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HEIGHT VARIATION MODEL REFLECTING BUILDING CONDITIONS AROUND SUBSCRIBER STATION FOR 5-GHz BAND WIRELESS ACCESS SYSTEMS

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1. Introduction

Broadband wireless access systems have been drawing a great deal of attention concerning broadband wireless access services such as wireless Internet access that provides tens of megabits per second or higher transmission speeds to users. A wide frequency spectrum is required to implement these broadband wireless access systems; therefore, research on the propagation characteristics in the microwave frequency band is a topic of great interest. In particular, a 5-GHz band became available for Fixed Wireless Access (FWA) and Nomadic Wireless Access (NWA). The propagation models for FWA or NWA systems are required to be more accurate in regard to the dependency on local conditions around subscriber stations (SSs) than models for mobile communication systems. The reason for this is that the propagation conditions betweens a base station (BS) and a SS are strongly influenced by the local conditions of the SS because the SS is stationary (or at least has very limited mobility) in the FWA or NWA scenarios. There is of course the Ray-Tracing propagation model, which represents the best site-specific modeling method [1], but this model generally requires a very long calculation time and huge digital terrain and building databases. Therefore, a model is required that is simpler and that can reflect the local conditions of the SS.

Modeling of the variation in height of the SS with respect to the received level (height variation) is an important issue in the design of FWA or NWA systems. A model is required that reflects the local conditions around the SS. Here, the local conditions around the SS comprise the building height, road width around the SS, and the distance between the BS and SS. There have been various studies such as [2] on this height variation for radio communications system design. However, most of these studies deal with the UHF band up to 2 GHz and focus on mobile communication systems (not FWA or NWA systems). The SS antenna height is limited to approximately 3 m in these models. The variation in height of the SS with respect to the received level for locations higher than 3 m is important for FWA scenarios in which the SS antenna is established on a rooftop or on a wall of a building.

This paper proposes a height variation model for a SS. This model can reflect the local conditions around the SS, and is based on geometrical optics (GO) and the uniform geometrical theory of diffraction (UTD) [1]. The target area of the model is a residential area, which is an important service area for wireless Internet access services. The validity of the model is tested by measuring the height variation of the SS in a 5.2-GHz band carried out in a residential area in Tokyo.

2. Height Variation Characteristics of Received Level at SS

2.1 Height variation model based on GO and UTD

The effect of the height variation on the received level can be calculated based on GO and UTD to identify the received multipath wave components. The assumed propagation model is shown in Fig. 1. The identified waves are the direct wave (only in the Line-Of-Sight region), one-time to eight-time regular reflected waves from building walls, one-time diffracted waves due to the corners of rooftops of buildings, and one-time diffracted and reflected waves from the corners of rooftops and walls of buildings. Neighboring buildings are considered and each building is approximated as a hexahedron with the complex permittivity of concrete. Figure 2 shows the calculated results compared to the measured results in the 5.2-GHz band. The calculated results agree with the measured results, and this indicates that GO and UTD are useful in describing the height variation of the received level

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at a SS.

2.2 Propagation mechanisms causing height variation dependency on local conditions of SS

The calculated results using the model employing GO and UTD mentioned above for different local conditions of a SS are shown in Fig. 3(a) and 3(b) with the measured results. The results plotted in these figures correspond to the results when $\theta = 4.06$ deg. and $\theta = 0.94$ deg. in Fig. 1, respectively. The calculated level of the component waves comprising the total level is also represented by the designated indexes of (1) - (5) in the figures. Here, (1) indicates the direct wave component, and (2), (3), and (4) indicate one-, two-, and three-time regular reflected wave components, respectively. Index (5) indicates the one-time diffracted wave component. The lengths of the straight lines designated (1) - (5) in the figures correspond to the arrival region of each component wave. The measured results are represented as 1-m height section median values of the acquired data from height variation measurements for 5.2 GHz / CW.

The calculated total level agrees with the measured results in both Figs. 3(a) and 3(b). Figure 3(a) shows that the one-time and two-time reflected wave components represented by indexes (2) – (4) are dominant compared to the one-time diffracted wave component represented by index (5). The level of the one-time and two-time reflected wave components is nearly equal to the total level when the SS antenna height is 6 m to 9.5 m and less than 6 m, respectively. In particular, the measured total level agrees with the calculated level of the direct, one- and two-time reflected wave components at the minimum height where the direct, one- and two-time reflected waves arrive at the SS, respectively. On the other hand, Fig. 3(b) shows that the arrival region of the regular reflected waves represented by indexes (2) – (4) is very short and the one-time diffracted wave component represented by index (5) is dominant compared to these regular reflected waves. In addition, the height variation of the total level is nearly equal to that of the one-time diffracted wave. These results show that a change in the height variation characteristics is caused by the difference in composition of the arriving waves at the SS, that is, whether or not the regular reflected waves that have a level higher than the one-time diffracted wave when arriving at the SS strongly influence the height variation characteristics.

In the next section, we describe a model of the height variation reflecting the local conditions of SS in terms of the arrival conditions of regular reflected and one-time diffracted wave components.

3. Height Variation Model of Received Level Considering Reflected Local SS Conditions

3.1 Height gain model reflecting local conditions of SS based on arrival conditions of regular reflected and one-time diffracted wave components

Here, the height gain for the total received level, G_h, is used as an evaluation parameter for the height variation with respect to the received level and is defined as the degree of variation in the received level that accompanies the change in the SS antenna height in meters. This is expressed in the units dB/m in this paper. Furthermore, the height gains, G_{hR} and G_{hD}, are defined such that they are calculated from only regular reflected wave components and the one-time diffracted wave component, respectively. Gain G_{hR} can be calculated from the calculated level of the direct and regular reflected wave components at the minimum height where the direct and regular reflected wave components can arrive at the SS, respectively. Gain G_{hD} can be calculated from the calculated level of the one-time diffracted wave component.

Both G_{hR} and G_{hD} correspond to the slope of the straight dotted lines shown in Fig. 3. It is clear that the regular reflected (one-time diffracted) wave components are dominant compared to the one-time diffracted (regular reflected) wave component when G_{hR} (G_{hD}) is less than G_{hD} (G_{hR}) as shown in Fig. 4. These arrival levels of the regular reflected and one-time diffracted wave components can be calculated geometrically using the dimensions in Fig. 4. Furthermore, G_{hR} and G_{hD} are derived as follows by regarding the arrival level at point A in Fig. 4 as the common standard level for both the regular reflected wave components and the one-time diffracted wave component.

$$G_{hR} = 20\log\left(\left|\frac{R^k}{1+A_k}\right|\right) \Big/ \left(h_1 - w_2 \cdot \frac{h_{BS}-h_1}{d-w_2} - h_{Rk}\right) \quad \text{(dB/m)}$$

$$h_{Rk} = h_1 - A_k\left(h_{BS} - h_1\right), \qquad A_k = \frac{w_2 + kw}{d - w_2}. \qquad k = \begin{cases} 2n & \text{for even - time reflection} \\ 2n-1 & \text{for odd - time reflection} \end{cases} \tag{1}$$

$$G_{h\mathrm{D}} = 20\log\left\{\left|\sqrt{\frac{D^2}{\sqrt{{w_2}^2 + \left(h_1 - h_r\right)^2}}}\right|\right\} \Bigg/ \left(h_1 - w_2 \cdot \frac{h_{BS} - h_1}{d - w_2} - h_r\right) \qquad \text{(dB/m)} \tag{2}$$

where n is a natural number greater than 1, R is the Fresnel's reflection coefficient, and D is the UTD diffraction coefficient. Figure 5 shows calculation examples of Eqs. (1) and (2). The horizontal axis represents the horizontal distance between the BS and SS, that is, the figure shows the SS location dependency of G_{hR} and G_{hD}. The BS antenna height, h_{BS}, changes to 50 m from 20 m as a variable calculation parameter, and $w = 20$ m, $w_1 = w_2 = 10$ m, and $h_1 = 9$ m in this calculation. Gain G_{hR} is less than G_{hD} in the near region, but G_{hD} is less than G_{hR} in the far region for any h_{BS}. This indicates that the dominant wave in the height variation changes to the one-time diffracted wave from the regular reflected waves as the distance between the BS and SS increases. The height gain, G_h, reflects the change in the dominant wave component as follows

$$G_h = \min\{G_{hR}, G_{hD}\} \qquad \text{(dB/m)} \tag{3}$$

3.2 Validation of the height gain model at SS

The height variation measurements are carried out in the Suginami area in Tokyo [3]. The area is flat. It should be noted that this area includes many two-story houses that are approximately 9-m high. The BS antenna height (h_{BS}) is 32-m high, and the SS antenna height (h_{SS}) is changed from 4-m to 10-m high continuously at each measurement point. The frequency is 5.2 GHz (CW). Both the BS and SS antennas are omni-directional in the horizontal plane and the polarization is vertical. The measured height gain is acquired from the 1-m section median value of the measured height variation of the received level.

The measured and calculation results using Eqs. (1) – (3) are shown in Fig. 6. Regardless of the SS location, $h_{BS} = 32$ m, $h_1 = 9$ m, $w = 20$ m, $w_1 = w_2 = 10$ m are used in this calculation. The tendency of the calculation results agrees with the measured results. It can be said that this height gain model can represent the characteristics of the height gain reflecting the local conditions of the SS. The height gain where the regular reflected wave components are dominant is approximately 2-3 dB/m. On the other hand, the height gain where the one-time diffracted wave component is dominant is 4-5 dB/m.

4. Conclusions

A height variation model reflecting the local conditions around a SS was proposed. The propagation mechanism that causes the dependency of the height variation characteristics of the received level at a SS on the SS location is shown in terms of GO with UTD. The difference in the composition of the arriving wave at the SS causes the change in height variation characteristics. The height variation characteristics strongly depend on whether or not regular reflected waves that have a higher level than that of the one-time diffracted wave arrive at the SS. The height gain where the regular reflected wave components are dominant is approximately 2-3 dB/m. On the other hand, the height gain where the one-time diffracted wave component is dominant is 4-5 dB/m. The model was validated by measured data and the validity of the model was indicated.

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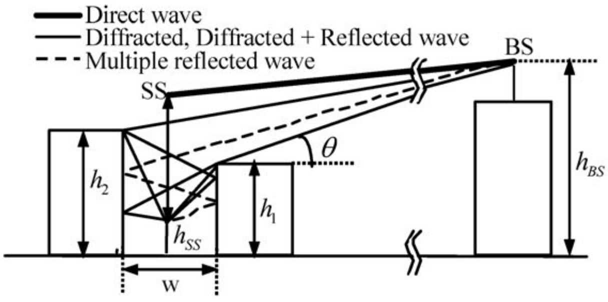


Figure 1. Propagation model based on GO with UTD.

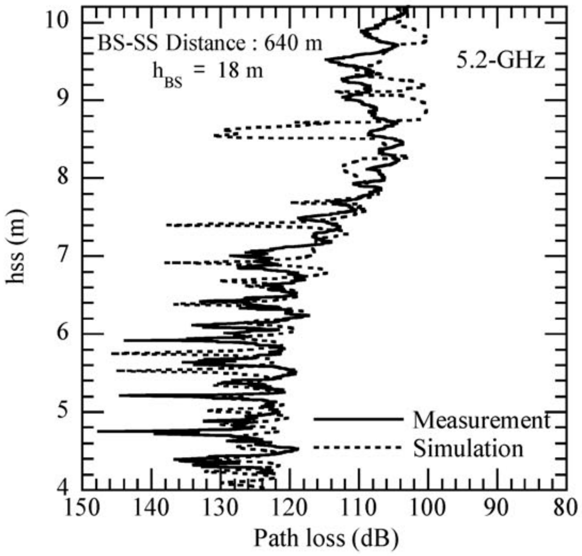
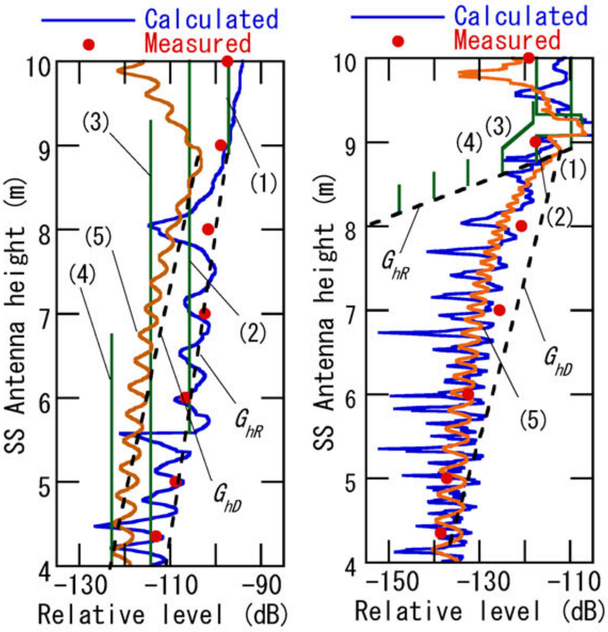


Figure 2. Example of height variation calculated based on GO with UTD.



(a) $\theta = 4.06$ (deg.) (b) $\theta = 0.94$ (deg.)

Figure 3. Typical example of the dependency of the height variation on local conditions.

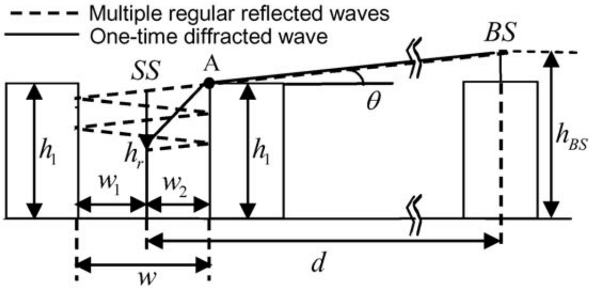


Figure 4. Height variation model. Reflected dominant wave components and dimensions of the model.

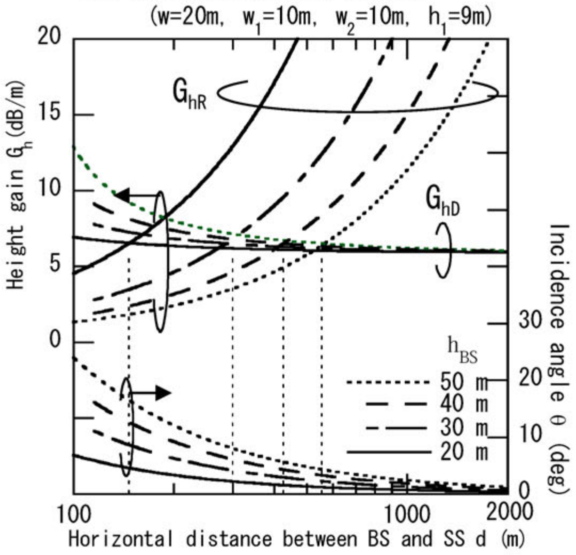


Figure 5. Examples of calculated height gain.

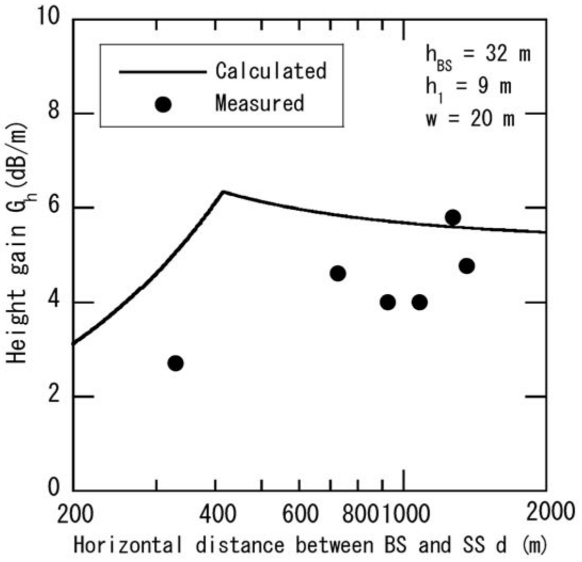


Figure 6. Example of height gain characteristics reflecting local conditions around subscriber station.