Path Loss Model with Over-Roof Propagation Paths between Mobile Terminals in a Residential Area

Motoharu SASAKI, Wataru YAMADA, Toshio ITO,
Naoki KITA, and Takatoshi SUGIYAMA
NTT Access Network Service Systems Laboratories, NTT Corporation
1-1 Hikari-no-oka, Yokosuka-Shi, Kanagawa 239-0847 Japan
E-mail: {sasaki.motoharu, yamada.wataru, ito.toshio, kita.naoki, sugiyama.takatoshi}@lab.ntt.co.jp

Abstract

We propose a path loss model with an over-roof propagation path between mobile terminals in residential areas. A double knife-edge diffraction model shows that over-roof propagation loss can be accurately estimated. Measurement results confirm the estimation accuracy of the new model.

Keywords: Path loss model, Low antenna height, Residential area, Double knife-edge diffraction

1. Introduction

The use of frequency resources in micro-wave bands is extremely tight, since micro-wave bands are widely used in wireless systems [1]. Therefore, there is a huge demand for frequency sharing wireless systems [2]. In cases where frequency is shared, it is necessary to study interference propagation characteristics to avoid or reduce interference. Fundamentally, there are three interference propagation scenarios. The first is between base stations, the second is between a base station and a mobile terminal (MT), and the third is between mobile terminals. So far, studies on interference between MTs have not been particularly important because MTs in conventional wireless systems have been definitely segregated in terms of time or frequency. To achieve greater frequency efficiency, the technique of segregating by space, such as that applied in adaptive array antennas, has been studied. In using this technique, however, MTs interfere with each other when they use the same frequency at the same time. Therefore, in this case, interference propagation characteristic between MTs should be considered.

Until now, several studies have been conducted on the propagation scenario between MTs in a street micro-cell environment [3]. However, the models used for these studies cannot be applied to residential areas because building density and height in such areas are quite low. To address this problem, we previously proposed a path loss model between MTs in a residential area [4]. It considers propagation paths below building height in a horizontal plane. In our current work, we studied the impact of vertical plane propagation loss, i.e., over-roof propagation loss, as opposed to horizontal plane propagation loss. We then used the results we obtained to develop and propose a new path loss model. In this paper, we show that the over-roof propagation loss can be estimated by using a double knife-edge diffraction model [5]. Finally, we show that this new model produces valid results by comparing them with those obtained in actual measurements.

2. Previously Proposed Model [4] and its Estimation Accuracy

We previously presented a path loss model for a low antenna height for use in residential areas to evaluate the interference propagation loss between MTs [4]. This model comprises two parts, one for propagation loss along a road L_r and the other for path loss between houses L_b.

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

This model considers only waves arriving from a horizontal plane. In actual environments, however, waves may also arrive from a vertical plane.

Figure 1 shows measurement and estimation results of path loss in a residential area and Fig. 2 shows the measurement area. Measurement frequency is 2.1975 GHz. The circles in Fig. 1 represent measurement results and the dashed lines represent estimation results obtained by using a previous path loss model. Tx and Rx antennas were set up 2.5 m above ground level and an omni-directional antenna was used. Here, the measured results show median values obtained at 10-m intervals to exclude the effect of fast fading. Figure 1 results clearly show that the previous model derives estimation error of more than 20 dB between points P.1 and P.3.

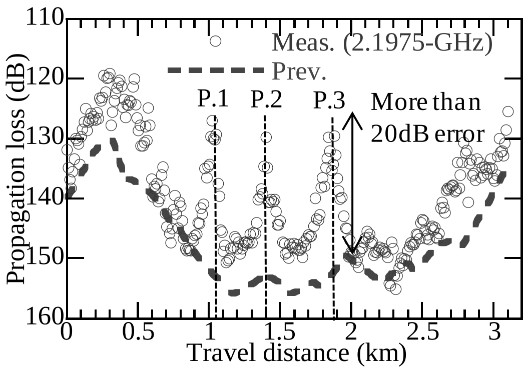


Figure 1: Measurement and estimation results

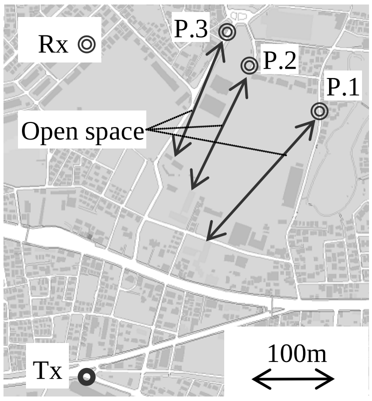


Figure 2: Measurement area

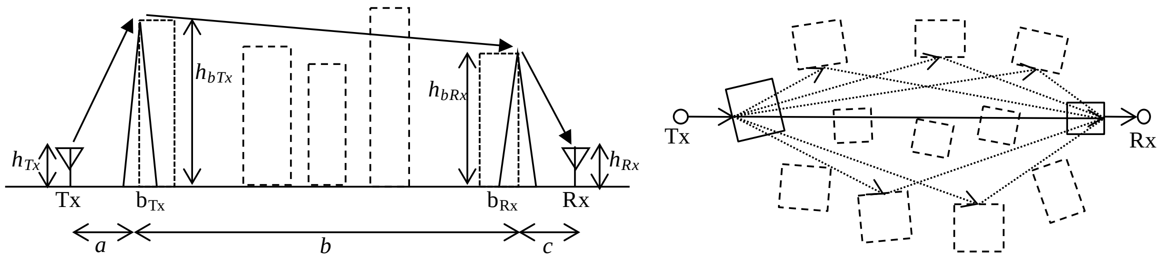
3. Newly Proposed Path Loss Model with Waves Arriving from Over-roof Propagation Paths

The points P.1-P.3 in Fig. 1 correspond to points P.1-P.3 in Fig. 2. The latter figure shows that there are open spaces in the direction to Tx from P.1, P.2, and P.3. Under these conditions, we presume that waves arriving from over-roof propagation paths negatively affect the path loss characteristic. We make this presumption because over-roof propagation paths can be regarded as diffraction paths from the nearest building-top between Tx and Rx. Therefore, diffraction loss becomes low when there are open spaces in the Tx direction. This makes the path loss of the over-roof propagation path low. Moreover, when the direct distance from Tx to Rx is relatively far, the propagation path of the horizontal plane encounters multiple turns as a result of corners and multiple shielding by buildings. Therefore, the horizontal plane propagation loss is increased. For this reason, we consider that over-roof propagation paths should be taken into account.

By using the over-roof propagation loss L_v, we propose a new path loss model for residential areas as expressed by the following equation:

$$L_{hv} = -10\log(1/L_r + 1/L_b + 1/L_v) \qquad (2)$$

In the work described in this paper, the over-roof propagation path is modeled as shown in Fig. 3.



(a) Side view of the straight line between Tx and Rx (b) Top view

Figure 3: Over-roof propagation model

We assume that a wave arriving from over-roof propagation is finally diffracted at the top of the nearest building from Tx and Rx. In residential areas, buildings tend to be of about the same height. Therefore, propagation paths are seldom shielded by the buildings between the nearest building from Tx and Rx. In addition, there are many over-roof propagation paths reflected around buildings, even if the propagation paths on the straight line between Tx and Rx are shielded. In consequence, the main feature of this over-roof propagation path model is that the number of diffraction edges is always set up as two. These edges are defined as the nearest building walls from Tx and Rx in the building profile between Tx and Rx. Buildings except for the nearest building from Tx and Rx are ignored. In Fig. 3, b_{Tx} and b_{Rx} are the nearest building walls from Tx and Rx, respectively. The top values of b_{Tx} and b_{Rx} are the line-of-sight ones from Tx and Rx. *a*, *b*, and *c* are the distances between Tx and b_{Tx}, between b_{Tx} and b_{Rx}, and between Rx and b_{Rx}, respectively. h_{bTx} and h_{bRx} are the heights of the nearest building from Tx and Rx, respectively. The heights of b_{Tx} and b_{Rx} are defined as h_{bTx} and h_{bRx}. h_{Tx} and h_{Rx} are the antenna heights of Tx and Rx.

4. Over-Roof Propagation Characteristics

4.1 Measurement environment parameters

Over-roof propagation characteristics were measured in a residential area in Tokyo. Figure 4 shows the measurement environment and Table 1 summarizes the measurement parameters.

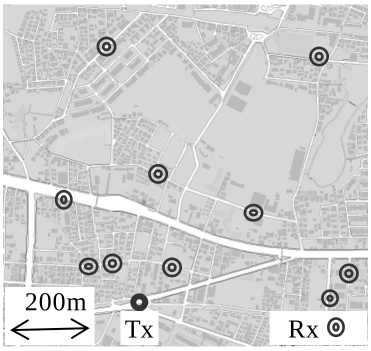


Figure 4: Measurement environment

Table 1: Measurement parameters

Measurement Frequency	2.1975 GHz
Height of antenna at Tx	5 m
Height of antenna at Rx	3.5-10 m
Measurement antenna	Omni-directional antenna

In this measurement environment, the average building height is 8.4 m and the average building density is 3171.7 buildings per square km. The measurement frequency is 2.1975 GHz. The Tx and Rx antennas' radiation pattern is omni-directional in a horizontal plane. Tx points are set up on the road and Tx antenna height is 5 m above the ground. Rx points are set at several measurement locations. To enable path loss characteristics to be measured from over-roof propagation paths, the Rx antenna height above the ground is continuously changed from 3.5 to 10 m.

4.2 Measurement and estimation results of over-roof propagation loss

Our proposed path loss model with an over-roof propagation path was developed on the basis of propagation loss L_v in Equation (2), as derived by the double knife-edge diffraction method [5]. Figure 5 shows the measurement results obtained at Tx-Rx distances of 112 m and 1137 m. Dotted lines and circles represent measurement results and median values at 1-meter intervals; solid lines and broken lines represent estimation results obtained by using the over-roof propagation model and the previous model. Here, the estimation parameters at d=112 m are h_{bTx}=7.6 m, h_{bRx}=6.9 m, a=6 m, b=99 m, and c=7 m. The parameters at d=1137 m are h_{bTx}=8.8 m, h_{bRx}=10 m, a=46 m, b=1087 m, and c=4 m. From the figure, we see that for antenna height of 9 or 10 m at d=112 m, estimation error is as high as 14 dB. Under these circumstances, the Rx antenna is above roof-top level and there is an arriving wave of reflection at the roof-top, which is not considered with an over-roof propagation model. Thus, this error is caused by reflection at the roof-top. For antenna heights of less than 6 m, the estimation results obtained by using the previous model are higher than those obtained by using an over-roof propagation model and are closer in value to measured results. This shows that the propagation path in a horizontal plane is dominant at d=112 m and that consequently over-roof propagation is not effective. On the other hand, at d=1137 m, estimation results obtained by using the over-roof propagation model are higher than those obtained by using the previous model and are closer in value to measured results. This shows that the over-roof propagation path is dominant in this case and that the estimation error is as high as 0.6 dB for an antenna height of 4 m.

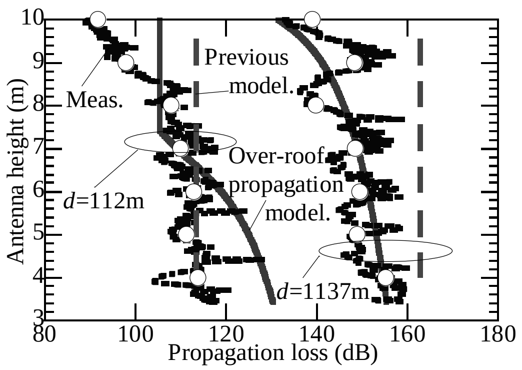


Figure 5: Measurement and estimation results

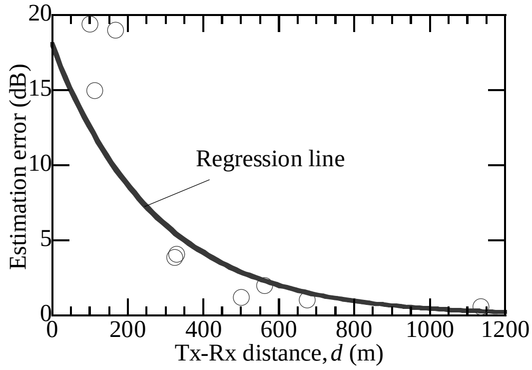


Figure 6: Comparative results at all measurement points

The circles in Fig. 6 represent estimation error at 4 m above the ground at all measurement points and the solid line represents the regression line. At less than *d*=180m, estimation error is more than 10 dB. In the case for *d*=112m in Fig. 5, the propagation path in the horizontal plane is dominant. Thus, estimation error obtained by using the over-roof propagation model becomes high. In this case, however, the error becomes lower as *d* increases, as is the case for *d*=1137 m in Fig. 5. When *d* is more than 800 m, the estimation error is less than 1 dB. This error is sufficiently small and it is apparent that over-roof propagation loss can be accurately estimated by using a double knife-edge diffraction model. We therefore use this model to estimate over-roof propagation loss.

5. Verification of New Path Loss Model Validity

Figure 7 shows the measurement and estimation results. The measurement environment and parameters are the same as those given in Section 2. Circles represent measurement results, the solid line represents estimation results obtained by using our new model, and dashed lines represent estimation results obtained by using the previous model. In this calculation, building height was set as 8.4 m by using the average building height around this measurement area and differences in elevation were ignored. The figure shows that using the new model improves the estimation accuracy. It is particularly noteworthy that from P.1 to P.3, the estimation error obtained by using the new model is about 17 dB lower than that obtained with the previous model.

Figure 8 shows the amount of estimation error improvement obtained with our new model over the previous model. Circles represent the amount of improvement and the solid line represents the regression line. The median of this improvement is 100-m intervals. The figure shows that our new model provides lower estimation error than the previous model. Further, the amount of improvement increases as Tx-Rx distance increases. Our model provides particularly notable results at *d* of over 600 m. For example, at *d* of 1 km, the estimation error obtained with the previous model was 10.7 dB; the new model improves it to 6.5 dB at the same distance.

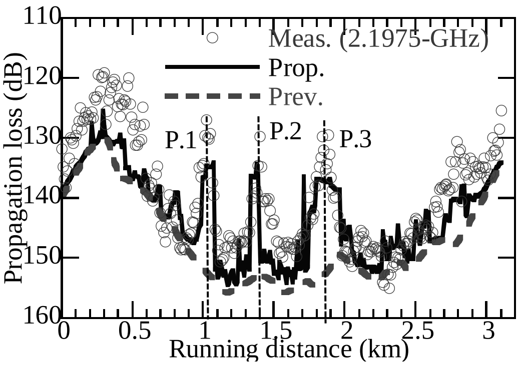


Figure 7: Measurement and estimation results

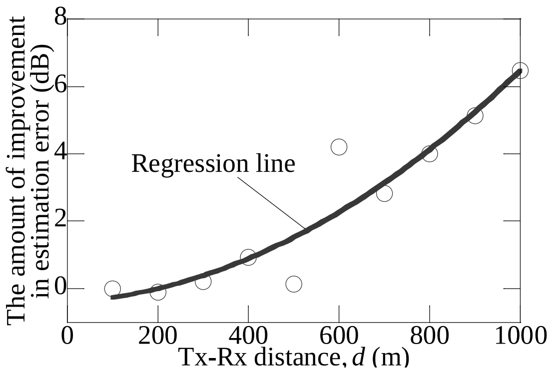


Figure 8: Estimation error improvement

6. Conclusion

In this paper, we presented a path loss model with an over-roof propagation path between mobile terminals (MTs) in a residential area. Measured results showed that the path loss of over-roof propagation can be estimated by using a double knife-edge diffraction model. Our new model can improve estimation error 6.5 dB at Tx-Rx distance of 1 km.

References

[1] http://www.tele.soumu.go.jp/j/adm/freq/search/myuse/index.htm.

[2] J. M. Peha, ”Approaches to spectrum sharing”, Communication Magazine, IEEE, Vol.43, pp.10-12, Feb 2005.

[3] Rec. ITU-R P.1411-5,” Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300MHz to 100GHz”, ITU-R Recommendations,Vol.4, P Series, ITU, Geneva (2009)

[4] M. Sasaki, and W. Yamada, N. Kita, and T. Sugiyama, “Propagation Loss Prediction Model in Residential Area for Interference Evaluation between Mobile Terminals”, IEICE Technical Report, A・P2010-142(2010-01). *(in Japanese)*

[5] Rec. ITU-R P.526-11, ” Propagation by diffraction”, ITU-R Recommendations, Vol.11, P Series, ITU, Geneva, 2009.