Study on Extension to Higher Frequency Band of 3GPP Outdoor-to-Indoor Path Loss Model

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***Abstract*—Recently, mobile communication system for the 5th generation (5G) has been extensively investigated to satisfy the need for high-speed and high-capacity communication. In order to realize the higher and larger data communication, one of the approaches is to utilize high frequencies such as high SHF (above 6 GHz) and EHF (30 – 100 GHz) [1]. These frequency bands are expected to be applied for outdoor or indoor small cell; hence it is critically important to investigate the characteristics of propagation and model it. Additionally, characteristics of 'Outdoor-to-Indoor (O2I) propagation' and its modelling are necessary from system design point of view. This report presents extensive investigation for "Extension of 3GPP model below 6 GHz [2]".**

Keywords—radio propagation; propagation loss; diffraction; Outdoor to Indoor propagation; 5G

I. INTRODUCTION

Recently, mobile networks employing high-speed high-capacity communications have been investigated extensively to satisfy the demand for the faster and larger data communication as the 5th generation (5G) mobile communication system. As one of the approaches to satisfy the needs, high frequencies between high SHF (above 6 GHz) and EHF (30 – 100 GHz) [1] are the candidates to be utilized for outdoor or indoor small cell. Accordingly, radio propagation in these frequency bands must be characterized. Additionally, characteristics of 'Outdoor-to-Indoor (O2I) propagation' and its modelling are necessary, especially, from the system design point of view. This report presents extensive investigation for "Extension of 3GPP model below 6 GHz [2]".

II. CONVENTIONAL MODEL

The 3D channel model standardized by 3GPP [2] in the scenario of urban micro (UMi) small cell provides path loss model for O2I propagation with parameters in Fig. 1 as

$$PL = PL_b + PL_{tw} + PL_{in} \quad (1)$$

Here,

$$PL_b = PL_{3D-UMI}\left(d_{3D-out} + d_{3D-in}\right) \quad (2)$$

$$PL_{tw} = 20 \quad (3)$$

$$PL_{in} = 0.5 d_{2D-in} \quad (4)$$

The term of $PL_{3D\text{-}UMi}$ in (2) indicates the function used for the propagation loss prediction in urban small cell environment (Outdoor-to-outdoor scenario). When Line-of-Sight (LOS) case between BS and UT, d_{BP} is defined as

$$d_{BP} = \frac{4\left(h_{BS}-1\right)\left(h_{UT}-1\right)}{0.3} f \quad (5)$$

Finally, the path loss is estimated with d_{BP} as following:

$$PL_{3D-UMi} = 22\log\left(d_{3D}\right) + 28 + 20\log f \quad ;\text{when } 10\text{m} < d_{2D} < d_{BP} \quad (6a)$$

$$PL_{3D-UMi} = 40\log\left(d_{3D}\right) + 28 + 20\log f - 9\log\left(d_{BP}^2 + \left(h_{BS} - h_{UI}\right)^2\right) \quad ;\text{ when } d_{BP} < d_{2D} \quad (6b)$$

Here, *f* is frequency in GHz and applicable below 6 GHz. It is obvious from (1) – (6) that there exists a unique term $PL_{3D\text{-}UMI}$ expressing frequency dependency in this prediction model. In addition, the frequency dependency equals to free space propagation loss. In this report, applicability of the prediction model is evaluated for higher frequencies above 6 GHz.

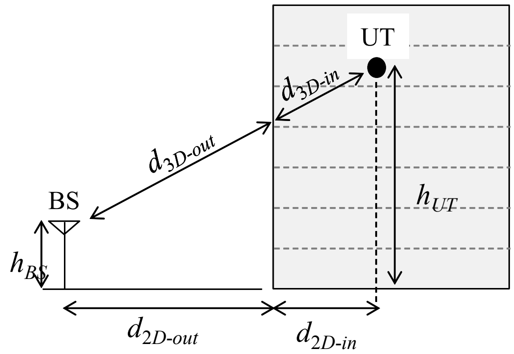


Fig. 1 Parameters in 3D channel model

III. MEASUREMENT

Measurement was conducted in the campus of Niigata University, Japan in order to evaluate the abovementioned conventional model. Measurement environment is illustrated in Fig. 2. Frequencies used for measurement are 0.8, 2.2, 4.7, 26.3 and 37.0 GHz. Six sleeve antennas for each frequency are installed on a car roof as BS with transmission of CW signal simultaneously. The altitudes of each antenna are uniformly 2.5 m. Three locations of BS are shown in Fig. 2 as A1 – A3.

Measurement was conducted with two receiver units of hand trucks. Each one installed three different sleeve antennas on it with the interval of 1.5 m between floor and the antennas. Measurement was repeated on the floors of 1st, 2nd, 4th, 6th and 8th (namely, 1F, 2F, 4F 6Fand 8F).

The measured data of received power are post-processed in the following manner: (1) reference points are established every meter. (2) The data at the reference point and other data acquired within 0.5 m before/after the reference point are considered as a data set belonging to the reference point. (3) The median of the data set is determined as the received power at the reference point. (4) Finally, the power is converted to path loss.

Fig. 3 shows measurement results for 0.8 and 37 GHz when BS is located at A1 where horizontal axis indicates a moving distance of UT (or Rx) along a red arrow in Fig. 2 and vertical axis indicates path loss normalized by free space loss at the building face.

IV. EVALUATION

The conventional model (3D channel model) is used to estimate path loss for the measurement scenario. Here, intervals of each building floor are approximately 3 m hence; $h_{UT} = 3(n - 1) + 1.5$ [m] depending on number of floor n.

Fig. 4 shows the evaluation of the error between the conventional model and measurement result for 1F, 2F, and 4F. Note the measurement result is subtracted from the estimated. Here, horizontal and vertical axes are frequency and the mean error for each route respectively. The error is as large as approximately 20 dB for 0.8 GHz while the error is observed as between 0 and -5 dB for 4F and 8F. It is expected that building penetration loss PL_{tw} as equation (3) in the conventional model is determined to be 20 dB. For instance, ITU-R recommendation (M.2135) for IMT-Advanced model [3] parameterizes PL_{tw} as

$$PL_{tw} = 14 + 15(1 - \cos\theta)^2 \qquad (7)$$

Here, θ is incident angle between perpendicular direction to the building face and the direction of BS from the building face. Based on (7), the penetration loss PL_{tw} of 20 dB is equivalent to $\theta \cong 68°$. Incident angle supposed to be large as altitude of floor becomes large. The reduction of error for 4F and 8F can be considered that actual incident angle approaches to 68° as a result. On the other hand, characteristics of the error in terms of frequency for 1F and 8F show reduction as frequency becomes large. It means the conventional model underestimates path loss as frequency becomes large. The conventional model does not include any frequency dependent term in PL_{tw} and PL_{in}. With the sense that diffraction loss should become large as frequency become large, the inclusion of the effect may improve the accuracy of the conventional model. However, no clear frequency dependency observed in the result of 4F. Therefore, the extension of the conventional model may require accounting for multi-path effect and detail analysis.

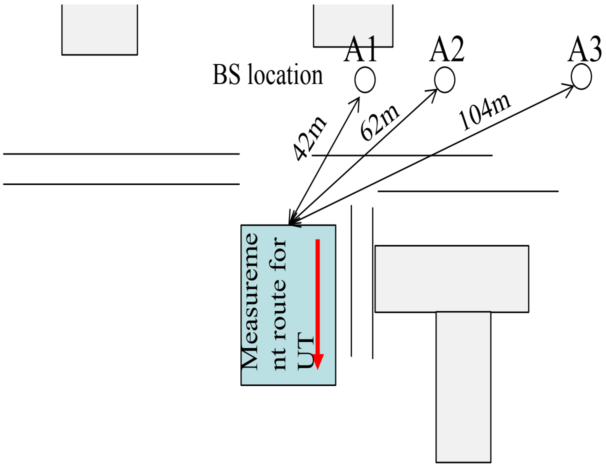
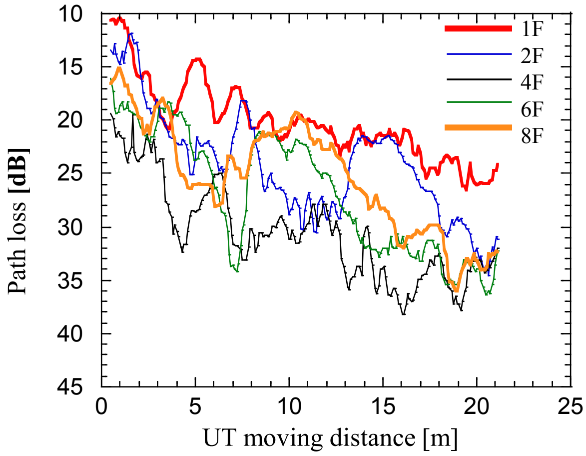
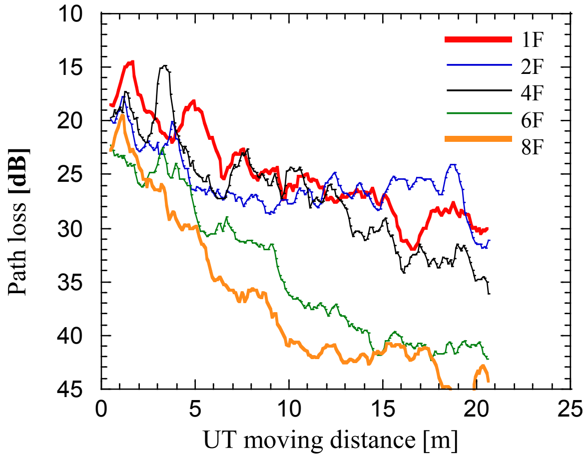


Fig. 2 Measurement environment



(a) 0.8 GHz



(b) 37.0 GHz

Fig. 3 Measurement result (BS location at Al)

V. SUMMARY

In this report, the extension of 3GPP model for O2I propagation loss (originally applicable below 6 GHz) is investigated and discussed about the extension for high SHF/EHF bands. In order to utilize the model for higher frequency, penetration loss with the parameter of incident angle should be necessary and appropriate diffraction loss or its equivalent term should be accounted. The extended modelling is left as a future work.

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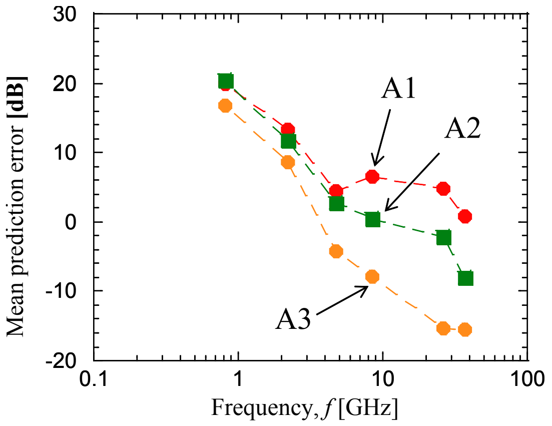
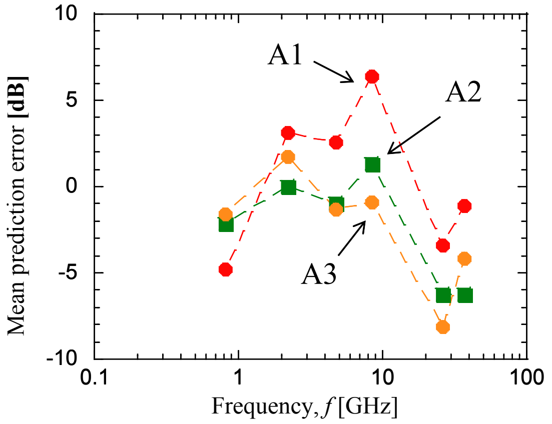
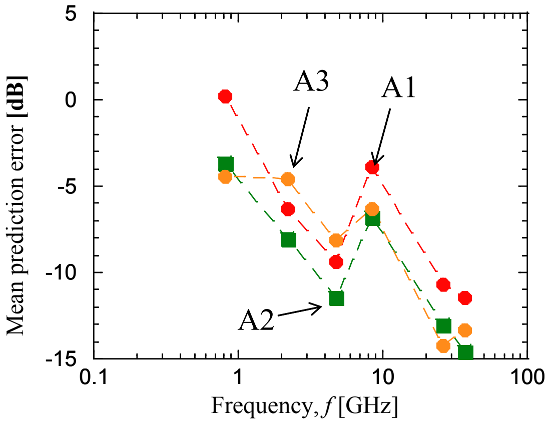


(a) 1F



(b) 2F



(c) 3F

Fig. 4 Evaluation of error