Applicability to Different Environment of Path Loss Model with Low Antenna Height in Residential Area

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Abstract

The applicability to different environment of a proposed path loss model comprising three propagation paths with low antenna height in a residential area is studied. Measurement results show that our model can accurately predict path loss in different building situation.

Keywords: Path loss model, Low antenna height, Residential area

1. Introduction

To address the problem of frequency resource shortages in microwave bands, there is a huge demand for frequency sharing wireless systems [1]. For frequency sharing with techniques to avoid or reduce interference, it is necessary to study interference propagation characteristics. Fundamentally, there are three interference propagation scenarios: between base stations, between a base station and a mobile terminal (MT), and between mobile terminals. The path loss model recommended in ITU-R P.1411 [2] is a representative model for propagation characteristics between MTs. However, it has been conducted in a street microcell environment and cannot be applied to residential areas because the number and height of buildings in such areas differ greatly from those in a street microcell environment. Accordingly, we previously proposed a model for predicting path loss between MTs in a residential area [3][4]. This model comprises three propagation paths: one along a road, one between buildings, and one above buildings. We have verified that this model can predict path loss more accurately than the ITU-R P.1411 model in a residential area of Musashino city in western Tokyo.

However, the model's three propagation paths are affected by building height and density. To confirm our model's usefulness for various environments, its applicability to different environment should be investigated. Therefore, we here describe our study of the model's applicability to different environment with different building situation. We show the results of measurements taken in a residential area of Tsukuba city, where building height and density are lower than in Musashino city. We also compare predicted and measured results of the model's three propagation paths. Finally, we show how we verified that the model can accurately predict path loss in an actual environment.

2. Path Loss Model with Low Antenna Height in Residential Area

We previously presented a path loss model for a low antenna height in residential areas to evaluate the interference between MTs [3][4]. Figure 1 shows the model, which predicts propagation loss for three cases: along a road L_r, between houses L_b, and over building rooftops L_v. Total path loss L is given by the following equations.

$$L = -10\log(1/L_r + 1/L_b + 1/L_v) \tag{1}$$

$$L_b = 20\log(4\pi d/\lambda) + 29.27\log(\log(100/v)) + 25.20 \tag{2}$$

$$L_v = L_1 + L_2 + L_c \tag{3}$$

$$L_1 = 6.9 + 20\log\left(\sqrt{(v_1 - 0.1)^2 + 1} + v_1 - 0.1\right) \tag{4}$$

$$L_2 = 6.9 + 20\log\left(\sqrt{(v_2 - 0.1)^2 + 1} + v_2 - 0.1\right) \tag{5}$$

$$v_1 = h_1\sqrt{\frac{2}{\lambda}\left(\frac{1}{a} + \frac{1}{b}\right)} \tag{6}$$

$$v_2 = h_2\sqrt{\frac{2}{\lambda}\left(\frac{1}{b} + \frac{1}{c}\right)} \tag{7}$$

$$L_c = 10\log\left[\frac{(a+b)(b+c)}{b(a+b+c)}\right] \tag{8}$$

where d is the direct distance from Tx to Rx, λ is the wavelength, v is the visibility [5], a is the distance from Tx to the nearest building in the Rx direction, c is the distance from Rx to the nearest building in the Tx direction, b is given by d-a-c, and h_1 and h_2 are the heights of the nearest buildings to Tx and Rx. Heights are calculated on the basis of a straight line from Tx and Rx to the building's rooftop.

Prediction results obtained by using this model are affected by building density and height. To study the model's applicability to different environment, we investigated path loss characteristics for different building situation. In this study, we focused on path loss between buildings L_b and over-roof path loss L_v since we reported our investigation of path loss along a road L_r in [4].

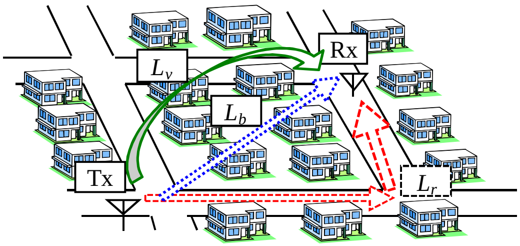

Figure 1: Path loss model with low antenna height in residential area

3. Measurement and Analysis of Propagation Paths

3.1 Measurement parameters and measurement environment

To clarify the characteristics for both path loss cases, we used two different measurement sets. Figure 2 shows the measurement environment and Tables 1 and 2 summarize the measurement parameters. Measurements were taken in a residential area of Tsukuba city. In this measurement environment, the average building height is 6.6 m and the building density is 461.2 buildings per square km. These parameters are quite lower than those for Musashino city, where the average building height is 8.4 m and the building density is 3171.7 buildings per square km.

Figure 2: Measurement environment

Table 1: Measurement parameters of path between buildings

Frequency	2.1975 GHz
Antenna height	2.5 m (Tx and Rx)
Tx antenna	Omni-directional
Rx antenna	70 degree half-power beam width

Table 2: Measurement parameters of over-roof path

Frequency	2.1975 GHz
Tx antenna height	2.5 m
Rx antenna height	3.5-10 m
Tx and Rx antenna	Omni-directional

Path loss between buildings was measured by using the parameters shown in Table 1. The measurement frequency is 2.1975 GHz. The radiation pattern of the Tx antenna is omni-directional in a horizontal plane. The Tx is set up on the road and the Tx antenna height is 2.5 m above the ground. To obtain path loss between buildings, an antenna with 70 degree half-power beam width is used for the Rx antenna. This antenna is set on the rooftop of a measurement vehicle with the main lobe faced vertically to the running direction. To eliminate the effect of fast fading, we derived the median value of path loss between 10-meter intervals.

On the other hand, we used the parameters in Table 2 to measure over-roof path loss. The measurement frequency, Tx antenna height, and Tx antenna radiation pattern are the same as those for measuring path loss between buildings. The Tx antennas are set at several measurement locations and the Rx antennas are set up on the road. The Rx antennas' radiation pattern is omni-directional in a horizontal plane. To clarify the over-roof top propagation path characteristics, we obtained the height pattern by varying the Rx antennas' height between 3.5 m and 10 m.

3.2 Path loss between buildings

It is assumed that shielding and scattering from buildings causes increased path loss between buildings. We therefore used excess loss and visibility [5], which increases in proportion to the number of buildings, to construct a prediction equation of path loss between buildings. Figure 3 shows measurement results obtained for excess loss and visibility. The circles represent excess loss and the solid line is visibility. As the figure shows, both tend to increase as the Tx-Rx distance increases. Consequently, a prediction method using visibility can also be used in this environment. Figure 4 shows measured and predicted path loss results obtained with such a method. The circles are measurement results and the solid line is prediction results. The latter is in good agreement with the dashed line, which represents the regression result of the measured path loss results. The standard deviation of prediction error obtained by using equation (2) and the regression result are respectively 5.60 dB and 5.57 dB. The near-equivalency of these results indicates that equation (2) can be used to accurately predict actual path loss.

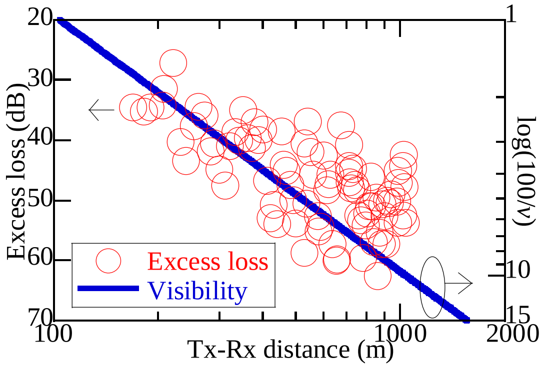

Figure 3: Relation of excess loss and visibility

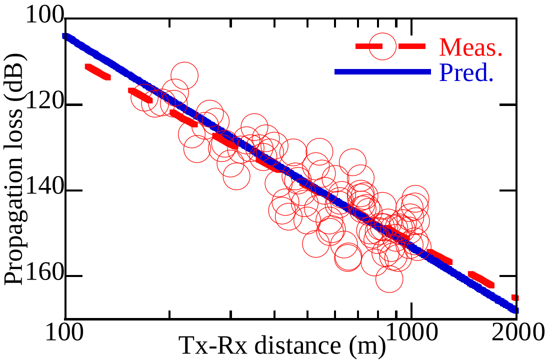

Figure 4: Prediction results by using visibility

3.3 Over-roof propagation path loss

Figure 5 shows over-roof path loss results measured at a Tx-Rx distance of 927.7 m. The circles are the median value of measurements taken at 1-meter intervals. The solid line is the prediction results of over-roof propagation loss L_v and the dashed line is a summation of the prediction results of path loss along a road L_r and path loss between buildings L_b. As the figure shows, the prediction results of L_v are more similar to the measurement results than the prediction results of L_r and L_b.

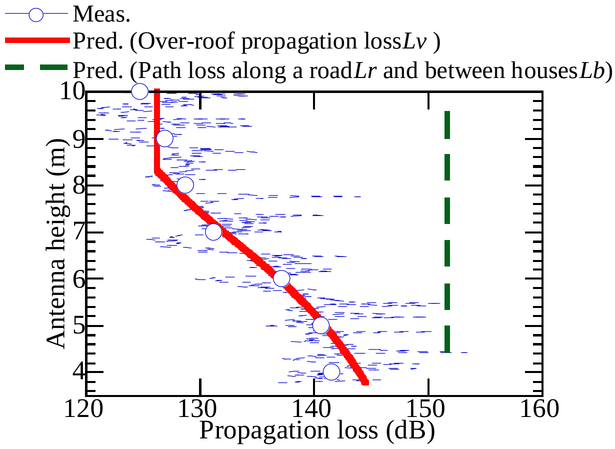

Figure 5: Over-roof path loss measurement results

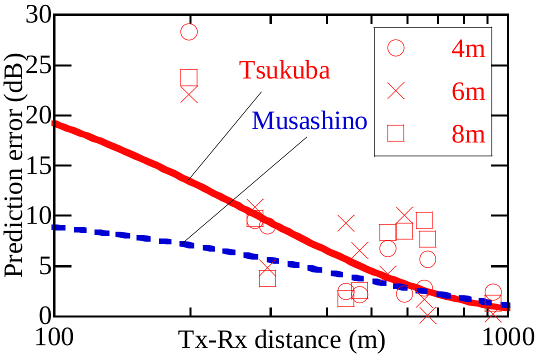

Figure 6: Prediction error

Figure 6 shows the relation between the prediction error and the Tx-Rx distance. It plots measurement results obtained with antenna heights of 4, 6, and 8 m. The solid and dashed lines respectively show the regression results of prediction error at Tsukuba city and Musashino city [3]. When the Tx-Rx distance is short, the prediction error of the over-roof path loss becomes large because the path along a road and the path between buildings are dominant. In contrast, when the

Tx-Rx distance is long, the over-roof path becomes dominant. Therefore, both lines decreased as the Tx-Rx distance increased and the prediction error became 0.74 dB and 1.1 dB at a distance of 1000 m.

3.4. Path loss along a road

Prediction of path loss along a road L_r is affected by the road geometry. Since we reported our investigation of L_r in [4], in this study we focused on path loss between buildings L_b and over-roof path loss L_v .

4. Prediction Accuracy of Path Loss Model in Different Environments

In Section 3, we showed that propagation path loss with low antenna height in a residential area can be predicted accurately by using our path loss model. In this section, we present evaluation results of total path loss predicted by using the model. To evaluate total path loss, measurements were carried out using omni-directional antennas at Tx and Rx. The other measurement parameters are the same as those for measuring path loss between buildings (Table 1).

The measurements were taken in Tsukuba city. Figure 7 shows the prediction error of the measurement results obtained by using our model and the model in ITU-R Rec. P.1411. The solid and dashed lines respectively represent prediction error of our model and the ITU-R P.1411 model. As the figure shows, the former has better prediction accuracy. The median values of prediction error for our model and the ITU-R P.1411 model are respectively 6.55 dB and 12.29 dB. As mentioned above, our model can accurately predict path loss in Tsukuba city, where building density and height are quite lower than in Musashino city.

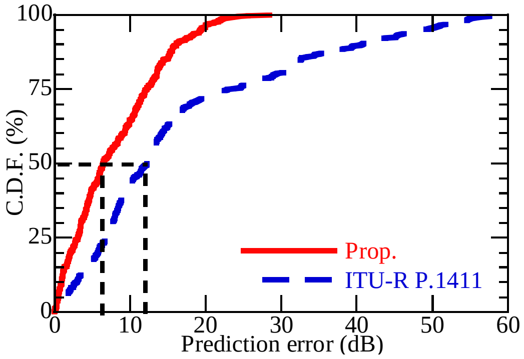

Figure 7: Prediction error in Tsukuba city

5. Conclusion

This paper describes a study of our path loss model's applicability to different environment. Measurements taken in different building situation showed that our model was able to predict path loss accurately in an environment where building density and height differed considerably from those of a previous environment we had used.

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