission power is 27 dBm.

In order to obtain the SNR and channel capacity in the outdoor small cell environment, the radio wave propagation measurement is performed on the uplink using center frequencies of 5.12 GHz and 19.55 GHz. In the measurement, the transmitter is moved linearly, and the signals are transmitted
and received at intervals of 2 m.

Fig. 1 shows a diagram of the measurement environment; it shows courses 1 to 5 (with the transmitter moved linearly) and the point of the receiver. The transmitter antenna height is 1.5 m, assuming that the users are using the terminal. The receiving antenna height is 11.15 m, assuming the base station antenna height. In the measurement, four transmitting and receiving antennas were used to eliminate the effect of decrease in received power due to fading.

![Fig. 1. Measurement environment.](image)

### 3 Characteristics of received SNR

In order to obtain the basic characteristics in the outdoor small cell environment, propagation measurements were carried out for the uplink with 5.12 GHz and 19.55 GHz [1]. Fig. 2 shows the received SNR of both frequencies for Course 1 to Course 5. These figures show that the received SNR with 5.12 GHz is much higher than that with 19.55 GHz. The SNR decreases according to the distance moved by the transmitter (D), when 5.12 GHz is used. On the other hand, the SNR obtained with 19.55 GHz decreases considerably at D = 22 m and between D = 70 and 90 m on Course 2. Similarly, the SNR obtained with 19.55 GHz decreases significantly between D = 20 and 70 m on Course 3. This is due to the influence of large tree and hedges between the transmitter and the receiver. Since the wavelength of
the 19.55 GHz signal is about 25% shorter than that of the 5.12 GHz signal, it is considered that these radio waves cannot pass through plants, etc. In addition, the radio wave of 19.55 GHz has a high rectilinearity compared to that of 5.12 GHz, which is considered to be a factor that makes diffraction at an obstacle difficult.

Fig. 2. Characteristics of SNR.

4 Relationship between the distance and channel capacity

Fig. 3 shows the transmission and reception distance characteristics of the channel capacities of 5.12 GHz and 19.55 GHz based on the measured propagation. In this letter, the channel capacity is defined as follows so that the ratio band of 5.12 GHz is 1:
\[
C = \frac{f_c}{5.12} \log_2 \det(I_{N_R} + \frac{SNR}{N_T \cdot 5.12} \cdot HH^H),
\]  
(1)

The center frequency \( f_c \) are 5.12 and 19.55 GHz. The number of transmitting and receiving antennas \( N_T \) and \( N_R \) are four. The \( SNR \) is based on the measured propagation. The \( H \) is propagation channel. \( H \) is Hermitian transpose. The propagation model is i.i.d. Rayleigh fading channel to derive the basic characteristics. The number of trials is 1000, and its median is graphed. The bandwidth of 19.55 GHz is 3.82 times the bandwidth of 5.12 GHz, assuming that the available relative bandwidths of 19.55 GHz and 5.12 GHz are the same.

As can be seen from the graph, the channel capacity of the 19.55 GHz signal is more than that of the 5.12 GHz signal when the distance is less than 90 m. On the other hand, the channel capacity of the 5.12 GHz signal is more than that of the 19.55 GHz signal when the distance is more than 90 m.

For 19.55 GHz signals, the portion of the channel capacity less than about 40 bps / Hz is the result obtained from the measured SNR of the non-line-of-sight (NLOS) environment. In the line of sight (LOS) environment, that part of channel capacity is more than 40 bps/Hz, and the channel capacity of the 19.55 GHz signal is more than that of the 5.12 GHz signal. On the other hand, in the NLOS environment, the channel capacity of the 19.55 GHz signal is less than that of the 5.12 GHz signal.

From the above, when constructing a communication system using a millimeter wave band, it can be said that it is necessary to use a sufficient bandwidth, assuming use in a service area far from a base station or a service area where there is considerable shielding. On the other hand, in a service area closer to a base station, it can be said that sufficient communication can be realized even in the millimeter wave band without using a large bandwidth supplement. In other words, it is necessary to use different frequency bands depending on the environment. For example, in the LOS environment, the millimeter wave band is used when the distance is sufficiently close such as less than 40 m, and when the distance is long such as more than 40 m or in the NLOS environment, the microwave band is used.

### 5 Conclusion

In this study, outdoor wave propagation was measured in a small cell environment for 5.12 GHz, which is a microwave band, and 19.55 GHz, which is a millimeter wave band. The base station antenna height was 11.15 m, and the transmission distance was up to 100 m. The basic performance of the multiple-input and multiple-output (MIMO) for each frequency was compared and examined in terms of the SNR and channel capacity.

First, the device configuration and measurement environment was shown. Then, the SNR characteristics of the 5.12 GHz and 19.55 GHz signals were shown for each measurement course. It was found that the SNR decreased
as the distance increased, and the millimeter wave band was significantly affected by the shielding of plants such as trees and hedges compared to the microwave band. Moreover, the performance of the MIMO channel capacity with respect to the transmission distance was confirmed when the fractional bandwidths of the 5.12 GHz and 19.55 GHz signals were identical. If the ratio bands of the millimeter wave band and the microwave band are the same, the microwave band is advantageous. However, it is found that in the NLOS environment, it is possible to obtain larger channel capacity in the millimeter wave band if the relative bandwidths are the same.

From the above, it was concluded that in an actual communication environment, it is necessary to choose between the millimeter wave band and the microwave band depending on the difference between the LOS / NLOS environment.

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