Path loss model for the 2 to 37 GHz band in street microcell environments

Minoru Inomata^{1a)}, Wataru Yamada¹, Motoharu Sasaki¹,
Masato Mizoguchi¹, Koshiro Kitao², and Tetsuro Imai²

¹ NTT Access Network Service Systems Laboratories, NTT Corporation,
1-1 Hikarinooka, Yokosuka, Kanagawa 239-0847, Japan

² NTT DOCOMO, INC., 3-6 Hikarino-oka, Yokosuka, Kanagawa 239-8536, Japan
a) inomata.minoru@lab.ntt.co.jp

Abstract: A path loss model based on the Rec. ITU-R P.1411 model, which can cover the frequency range from microwave to millimeter-wave bands, is presented. The path loss characteristics are analyzed on the basis of measurement results obtained using the 2 to 37 GHz band in street microcell environments. It is clarified that the characteristics depend on distance from transmitter to intersection and frequency dependency. By taking these dependencies into account, the proposed model can decrease the root mean square error of prediction results to within about 5 dB in the 2 to 37 GHz band.

Keywords: propagation, millimeter wave, street microcell environment

Classification: Antennas and Propagation

References

- [1] NTT DOCOMO, INC., “DOCOMO 5G White Paper, 5G Radio Access: Requirements, Concept and Technologies”, July 2014.
- [2] METIS, <https://www.metis2020.com/>.
- [3] Rep. ITU-R M.2135-1, “Guidelines for evaluation of radio interface technologies for IMT-Advanced,” ITU-R Report, vol. 1, M Series, ITU, Geneva, 2009.
- [4] Rec. ITU-R P.1411-7, “Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz,” ITU-R Report, vol. 7, P Series, ITU, Geneva, 2013.
- [5] X. Zhao, T. Rautiainen, K. Kalliola, and P. Vainikainen, “Path-loss models for urban microcells at 5.3 GHz,” *IEEE Antennas Wireless Propag. Lett.*, vol. 5, pp. 152–154, Dec. 2006. DOI:10.1109/LAWP.2006.873950
- [6] K. Sakawa, H. Masui, M. Ishii, H. Shimizu, and T. Kobayashi, “Microwave path-loss characteristics in an urban area with base station antenna on top of a tall building,” International Zurich Seminar on Broadband Communications, pp. 31-1–31-4, 2002. DOI:10.1109/IZSBC.2002.991774

1 Introduction

Traffic in wireless communication systems has been rapidly increasing in recent years and is assumed to reach 1000 times higher than the current traffic amount in the next 10 years [1]. To cope with this growth, the application of both microwave and millimeter-wave bands for the next generation mobile systems is being examined since millimeter-wave bands can use wider frequency bandwidth that can provide attractive higher throughput.

It is assumed that one of the possible service areas of mobile systems using millimeter-wave bands is urban downtown areas, well known as street microcell environments [2]. A lot of path loss models for street microcell environments have been proposed; most of them can be categorized into two types. The first type is two-slope models, of which the Rep. ITU-R M.2135 model [3] is the representative example. However, the applicable frequency range of this model is only from 2 to 6 GHz. The other is three-slope models, of which the Rec. ITU-R P.1411 model [4] is the representative example. The applicable frequency range of this model is from 2 to 16 GHz. However, no models covering millimeter-wave bands have yet been reported.

A single path loss model that can cover the frequency range from microwave to millimeter-wave bands is preferable in terms of measuring the consistency of frequency characteristics, though to the authors' knowledge no such models have been reported. To address this deficiency, we propose a model that is based on the Rec. ITU-R P.1411 model and can cover the frequency range from microwave to millimeter-wave bands. Since the P.1411 model is constructed with parameters it can extend the frequency range so as to cover bands from microwave to millimeter-wave. However, since each of the coefficients of Rep. ITU-R M.2135 model are optimized in the target frequency range, it will be necessary to reconstruct the coefficients to extend the frequency range [5, 6].

2 Measurement parameters and environments

The path loss measurements were taken in the environment shown in Fig. 1(a). The measurements were taken in four frequency bands 2, 4.7, 26, and 37 GHz in order to ascertain the frequency dependence of the measurements. The transmitter (Tx) antenna was set to a height of either 6 or 10 m and used to transmit continuous waves. A receiver (Rx) antenna was fixed on the roof of a measurement car whose height was 2.5 m. The antenna directivity was omni-directional. The received power level was measured while driving the measurement car along the line-of-sight (LOS), non-line-of-sight (NLOS) 1, NLOS 2, and NLOS 3 routes as shown in Fig. 1(b). The measurement procedure was conducted in Tokyo, Japan. The distance from Tx antenna to intersection was about 242 m for NLOS 1, 57 m for NLOS 2, and 169 m for NLOS 3. Tall buildings of about ten stories about 40 m height surrounded the street in the measurement site.

Fig. 1. Measurement environment.

3 Path loss characteristics in 2 to 37 GHz band in NLOS street microcell environments

3.1 Introduction of ITU-R P.1411 model and measurement results

In this subsection we discuss the path loss characteristics in the 2 to 37 GHz band at the LOS and NLOS 3 routes at $h_{BS} = 6$ m as shown in Fig. 2(a). The path loss predicted by the P.1411 model is obtained by using the following equations.

(i) The free space loss is obtained by using equations (1), (2), (3).

$$L_{LOS,m} = L_{bp} + 6 + \begin{cases} 20 \log_{10} \left(\frac{d_1}{R_{bp}} \right) & \text{for } d_1 \leq R_{bp} \\ 40 \log_{10} \left(\frac{d_1}{R_{bp}} \right) & \text{for } d_1 > R_{bp} \end{cases} \quad (1)$$

$$L_{bp} = \left| 20 \log_{10} \left(\frac{\lambda^2}{8\pi h_1 h_2} \right) \right| \quad (2)$$

$$R_{bp} = 4 \frac{(h_{BS} - h_s)(h_{MS} - h_s)}{\lambda} \quad (3)$$

where L_{bp} is the value for the basic transmission loss at the breakpoint and R_{bp} is the breakpoint distance, h_{BS} is Tx antenna height, h_{MS} is Rx antenna height, h_s is the effective road height, and d_1 is the traveling distance calculated from equation (4).

$$d_1 = \sqrt{x_1^2 + (h_{BS} - h_{MS})^2} \quad (4)$$

where x_1 is distance from Tx antenna to intersection. We assumed that $h_s = 0$.

(ii) The pass loss L_C in the corner loss region is obtained by using equation (5), (6).

$$L_C = \begin{cases} \frac{L_{corner}}{\log_{10}(1+d_{corner})} \log_{10}(d_2 - w_1/2) & \text{for } w_1/2 + 1 < d_2 < w_1/2 + 1 + d_{corner} \\ L_{corner} & \text{for } d_2 > w_1/2 + 1 + d_{corner} \end{cases} \quad (5)$$

$$d_2 = \sqrt{x_2^2 + (h_{BS} - h_{MS})^2} \quad (6)$$

where the corner loss L_{corner} is expressed as the additional attenuation over the distance d_{corner} . Distance from intersection to Rx antenna is denoted by X_2 and LOS street width is denoted by w_1 . For an urban environment, the recommended L_{corner} value is 20 dB and the recommended d_{corner} value is 30 m.

- (iii) The path loss L_{att} in an NLOS region is obtained from equation (7). The NLOS region lies beyond the corner loss region, where a coefficient parameter β applies. Total path loss L_{NLOS} is calculated from equation (8).

$$L_{att} = \begin{cases} 10\beta \log_{10}\left(\frac{d_1+d_2}{d_1+w_1/2+d_{corner}}\right) & \text{for } d_2 > w_1/2 + 1 + d_{corner} \\ 0 & \text{for } d_2 \leq w_1/2 + 1 + d_{corner} \end{cases} \quad (7)$$

$$L_{NLOS} = L_{LOS,m} + L_c + L_{att} \quad (8)$$

From Fig. 2(a), it can be seen that from 0 to 200 m the P.1411 model obtains the good fit with measured results for the LOS and corner loss regions. Up to 200 m the root mean square error (RMSE) is about 3 dB, but after that it increases to about 19 dB at 2 GHz and about 12 dB at 37 GHz in the NLOS region. It is therefore important to analyze the path loss characteristics in the NLOS region.

3.2 Analysis of the attenuation coefficient

We mainly analyzed the attenuation coefficient β in equation (7), which is used as a fitting parameter in the NLOS region, in terms of its dependence on frequency, Tx antenna height, and distance from Tx antenna to intersection. The coefficient is obtained by calculating its maximum likelihood value such that the RMSE for L_{NLOS} and that for the measurement path loss are minimized. Fig. 2(b) shows the dependency between the coefficient and the distance from Tx antenna to intersection. The coefficient is obtained by using the median value of each frequency band. From Fig. 2(b) it can be seen that the coefficient decreases as distance from Tx antenna to intersection increases. Fig. 2(c) shows the dependency between the coefficient and the frequency. It shows that the coefficient increases as the frequency increases in each route and for each antenna height. The coefficient has frequency dependency because scattered and diffracted waves are dominant. It is also affected by the distance from Tx antenna to intersection because the slope values of approximation vary. However, it does not depend on the Tx antenna height because the value of 6 m Tx antenna height approximately corresponds to the value of 10 m Tx antenna height. Accordingly, its dependency on both frequency and distance from Tx antenna to intersection need to be taken into account.

3.3 Proposed path loss model

As the measurement results in 3.2 indicate, in order to predict the path loss in bands from microwave to millimeter-wave it is important to take into account the dependency on frequency and distance from Tx antenna to intersection. We therefore propose a path loss model that takes these into account for extending the applicable frequency band. The model is shown below in (9). We assumed that the effects of both the Tx-antenna-to-intersection distance and the frequency could be formulated by multiplying logarithmic functions of frequency and distance from Tx antenna to intersection. Here, the fitting parameters for the proposed model are carrying out multiple regression analysis of the measurement results for both 6 m and 10 m Tx antenna heights. The median value of fitting parameters is calculated. The path loss calculation for the attenuation coefficient is substituted into equa-

(a) Comparison of measurement and prediction results with P.1411 model.

(b) Dependency on distance from Tx to intersection.

(c) Frequency dependency.

Fig. 2. Measurement results.

tion (9). The fitting parameters are calculated for $\beta_{\text{const}} = 4.15$, $\alpha_f = 1.41$, $C_f = -7.82$, $\alpha_x = 0.79$, and $C_x = -1.00$. The unit of frequency is MHz and unit of distance is m.

$$\beta = \beta_{\text{const}} + (\alpha_f \log_{10} f + C_f)(\alpha_x \log_{10} x_1 + C_x) \quad (9)$$

3.4 Verifying validity of proposed path loss model

Fig. 3(a) shows path loss measurement results, prediction results obtained with the P.1411 model, and prediction results obtained with the proposed model for the LOS and NLOS 3 routes at $h_{BS} = 6$ m. Quantitative evaluation results are depicted in Fig. 3(b), where RMSE values for each frequency band are calculated. Black dots indicate NLOS 1 with $h_{BS} = 6$ m, blue dots NLOS2 with $h_{BS} = 6$ m, green dots NLOS 3 with $h_{BS} = 6$ m, red dots NLOS 1 with $h_{BS} = 10$ m, purple dots NLOS 2 with $h_{BS} = 10$ m, and brown dots NLOS 3 with $h_{BS} = 10$ m. From Fig. 3(a) it can be seen that better fitting between predicted and measured values is obtained with the proposed model than with the P.1411 model, with the former reducing the mean RMSE value to about 11 dB. Fig. 3(b) shows that with the P.1411 model the RMSE values were about 6.6 dB at 37 GHz and 23.9 dB at 2 GHz. The values decrease as the frequency increases because the recommended attenuation coefficient value is six, which is a large value to apply to the high frequency band. Fig. 3(b) shows that with the proposed model the RMSE values are about 2.2 dB at 2 GHz and 4.7 dB at 37 GHz. This shows that the proposed model can cover the frequency range from 2 to 37 GHz.

(a) Path loss in the 2 to 37 GHz band. (b) RMSE in the 2 to 37 GHz band.

Fig. 3. Comparison of proposed and conventional model results.

4 Conclusion

We analyzed path loss characteristics in the 2 to 37 GHz band in street microcell environments with the aim of developing a path loss model that can cover the frequency range from microwave to millimeter-wave bands. The measurement results clarified that path loss depends on distance from Tx antenna to intersection and on frequency. We proposed a frequency extension model that takes account of these dependencies and confirmed its validity by evaluating the RMSE values of prediction results obtained with it. The evaluations confirmed it can predict path loss with RMSE of less than 5 dB in the 2 to 37 GHz band.