Study on path loss model for macrocell environment using percentage of area occupied by buildings for 5G

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Abstract: We propose a correction formula using the percentage of area occupied by buildings, $\alpha$, for a path model in the urban macrocell environment defined in ITU-R M.2135 based on measurements performed in Japan for below 6 GHz for 5G. Based on analysis, the regression results of the correction formula in which $S$, the median of the difference between the measured path loss and that of the reference path model is proportional to $\alpha$, is better than when $S$ is proportional to the logarithm of $\alpha$.

Keywords: Mobile radio, 5G, path loss model, percentage of area occupied buildings

Classification: Antennas and propagation

References

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1 Introduction

Research and development on the fifth generation mobile communication system (5G) were pursued to actualize high-speed and high-capacity communications, and commercial services have started. Use of the microwave band under 6 GHz is considered for 5G [1, 2]. In general, a path loss model that can be applied to various
environments such as urban and suburban areas is required in order to design service areas for mobile communication systems. In previous studies, applying an empirical correction formula that employs the percentage of area occupied by buildings based on measurement to a reference path loss model for urban environments were proposed in order to predict path loss with high accuracy in a macrocell environment, which is a typical cell deployment for the microwave band [3, 4]. Regarding the path loss model for macrocell environment for 5G, the ITU-R M. 2412 model [2] is widely recognized; however, a correction formula using the percentage of area occupied buildings for this model has not yet been proposed. In ITU-R M. 2412, there are two path loss models for a macrocell environment which is UMa_A and UMa_B. UMa_A is based on the ITU-R M.2135 model that was originally developed for 4G systems and is widely used for system design and evaluation. We investigate a correction formula for the model applied to an urban macrocell environment in ITU-R M.2135 based on measurements [5]. We first outline the measurements and then derive the correction formula for the ITU-R M.2135 model.

2 Measurements
Path loss measurements were performed to derive the path loss correction formula in five areas in Japan. Table I gives the measurement parameters. In this experiment, the base station (BS) antenna transmits a continuous wave (CW) and the mobile station (MS) antenna receives the wave and records the received level. The maximum distance between the BS and MS is 3 km. The BS antenna is mounted on a tower or building roof at the height of 10 m to 117 m. The MS antenna is mounted on a measuring car at the antenna height of 2.1 m or 2.7 m. Both antennas are sleeve antennas. The measurement frequency is 0.81 GHz to 8.45 GHz. Path loss is obtained based on the average received level over the interval of 50 m. Table I gives the percentage of area occupied by buildings, $\alpha$, and is expressed as

$$\alpha = \frac{A_b}{A_p}$$

where $A_b$ (m$^2$) is the area occupied by buildings and $A_p$ (m$^2$) is the area of the prediction target. In the Samukawa area, there are two different $\alpha$ values and values are obtained for each area. Moreover, only data from non-line-of-sight (NLOS) areas are analyzed.

| Base station  | BS height (m) | $\alpha$ (%) | Mobile station (m) | Frequency (GHz) |
|---------------|---------------|--------------|--------------------|-----------------|
| Yokohama      | 80, 35        | 37           | 2.1 or 2.75        | 0.458, 4.7, 0.813, 5.2 |
| Kuramae       | 80, 35        | 42           |                    |                 |
| Chiyoda       | 117, 35       | 7, 19        |                    | 2.2, 8.45, 3.35, |
| Tamagawa      | 45, 10        | 31           |                    |                 |
| Samakawa      | 50, 15        | 37           |                    |                 |

1 In this letter, empirical correction formula for ITU-R M.2135 is newly studied.
3 Path loss correction formula using percentage of area occupied by buildings

Similar to traditional methods to derive the path loss correction formula using $\alpha$, the formula is derived by applying regression analysis to the difference between the measured path loss in various environments and the value from the reference path loss model for an urban area [3]. In this study, the reference path loss model is the model for an urban macro (UMa) NLOS environment from ITU-R M. 2135, which is expressed as

$$PL_{UMa} = 161.04 - 7.1 \log_{10}(W) + 7.5 \log_{10}(h) - (24.37 - 3.7(h/h_{BS})^2) \log_{10}(h_{BS}) + (43.42 - 3.1 \log_{10}(h_{BS})) (\log_{10}(d) - 3) + 20 \log_{10}(f_c) - (3.2 (\log_{10}(11.75 h_{UT}))^2 - 4.97)$$

(2)

where $PL_{UMa}$ is the path loss (dB), $W$ is the road width (m), $h$ is the average building height (m) in the target area, $h_{BS}$ is the BS antenna height (m), $d$ is the distance between the BS and the MS (m), $f_c$ is the frequency (GHz), and $h_{UT}$ is the MS antenna height [5]. $h_{BS}$ and $h_{UT}$ are the same for the measurements and typical values $W = 20$ (m) and $h = 20$ (m) described in [5] are used for analysis.

The path loss model using the correction formula, $S(\alpha)$, and the above $PL_{UMa}$ of ITU-R M. 2135 are expressed as

$$PL = PL_{UMa} - S(\alpha)$$

(3)

Similar to a previous study [3], correction value $S$ is the median of the difference between the measured path loss and that of the reference model within a 500 m by 500 m area.

Fig. 1 shows the distribution of $\alpha$ per 500 m by 500 m area in the measurement area. Moreover, Fig. 2 shows the relationship between $\alpha$ and $S$. Similar to [4], results of $S$ regressed by the logarithm of alpha is expressed as

$$S(\alpha) = 35.1 - 21 \log \alpha$$

(4)

The root mean square (RMS) of the residual error, which is the difference between the measured path loss and calculated value of (4), is 9.4 (dB). Fig 2 shows that $S$ tends to be proportional to $\alpha$. The results of $S$ regressed by $\alpha$ is express as

$$S(\alpha) = 22.5 - 0.6 \alpha$$

(5)

The RMS of the residual error, which is the difference between the measured path loss and calculated RMS value of the residual error of (5), is 8.8 (dB). This value is better than that obtained in (4). From these results, (5) can be used for the correction formula for (2).

Fig. 1. Distribution of percentage of area occupied by buildings, $\alpha$. 

![Distribution of percentage of area occupied by buildings, $\alpha$.](image-url)
4 Conclusion
We investigated a path loss correction formula for a path loss model in a UMa NLOS environment in ITU-R M. 2135 based on measurements in order to predict the path loss in a macrocell environment for frequency bands below 6 GHz for 5G. The regression results of the correction formula in which $S$ is proportional to $\alpha$ are better than that in which $S$ is proportional to the logarithm of $\alpha$. A correction formula for higher frequencies such as the millimeter wave band is left for future study.

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