Path Loss Estimation of 2 GHz and 5 GHz Band FWA within 20 km in Rural Area

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Abstract

We present a statistical path loss model derived from 2.2 GHz and 5.2 GHz experimental data collected in rural areas. The frequency range of the model is extended from that of the COST-231 Hata model (from 1500 to 2000 MHz) to assume broadband fixed wireless access service using the S band or C band, and the correction factor for the subscriber antenna height in rural areas from the Hata model and the COST-231 Hata model is reconsidered because both models use the same factor as urban area. To understand the basic propagation characteristics, the experiment was conducted over quasi-smooth terrain by not including the influence from ground undulations. The resulting path loss model is applicable to base station antenna heights from 10 to 43 m, subscriber antenna heights from 4.5 to 10 m, and base-to-subscriber distances of less than 20 km for suburban and quasi-open areas.

1. INTRODUCTION

In the same way that broadband service has extended to the mobile and nomadic markets, it is likely that this service will also extend to the fixed wireless access (FWA) market. The fact that the Institute of Electrical and Electronic Engineers (IEEE) standardized 802.16-2004 [1] and the WiMAX Forum has discussed extended usage models based on IEEE 802.16e-2005 [2] are evidence of this extension. The advantage of broadband service using FWA compared to the cable system infrastructure is particularly noticeable in rural areas when considering the last mile problem, and FWA presents a clear advantage in terms of cost. The S band or C band is expected to be used for FWA as well as for mobile and nomadic applications because these bands have a high tolerance to non line-of-sight propagation environments.

The Hata model [3] is well-known as an empirical propagation model for the P and L bands. The model is based on the original Okumura experimental data [4], and is designed to be used in the frequency band from 150 MHz to 1500 MHz. To enhance the frequency range of the Hata model, the COST-231 Hata model [5] (CH model hereafter) was devised to extend the frequency from 1500 MHz to 2000 MHz based on the Okumura data. However, when considering the requirements established by broadband FWA using S band or C band in rural areas, there is not appropriate propagation model.

In [4], Okumura et al. classified the propagation model of quasi-smooth terrain into three categories: urban, suburban, and open. In addition, the urban area is divided into a large city and a medium-small city. Furthermore, the equation correction factor for a quasi-open area is defined to be 5 dB greater than that for an open area. Although a rural area is considered to include open, quasi-open, and suburban areas, the path loss equations for these areas, which are originated from the Okumura data, are based on that for urban areas. Thus, the same correction factor for the subscriber antenna height that is used for urban areas is used for rural areas. There is certainly room for improvement in the accuracy of the correction factor because the same factor is used for the different kinds of areas.

In this paper, based on this background we tried to expand the frequency range based on the results of propagation experiments in rural areas for quasi-open and suburban areas, and also tried to revise the correction factor for the subscriber height. We analyzed the experimental data and compared the existing models. To understand the basic characteristics, the experiments were conducted using the 2.2 GHz and 5.2 GHz bands over a quasi-smooth terrain to get rid of the influence of ground undulations. The maximum antenna height of the base station and subscriber is 43 m and 10 m, respectively. The measurement points for the subscriber antenna are selected discretely within 20 km from the base station. At the measurement points the height pattern of the path loss is obtained. Following the use of the distance attenuation factor and the correction factor for the base station height for the existing model, we propose applying the correction factor for the subscriber antenna height and the frequency scaling factor.

2. MEASUREMENT PROGRAM

Fig. 1 shows the measurement regions. As shown in the figure, the measurements were conducted in two regions, Ajiki and Tsukuba where base stations were established. The measurement points are selected so that the distance from the base station, *d*, is approximately 3.5 km, 5 km, 7 km, 10 km, 12 km, 15 km, and 17 km. There are two or three measurement points at each distance.

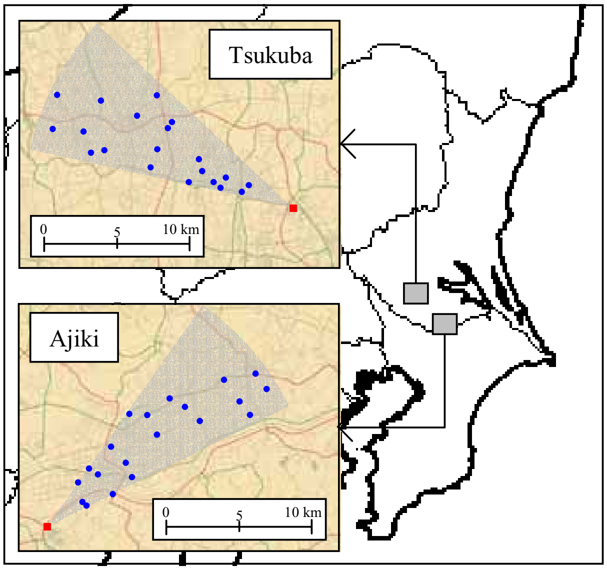

Fig. 1: Measurement Regions

TABLE 1: MEASUREMENT PARAMETERS

Frequency: f [MHz]	2197.5 and 5200 (CW)
Distance: d [km]	Approximately 3.5, 5, 7, 10, 12, 15, and 17
Base station height: H_b [m]	20, 30, 40 @Ajiki 23, 33, 43 @Tsukuba
Subscriber height: H_s [m]	4.5 to 10.0

Obstacles in the direction of the base station were less than a few hundred meters away from each measurement point. The measurement regions are generally flat, and the standard deviations of the ground undulations obtained from the topographical data for the regions were 5 m or less. When these regions are classified by condition of ground obstacles, Ajiki and Tsukuba are considered to be a quasi-open area and a suburban area, respectively. The antenna heights of the base station and the subscriber, H_b and H_s, respectively, are shown in Table 1. H_s was continuously changed in the range indicated in the table. Continuous waves (CWs) were generated at 2.2 GHz and 5.2 GHz band by transmitters, and were received at the same time. Though the antennas are set closely, special attention is paid so that the characteristics do not degrade.

3. STANDARD EMPIRICAL MODEL BASED ON OKUMURA'S CURVES

The empirical models based on Okumura's curves [4] are described in this session.

Hata proposed empirical formulas [3] for path loss, $L_{H\text{-}U}$, in the urban area on quasi-smooth ground by the use of the experiment result obtained by Okumura et al. The equation for path loss $L_{H\text{-}U}$ in dB is

$$L_{H-U} = 69.55 + 26.16 log(f) - 13.82 log(H_b) - a(H_s) + \{44.9 - 6.55 log(H_b)\} log(d) \quad (1)$$

where f is the frequency (150-1500 MHz), d is the distance (1-20 km) between the base station and the subscriber, and H_b and H_s are 30 m to 200 m and 1 m to 10 m, respectively. The term $a(H_s)$ is the correction factor for the subscriber antenna height and is defined for a medium-small city as

$$a(H_s) = (1.1 log(f) - 0.7)H_s - (1.56 log(f) - 0.8) \quad (2)$$

On the other hand, the expression to enhance the coverage of the frequency to the range of 1500-2000 MHz is given in the CH model [5]. The model is also obtained through Okumura's experiment results. The equation for path loss $L_{CH\text{-}U}$ for a suburban area is defined as

$$L_{CH-U} = 46.3 + 33.9 log(f) - 13.82 log(H_b) - a(H_s) + \{44.9 - 6.55 log(H_b)\} log(d) \quad (3)$$

where $a(H_s)$ is used in the same equation as (2). Equations (1) and (3) are applied to an urban area, and are also applied to suburban and quasi-open areas using the respective correction factors as follows

$$L_{\eta-S} = L_{\eta-U} - 2\{log(f/28)\}^2 - 5.4 \quad (4)$$

$$L_{\eta-QO} = L_{\eta-U} - 4.78\{log(f)\}^2 + 18.33 log(f) - 35.94 \quad (5)$$

where η is H and CH for the Hata model and the CH model, respectively. Equation (5) exceeds the propagation loss for an open area by 5 dB [4].

As mentioned above, the correction factor for the subscriber antenna height, i.e., (2), is applied for not only an urban area, but also suburban and (quasi-) open areas. Furthermore, the frequency range is expected to be established in a higher band such as the S band or C band for broadband wireless access systems. Considering these facts, (3) is enhanced in the following discussion through experimental study.

4. DATA REDUCTIONS AND RESULTS

A. Correction Factor for Subscriber Antenna Height

The dependency of the path loss on H_s is estimated in this section. Height patterns of path loss are obtained at each measurement point because the CW signals for two frequencies were continuously received according to the change in the subscriber antenna height. Fig. 2 shows a simplified example of the height pattern that was processed based on the data sets from the measurement points, where the same distance from the base station is assumed. The data processing routine is shown below.

(i) Height patterns of the relative path loss (L_r) are calculated using the medium values of the height patterns (L_m) at each measurement point.

(ii) The medium values for each 0.5-m interval (4.5-5 m, 5-5.5 m, … , 9.5-10 m) are calculated using the L_r data sets. These values are denoted as L_{rm}.

(iii) L_{rm} represents the value at the middle height corresponding to each 0.5-m interval.

The L_{rm} is dependent on H_s as shown in Fig. 2. The figure is the case for d = 3 km and H_b = 33 m at Tsukuba. The other cases also showed a similar tendency. We performed liner regression using the L_{rm} data to explain this dependency using the following equation,

$$a'(H_s) = \alpha(H_s - 7.25) \tag{6}$$

After estimating the difference between L_m and L_{rm} at H_s = 7.25 m, the medium value of the difference was 0.08 dB, and the standard deviation was 3.3 dB. Therefore, it was considered to be appropriate that the intercept is 7.25. The regression results are shown in Fig. 3, for H_b = 30 m at Ajiki and H_b = 33 m at Tsukuba. There does not seem to be a dependency on distance, and similar tendencies are obtained for the other H_bs. Thus, α, the dependency of the path loss on the subscriber antenna height, is not affected by the distance. Such a result can be said to be appropriate from (2), which does not include the distance factor.

Fig. 4 shows the results by processing the measured data from all measurement points at each H_b in the same way as described in (i) to (iii). Fig. 4(a) and (b) show the results for Ajiki and Tsukuba, respectively. In these figures, the regression results from (6) are also plotted. The figures show that L_m is considered to be independent on the frequency and H_b because the inclination of L_m changes regardless with the frequency and H_b. Finally, the regression results for Ajiki and Tsukuba using all the measured data with (6) are respectively,

$$a'(H_s) = 16.8(H_s - 7.25) \tag{7}$$

$$a'(H_s) = 18.0(H_s - 7.25) \tag{8}$$

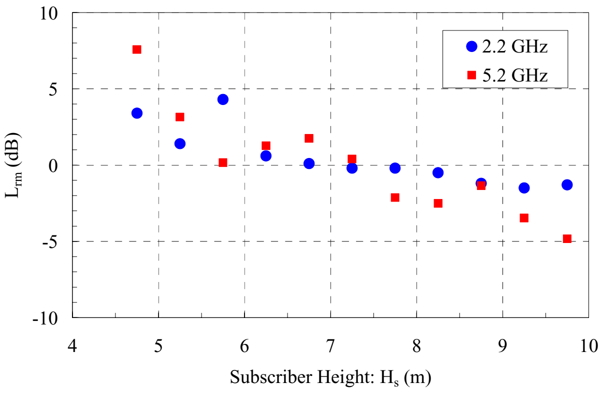

Fig. 2: Height Pattern Example

Fig. 5 shows a comparison of (7) and (8) with (2), which is calculated at f = 2200 MHz and shifted so that the intercept is 7.25.

In the following discussion, L_m represents the value at each measurement point.

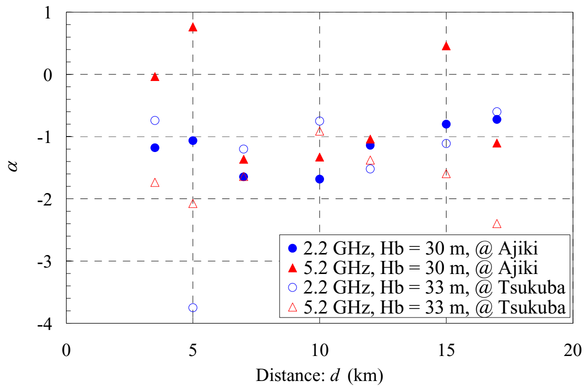

Fig. 3: Independence of a to Distance

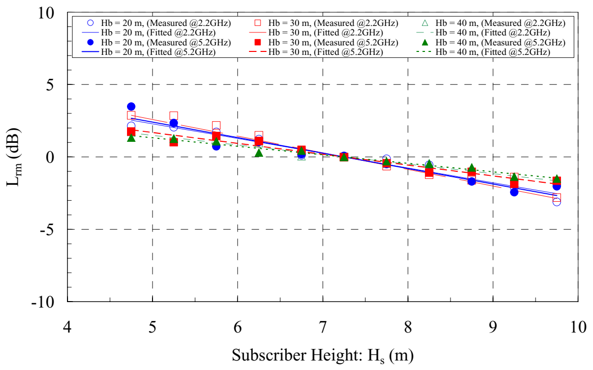

Fig. 4(a): Height Pattern Using Merged Data of All Points (Ajiki)

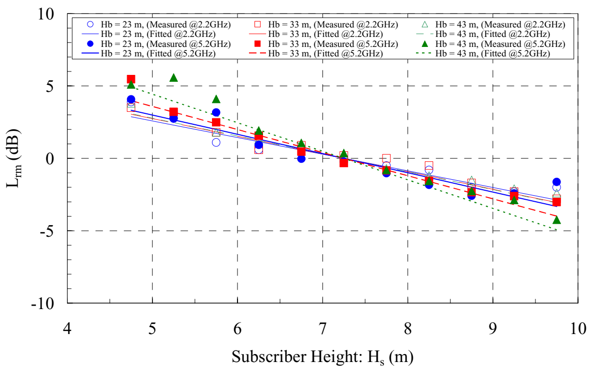

Fig. 4(b): Height Pattern Using Merged Data of All Points (Tsukuba)

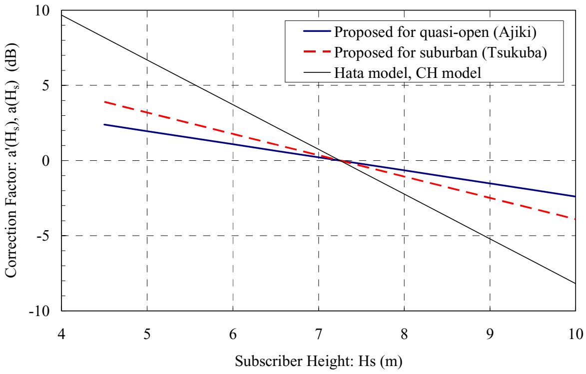

Fig. 5: Correction Factor for Subscriber Antenna Height Compared to (2)

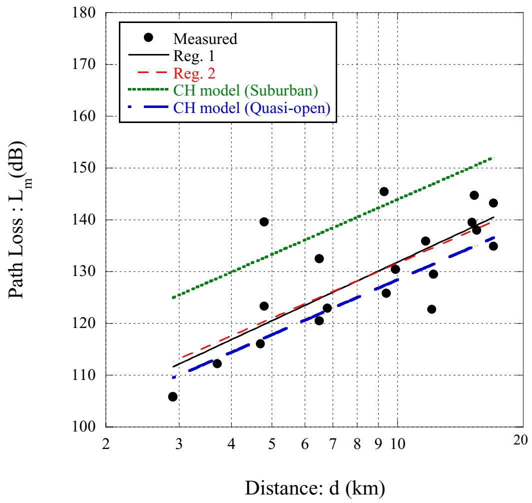

Fig. 6: Comparison of Fitted Results to CH model (Ajiki)

B. *Correction Factor for Frequency*

(a) Quasi-open area

An example of the measured results for the path loss (L_m) is plotted in Fig. 6 for H_b = 30 m and the 2.2 GHz band at Ajiki. In the figure, two types of logarithmic regression results are also shown. Reg. 1 is simply obtained by the logarithmic regression for the measured data. Reg. 2 is obtained by drawing the logarithmic regression line, which the path loss exponent is the same as (1) or (3), through the scatter of measured points in such a way that the root mean square deviation for this curve is minimized. Furthermore, the results calculated using the CH model for suburban and quasi-open areas are shown respectively. Reg. 1 is nearly equal to Reg. 2, and both lines are also close to that for the CH model for a quasi-open area, especially with regard to the inclination, which expresses the distance dependency of the path loss ($\{44.9 - 6.55\log(H_b)\}\log(d)$). Similar tendencies are observed in the other estimated results as well as for the 5.2 GHz band. We use the same distance attenuation factor as in the CH model. The correction factor for H_b in (1) or (3) ($-13.82\log(H_b)$) is followed as well, because the Hata and the CH model use the same factor even for the difference frequency applicability. Considering the discussion above, the L_{rm} is resolved using regression analysis regarding the frequency as an independent variable, and the obtained results are as follows

$$L_{QO} = 47.8 + 19.0\log(f) - a'(H_s) \\ -13.82\log(H_b) + \{44.9 - 6.55\log(H_b)\}\log(d) \quad (9)$$

where $a'(H_s)$ is the one used in (7). An example is shown in Fig. 7 comparing the measured data in Ajiki at H_b = 20 m and 40 m for the 2.2 GHz and 5.2 GHz bands using (9). The regression results seem to represent the tendency of the measured data.

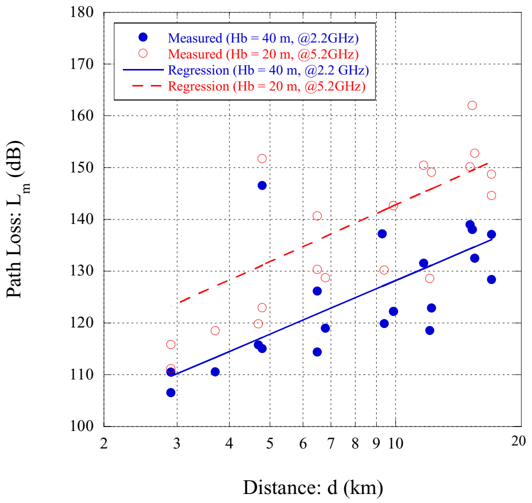

Fig. 7: Comparison of Regression Results to Measured Data in Quasi-open Area (Ajiki)

(b) Suburban area

An example of the measured results for the path loss (L_m) is plotted in Fig. 8 for H_b = 33 m and the 2.2 GHz band at Tsukuba. In the figure, two types of logarithmic regression results are also shown. Similar to Fig. 6, Reg. 1 is simply obtained using the logarithmic regression for the measured data, and Reg. 2 is obtained by drawing the logarithmic regression line, for which the path loss exponent is the same as (2), through the scatter of the measured points in such a way that the root mean square deviation for this curve is minimized. Furthermore, the results calculated using the CH model for suburban and quasi-open areas are shown respectively. Reg. 1 is nearly equal to Reg. 2, and both lines are also close to that for the CH model for a suburban area. Similar tendencies are observed in the other estimated results and the 5.2 GHz band. The plots for both Reg. 1 and Reg. 2

are close to that the CH model in Fig. 8. Because of the reason determined previously, we use the same distance attenuation factor and the same correction factor for the base station height as used in the CH model. Considering this discussion, L_{rm} is resolved using regression analysis regarding the frequency as an independent variable, and the obtained results are as follows

$$L_S = 31.5 + 16.8\log(f) - a'(H_s) - 13.82\log(H_b) + \{44.9 - 6.55\log(H_b)\}\log(d) \quad (10)$$

where $a'(H_s)$ is the one used in (8). An example is shown in Fig. 9 comparing the measured data in Tsukuba at H_b = 23 m and 43 m for the 2.2 GHz and 5.2 GHz bands using (10). The regression results seem to represent the tendency of the measured data.

Fig. 10 shows the comparison of results for (9) and (10) with the Hata and the CH model. They are calculated at d = 5 km. As shown in the figure, the proposed formula successfully expands the applicable frequency range without abrupt disconnection to the existing ones.

5. Conclusion

We carried out two sets of propagation measurements at 2.2 GHz and 5.2 GHz in order to enhance the existing path loss prediction for suburban and quasi-open areas, or rural areas, using frequency scaling and a correction factor related to the subscriber height. We proposed a corrected prediction for rural areas, and showed that the prediction for the applicable parameter agrees with the measured data. Further examination and experiments for other rural areas are planned, and the path loss characteristics must be further clarified.

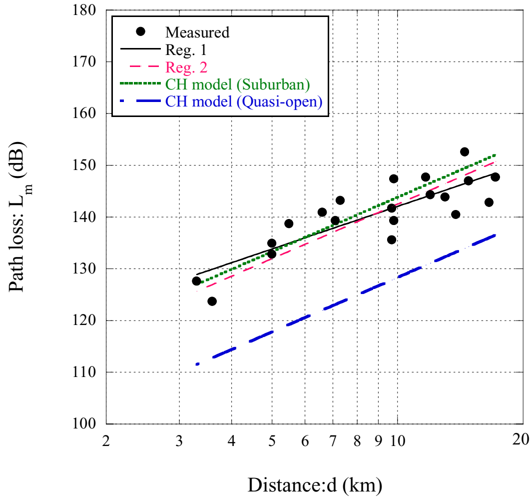

Fig. 8: Comparison of Fitted Results to CH model (Tsukuba)

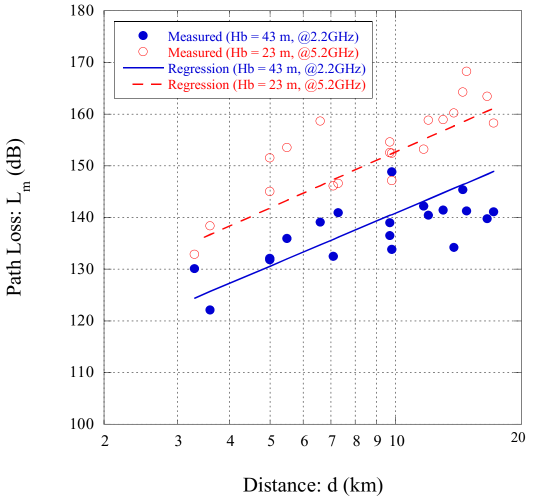

Fig. 9: Comparison of Regression Results to Measured Data in Suburban Area (Tsukuba)

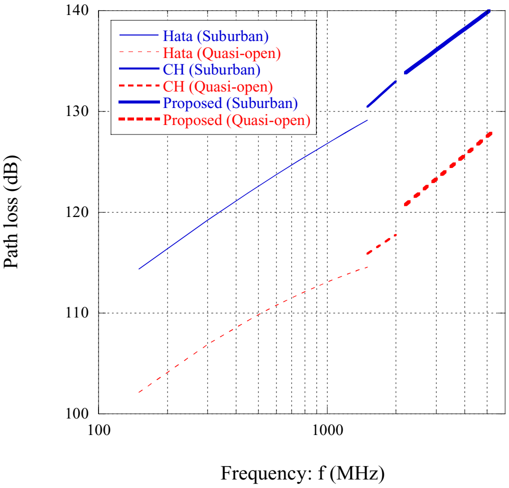

Fig. 10: Comparison of (9) and (10) with Hata and CH model (d = 5 km)

References

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