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Path Loss Prediction Model for a Sloped Area in Microcell Based on Scale Model and Real Environment Measurements

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Abstract— We propose a model for predicting the path loss of a sloped area in a microcell service area of a mobile communication system. This is the prediction model to be proposed that targets a microcell. For practical use, a model requires parameters such as the base station height, angle of the sloped area, and distance from the base station to the sloped area. The proposed model uses a correction method based on the characteristics of the base station height to predict the path loss of the sloped area based on the path loss of flat terrain. The proposed model is verified based on measurements of a scale model and real environments. A 1/70 scale model is constructed of a residential area and the path losses are measured at 10.5 GHz. In real environments, the path losses are measured at 902 MHz. The measurement results show that the path losses predicted using the proposed model are close to the measured results.

keywords— radio propagation, propagation loss, sloped area, scale model, microcell

I. INTRODUCTION

The forests in Japan occupy 70% of the country, and there are many mountains and hills in Japan. As cities and residential areas have expanded the living space for people has spread to such hilly or sloped areas. Mobile communication systems are already a vital infrastructure to daily life, so covering these sloped areas is important in terms of service provisioning. It is necessary to predict propagation losses over the sloped areas for radio link design.

The Okumura-Hata model [1-2] is known as a path loss prediction model for mobile communications. The model yields correction data that are used to predict the pass loss of the hilly terrain based on the path loss of flat terrain. The application range of the correction method is limited in a macrocell whose cell radius is several kilometers, and the application range for the slope angle is small from -1 to $+1$ degrees. The correction for macrocells is focused on the sloped area with a length of several kilometers, and a slope

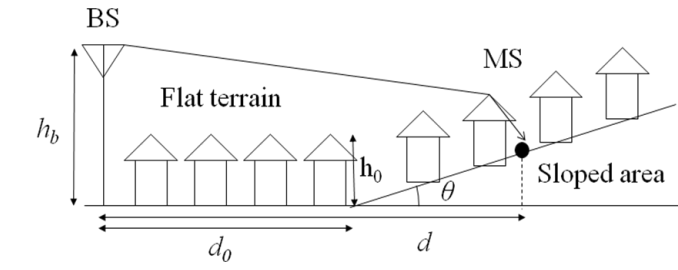
angle of a long sloped area is generally small. In recent years, microcells with a cell radius of up to 1 km have been deployed to use frequencies effectively. When the angle of a sloped area in a macrocell is large, the path loss greatly changes even if the length of the sloped area is short. Therefore, the correction method for a large sloped angle is required. The correction method of the Okumura model cannot be applied to a microcell. The Lee model [3] is also known as a path loss prediction method for hilly terrain. The Lee model can be applied if the path between a base station (BS) and mobile station (MS) is line-of-sight (LOS) and the MS is on hilly terrain in a macrocell. However, the Lee model cannot be applied to a Non-LOS (NLOS) path in a microcell. Up until now, there have been only a few reports on the path loss for a sloped area in a microcell until recently.

Recently, path loss prediction for a sloped area in a microcell has been investigated more intently. In [4] and [5], prediction methods that use the elevation angle for the MS direction as observed from the BS were proposed based on experimental study. However, these methods are still in the verification stage. For practical use, a model requires parameters such as the base station height, angle of the sloped area, and distance from the base station to the sloped area. Previous prediction methods use only the elevation angle as a parameter.

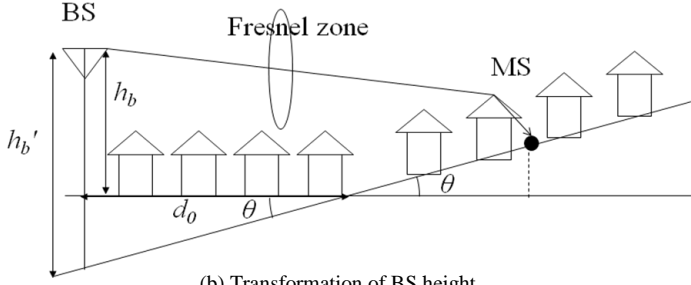
The purpose of this paper is to establish the path loss prediction model for a sloped area in a microcell. The target frequency is the microwave band used with cell phones. The target environment is an urban area or a residential area on a slope. When the characteristics of the path loss on flat terrain are well known, the correction method to predict the path loss of sloped area is examined.

II. PROPOSED MODEL

Fig. 1(a) shows a flat terrain and a sloped area with buildings. There is a BS on the flat area, and the mobile



(a) Sloped area and parameters



(b) Transformation of BS height

Fig.1. Equivalent base station height model.

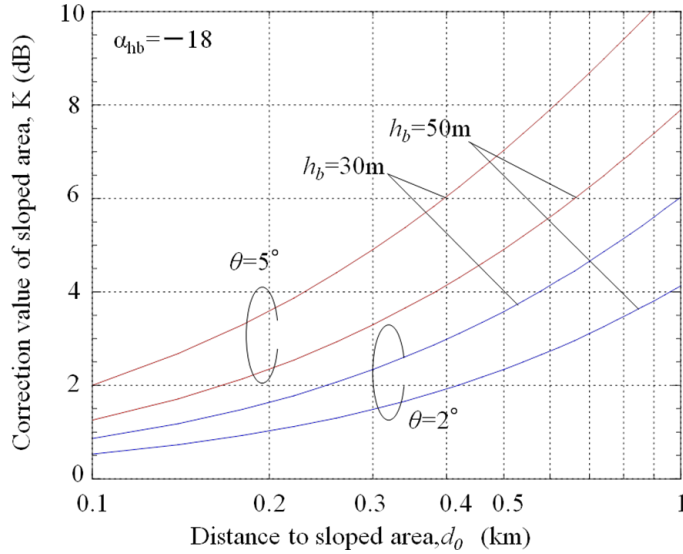


Fig.2. Correction value of sloped area, K.

communications service area of the BS covers the flat area and the sloped area. The distance from the BS to the start point of the sloped area is d_0 , the angle of the sloped area is θ , the height of the BS is h_b , and the height of the building is h_0 . Based on the precondition that the path loss characteristics of the flat terrain are well known, the path loss of the sloped area is predicted. The characteristics of the path loss on the flat area, L_f , are expressed as

$$L_f = \alpha_d \log d + \alpha_{hb} \log h_b + C \quad [\text{dB}]. \quad (1)$$

where d is the distance between the BS and MS, h_b is the BS height, α_d and α_{hb} are coefficients, and C is a constant value. If it is assumed that the BS is located on the extended line of the

sloped area as shown in Fig. 1(b), the BS height, h_b' , is expressed as

$$h_b' = h_b + d_0 \tan \theta. \quad (2)$$

Under the conditions in Fig. 1(b), the path loss of the sloped area can be predicted by exchanging h_b for h_b' for the BS height in (1). Therefore, the correction value, K , for the path loss of the sloped area is expressed as

$$K = \alpha_{hb} \log(h_b / h_b') \quad [\text{dB}]. \quad (3)$$

We named this correction method the “equivalent base station height model,” because it is based on the characteristics of the BS height. The path loss of the sloped area, L_s , is calculated as

$$L_s = L_f - K \quad [\text{dB}]. \quad (4)$$

The application range of distance d and BS height h_b' in this correction method is the same as that in (1). The following conditions are needed to apply the correction method.

- The building situation in the flat terrain and that in the sloped area must be the same.
- The slope angle must be constant, and the slope plane cannot curve.
- The buildings on a flat terrain do not cause diffraction loss due to the shadowing of the Fresnel zone for a radio wave.

Since the buildings on the flat terrain cause diffraction loss when the MS is near the start point of the sloped area, this method cannot be applied in this case. Since the buildings on the flat terrain do not cause diffraction loss if the MS moves to the upper part of the sloped area, the method can be applied. If buildings do not cause shadowing of the Fresnel zone of a specific size of radio wave, the buildings do not cause diffraction loss. This size of Fresnel zone is examined in Section III. For the path loss prediction formula on flat terrain, the Okumura- Hata model [2] shown below is commonly used.

$$L_f = 69.55 + 26.16 \log f - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log D \quad [\text{dB}]. \quad (5)$$

where f is the frequency [MHz], h_b is the BS height [m], and D is the distance between the BS and MS [km].

To calculate correction value K using (3), the value of the BS height coefficient, α_{hb} , is required. Coefficient α_{hb} of the Okumura- Hata model, which can be applied in a macrocell, depends on the distance between the BS and MS, and the coefficient value is $\alpha_{hb} = -13.82$ for $d = 1$ km. The BS height characteristic of the Xia model [6], which can be applied to a microcell, is expressed as $-18 \log(h_b - h_0)$, and h_0 is the building height. The coefficient value of the Xia model is $\alpha_{hb} = -18$ for $h_b \gg h_0$. The coefficient value of the model

TABLE I. MEASUREMENT SPECIFICATION FOR SCALE MODEL

Item	Specification
Frequency	10.475 GHz
Output power	1 W
BS antenna	Horn antenna (16 dBi)
MS antenna	Monopole antenna (2 dBi)

TABLE II. THE SIZE FOR SCALE MODEL

Item	Size
Height of the block, h_0	0.12m(8.4m)
Width of the block, w	0.3m(21m)
Length of the block	2m(140m)
Interval of the block	0.44m(31m)
Road width	0.14m(10m)
Height of MS, h_m	0.021m(1.5m)
Slope angle, θ	5.5°

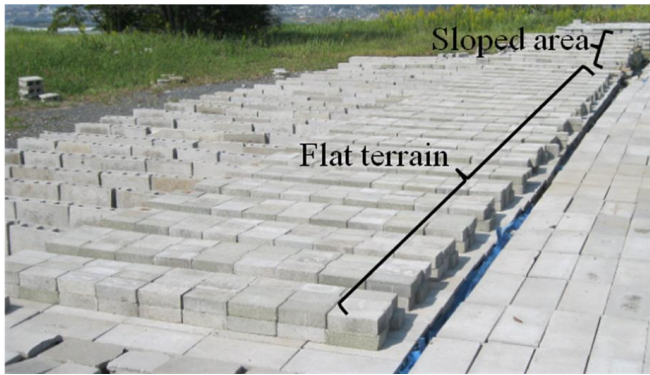


Fig.3. Scale model (1/70) for a housing development.

proposed in [7], which can be applied to a microcell, is $\alpha_{hb} = -30$. Because coefficient α_{hb} varies in this way, the coefficient of $\alpha_{hb} = -18$ is assumed in this paper.

Fig. 2 shows correction value K calculated using (2) and (3). The parameters in Fig. 2 are BS height h_b , slope angle θ , the distance from the BS to the sloped area d_0 , and the value of the BS height coefficient is $\alpha_{hb} = -18$.

III. VERIFICATION BASED ON SCALE MODEL MEASUREMENT

The proposed model is verified using a scale model method.

A. Scale Model

The Xia model is based on a simplified city model in which an oblong flat board is substituted for a building group and the boards are arranged in equal intervals. In reference to this simplified city model, a 1/70 scale model is used as a housing development with two-story houses. Fig. 3 shows the

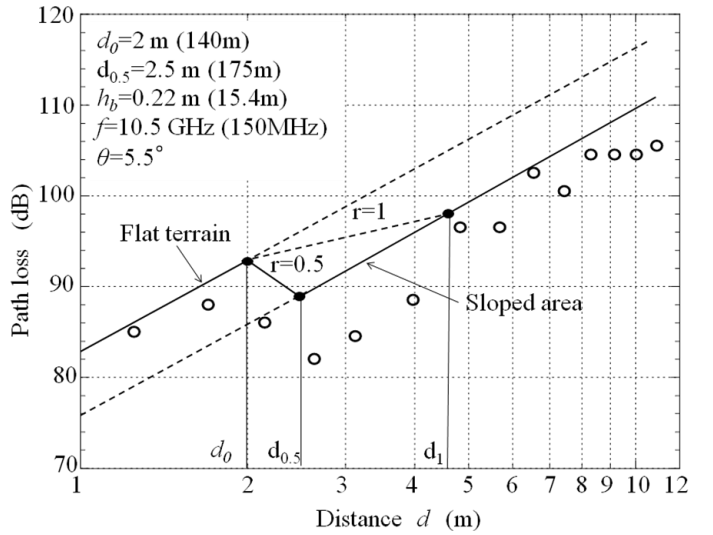


Fig.4. Path loss of scale model ($d_0=2m$).

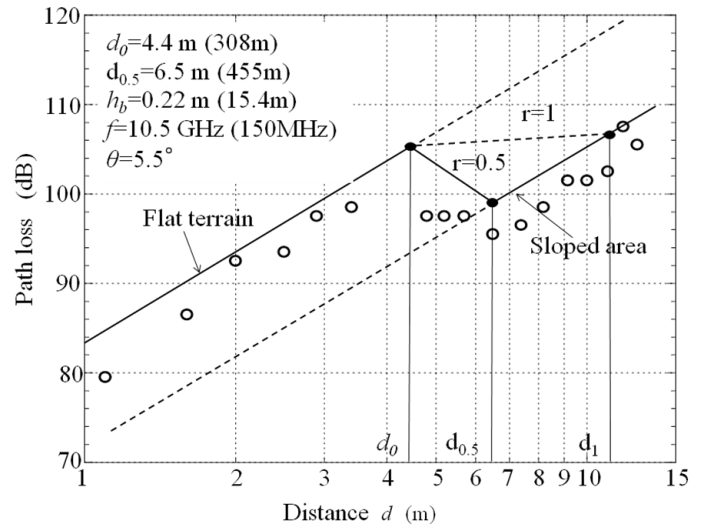


Fig.5. Path loss of scale model ($d_0=4.4m$).

constructed 1/70 scale model. Concrete blocks are combined instead of the flat board in the Xia model. A combined block represents a miniature of a line of buildings. The size of the scale model is given hereafter. The height of the block is $h_0 = 0.12$ m (8.4 m), the width of the block is 0.3 m (21 m), the length of the block is 2 m (140 m), the interval of the blocks is 0.44 m (31 m), the road width is 0.14 m (10 m), the height of the MS is $h_m = 0.021$ m (1.5 m), the slope angle is $\theta = 5.5^\circ$, the length of the flat terrain is 9.0 m (630 m), and the length of the sloped area is 4.8 m (340 m). The numerical values in parentheses are the values corresponding to a real environment.

The measurement specifications are given in Table I. The size for scale model are given in Table II. The measurement frequency is 10.5 GHz, the BS antenna is a horn antenna (16 dBi), and the MS antenna is a monopole antenna (2 dBi).

B. Path Loss of Flat Terrain

First, the path loss characteristics are clarified in a flat terrain of the scale model. The path losses are measured for every BS height. Multiple regression analysis is executed based on the measurement data. The multiple regression formula for the path loss is expressed as

$$L_f = 33.7 \log d - 24.9 \log h_b + 66.9 \text{ [dB]}. \quad (6)$$

C. Path Loss of Sloped Area

The path losses of the sloped area are measured by locating the BS in flat terrain. The BS height is fixed at $h_b = 0.22$ m, and the distance from the BS to the start point of the sloped area, d_0 , is changed from $d_0 = 2$ m and 4.4 m. Figs. 4 and 5 show the measured results and the calculated curves. The curves labeled "flat terrain" in the figures are calculated using (6), and the curves labeled "sloped area" are calculated using (3) and (4). The coefficient of $\alpha_{hb} = -24.9$ of (6) is used. The measured path losses of the sloped area are fairly close to the predicted curves and validate the proposed model.

The proposed model is not necessarily applicable from the beginning point of the sloped area. It can only be applied from the distance where the buildings on the flat terrain do not cause diffraction loss. Hereafter, the applicable distance is examined. The first Fresnel radius is expressed as r_1 , and half of radius r_1 is expressed as $r_{0.5}$. The zone of radius r_1 is the first Fresnel zone. The distance between the BS and MS in which the first Fresnel zone is not shadowed by the buildings on the flat terrain is expressed as d_1 , and the distance that the zone of radius $r_{0.5}$ is not shadowed by those buildings is expressed as $d_{0.5}$. Distances d_1 and $d_{0.5}$ can be obtained by geometrical calculation. In Figs. 4 and 5, the point for distance d_0 on the "flat terrain" curve and the point for distance d_1 or $d_{0.5}$ on the "sloped area" curve are indicated with lines. These lines are used for comparison to the measurement values. The results show that the line using distance $d_{0.5}$ is close to the measurement value. Therefore, the line of $d_{0.5}$ is used for the prediction curve of the sloped area.

IV. VERIFICATION BASED ON REAL ENVIRONMENT

To verify the proposed model based on measurement in a real environment, the BS is established in two places and the path losses are measured in the sloped area and flat terrain. For verification of the proposed model, since the curve of the path loss on flat terrain is necessary, the path losses on flat terrain are also measured.

A. Measurement in Real Environment 1

The measurement area is Shiinoki, Tobata ward, Kitakyushu city, Fukuoka, Japan. Fig. 6 shows the sloped area of Shiinoki. Fig. 7 shows the measurement courses. The dotted lines represent the courses in flat terrain and the solid lines represent the courses in the sloped area. The status of the buildings, such as building density and building height, is almost the same in the flat terrain and the sloped area. The two areas have many two-story buildings and some buildings



Fig.6. Sloped area (shiinoki).

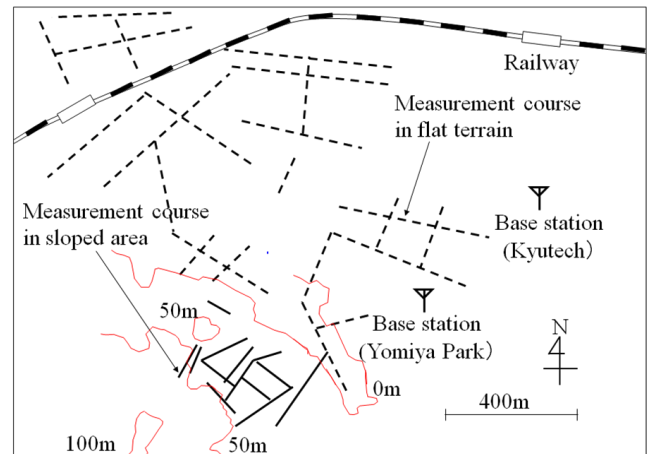


Fig.7. Measuring courses in real environment (shiinoki).

TABLE III. MEASUREMENT SPECIFICATION IN REAL ENVIRONMENT

Item	Specification	
Base station (BS height, h_b)	Kyutech (28 m)	Yomiya Park (33 m)
Measuring area	Shiinoki, Tobata ward, Kitakyushu	
Distance to sloped area, d_0	1200 m	414 m
Length of sloped area, D_s	600 m	694 m
Slope angle, θ	4.7°	4.1°
Frequency, f	902.8 MHz	
Output power	10 W	
BS antenna	Yagi-Uda antenna (6.5 dBi)	
MS antenna	Monopole antenna (3 dBi)	

and some buildings that are higher. The measurement specifications are given in Table III. The BS is established on the sixth floor (28 m) of a building in the Kyushu Institute of

Technology (Kyutech). Distance d_0 to the beginning point of the sloped area from the BS is 1200 m. The BS height in Table III is not the height from ground level to the BS, it is the height based on the ground level of the beginning point of the sloped area. The MS is established on a measurement vehicle. The measurement frequency is 902 MHz. All measurement points are in environments with NLOS paths between the BS and MS.

Fig. 8 shows the measurement results where the crosses indicate the path loss in the flat terrain and the circle plots indicate the path loss in the sloped area. The regression formula of the path losses in the flat terrain is expressed as

$$L_f = 45.3 \log d - 3.4 \text{ [dB]}. \quad (7)$$

where d is the distance between the BS and MS. Since the dispersion of the path loss in the sloped area is large, the average value of the path losses is calculated every 50 m along the distance between the BS and MS. The average values are indicated by "Sloped area" in Fig. 8. Correction value K is 12.6 dB in this environment. Therefore, the predicted curve of the sloped area is 12.6 dB lower than the curve of the flat terrain. To obtain distance $d_{0.5}$, we need to obtain the height of the buildings on the flat terrain. Since the measurement area has some multi-story buildings, it is assumed that the building height is 15 m (five-stories) and distance $d_{0.5}$ is determined to be 1200 m. Based on these, the curve predicted using the proposed model is labeled as "Proposed model" in Fig. 8. The curve "Proposed model" is compared to the measured curve of "Sloped area," and both correspond roughly.

B. Measurement in Real Environment 2

The BS is established in Yomiya Park and the path losses are measured in the same sloped area at 902 MHz. The BS height is 33 m, and distance d_0 is 414 m. Fig. 9 shows the measurement results where the crosses represent the path loss in the flat terrain and the circle plots represent the path loss in the sloped area. The regression formula of the path loss in the flat terrain is expressed as

$$L_f = 44.4 \log d - 0.5 \text{ [dB]}. \quad (8)$$

where d is the distance between the BS and MS. The average value of the sloped area is calculated every 50 m, and its curve is indicated as "Sloped area" in Fig. 9. The correction value is 5.0 dB, and the predicted path loss of the sloped area is 5.0 dB lower than that for the flat terrain. Distance d_0 is 414 m, and distance $d_{0.5}$ is 550 m. Based on these, the curve predicted using the proposed model is indicated by "Proposed model" in Fig. 9. The curve "Proposed model" is close to the "Sloped area" curve but a difference between the two curves is observed in the latter half. The prediction error of the proposed model is approximately 5.0 dB.

V. DISCUSSION

The equivalent base station height model is proposed that predicts the path loss of the sloped area. This model is

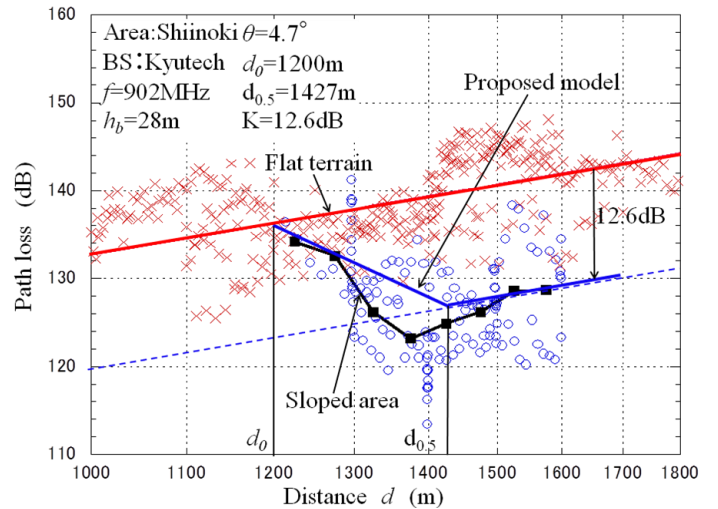


Fig.8. Path loss in real environment (BS:Kyutech).

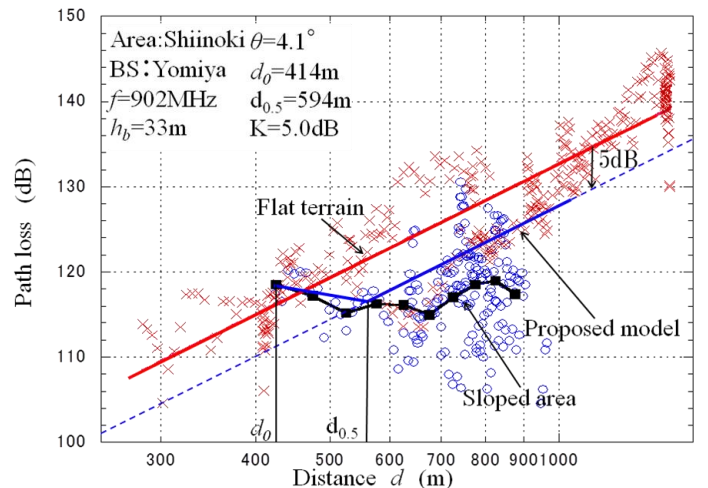


Fig.9. Path loss in real environment (BS:Yomiya Park).

examined based on a scale model and real environment measurements, and its validity is verified. Let's examine distance $d_{0.5}$, here. This model cannot be applied when buildings on flat terrain cause path loss, in other words, when a MS is near the start point of a sloped area. From the measurement results of the scale model, it is clear that the model can be applied when the distance between the BS and MS is further than distance $d_{0.5}$. The measurements in a real environment show the same results. Distance $d_{0.5}$ can be calculated from the height of the buildings on the flat terrain; however, the heights of the existing buildings are not uniform. A method for calculating the building height for distance $d_{0.5}$ is necessary.

Since the proposed model is based on a physical concept in a simplified environment, the following conditions stated in Section II are necessary: (1) The building situations in the flat terrain and that in the sloped area must be the same, and (2) the angle of the sloped area must be constant. In a real environment, however, the building situations in the flat terrain and the sloped area are not necessarily the same, and there are curved sloped areas. For this reason, a prediction

method that can be applied to a real complex environment is necessary. The applicable conditions for the proposed model are in the NLOS case. An examination of the LOS case will be necessary in future work. The difference in the path loss between the LOS and NLOS cases should be clarified.

VI. CONCLUSION

In order to predict the path loss of a sloped area in a microcell, correction method to obtain the path loss of a sloped area from that of a flat terrain was considered. We clarified the following.

- The equivalent base station height model was proposed, and its applicable conditions were clarified. Correction value K in a general sloped area is predicted using the proposed model and its value is 1 to 10 dB.

- The proposed model was verified using a scale model. A 1/70 scale model of a residential area on a slope was constructed in an open space, and the buildings were constructed referring to the Xia model. The path losses at 10.5 GHz were measured in the scale model. The results showed that the path losses predicted using the proposed model roughly agree with measurement values. The path loss of the section from distance d_0 to distance $d_{0.5}$ transits from the curve of the flat terrain to the curve of the sloped area. This distance $d_{0.5}$ can be calculated on the condition that the zone whose radius is half of the first Fresnel radius is not shaded by the buildings on the flat terrain.

- The path losses at 902 MHz were measured in a real sloped area, and the validity of the proposed model was verified. The results showed that the path losses predicted using the proposed model agree fairly well with the measurement values.

The proposed model was discussed in Section V. Future work will focus on cases such as when the building situations on flat terrain and sloped area are not the same, the angle within the sloped area is not constant, and LOS cases between the BS and MS.

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