LETTER

Enhanced Urban Path Loss Prediction Model with New Correction Factors

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SUMMARY Modification of ITU-R P.1411 model to enhance the prediction accuracy in urban environments having variable heights of buildings is proposed in this paper by introducing two kinds of novel correction factors. One is considering the relationship of the highest building height and the transmitter (Tx) antenna height, and the other is considering the effect of receiver (Rx) position on crossroads. After introducing two correction factors, the prediction accuracy is shown to be improved.

key words: *correction factors, path loss prediction, ITU-R P.1411 model, urban environment*

1. Introduction

Recently, most channel models are describing wide-band channel characteristics for the high data rate wireless transmission. But the narrow-band channel model, such as path loss model is still important for the deployment strategy of wireless communication service and the analysis of interferences. Okumura-Hata [1], [2], COST231-hata [3] and COST231-WI [3] models are known as representative narrowband models. However ITU-R P.1546 [4] and ITU-R P.1411 [5] models recently modified to include the properties of these existing models.

Although these models are widely used, the models provide relatively accurate results only for simple environment. Some prediction errors are observed for actual urban environment because the heights of buildings are not so uniform. In this paper, new correction factors for ITU-R P.1411 model are suggested, which results in the considerable improvement of prediction accuracy.

2. Measurement Campaign

The continuous wave (CW) propagation loss measurements campaign and its prediction based on the path loss model at 2.17 GHz were carried out for two types of urban environments (Yeouid-do and Gangnam, two typical urban environments of Seoul, Korea). In the urban type I (Yeoui-do area), low buildings and high-rise buildings are mixed along boulevards and the average building height is 34 m. On the other hand, high-rise buildings are mostly located along boulevards while low buildings are located behind high-rise buildings in the urban type II (Gangnam area). The average building height is 12.2 m in the urban type II but about 440 buildings (about 5% of the total buildings) are higher than 30 m and about 90% of the total buildings are lower than 20 m. The street shapes of both environments are close to rectangular grids. The measured area for each environment was about 2 km × 2 km with transmitter (Tx) antenna as its center.

The Tx antennas were located on the top of building with heights of 48.7 m for Yeoui-do area and 54 m for Gangnam area. The receiving antenna was mounted on the top of the measurement van at the height of 2.6 m from the ground. Omni-directional antennas were used for both Tx and Rx. The input power to the transmitting antenna was fixed at 30 dBm. The measurement van moved at the speed of about 15 km/hr along street and the speed was slower than that depending on the traffic condition while signal strengths were recorded at the rate of a sample per a second.

The instantaneous CW power was obtained during measurement, but the local mean $\hat{m}(x)$ is calculated to compare with predictions using following equation [6], which is denoted as “running means”:

$$\hat{m}(x) = \frac{1}{2L}\int_{x-L}^{x+L} r(y)dy \qquad (1)$$

where $r(y)$ is the envelope of the signal, $2L$ the window length, respectively. In this study, the length $2L$ is chosen as 80λ (~11.6 m) to obtain the true local mean, which leads more than 3 samples to be included in computing the local mean.

3. Application of Existing Model

Generally, path loss is modeled as the sum of the free space path loss L_{bf}, the excess loss $L_{ex,1}$ due to terrain variation, $L_{ex,2}$ due to buildings and trees and gain G due to antenna heights as follows:

$$L = L_{bf} + L_{ex,1} + L_{ex,2} + G(h_b,h_m) \qquad (2)$$

where h_b and h_m are Tx and Rx antenna heights, respectively. Propagation along paths less than 1 km in urban is known to be affected primarily by buildings and trees rather than by terrain variation [5]. ITU-R P.1411 model is proper

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to describe path loss along short distances at the urban environment since it carefully considers the effects of buildings, street and antenna heights by $L_{ex,2}$.

The measurement frequency is outside of the range of the applicable frequency range of ITU-R P.1411 model (800 MHz–2 GHz). But the frequency difference of a few hundreds MHz at high frequency band results in small path loss difference as reported in the literature [7]. Therefore the measurement results at 2.17 GHz are also valid for comparison with the prediction results.

In this study, Tx antennas are on the top of building but there rarely exist line of sight (LoS) paths between Tx and Rxs. Therefore, NLoS ITU-R P.1411 model for propagation over rooftops could be applied and modified. The model is expressed as the sum of L_{bf}, the diffraction loss over roof-top of last building to street (L_{rts}) and the loss due to multiple diffractions past rows of buildings (L_{msd}) as follows:

$$L_{NLoS,1} = \begin{cases} L_{bf} + L_{rts} + L_{msd}, & L_{rts} + L_{msd} > 0 \\ L_{bf}, & L_{rts} + L_{msd} \le 0 \end{cases} . \quad (3)$$

$$L_{bf} = f(d, f_c),\ L_{rts} = f(w, \varphi, h_r, h_m, f_c)$$

$$L_{msd} = f(h_r, h_b, d, f_c, b)$$

In Eq. (3), d is distance between Tx and Rx, f_c carrier frequency, w street width, φ street orientation with respect to the direct path, h_r the average height of buildings, and b the average building separation, respectively.

In order to consider the variable heights of the buildings between Tx and Rx, the ITU-R P.1411 model recommended that it is preferred to replace the excess loss ($L_{rts} + L_{msd}$) by the knife-edge diffraction loss L_{ke}. In other words, when building height differences vary by much more than the 1st Fresnel zone radius over a path of length l, the path loss is expressed as the sum of L_{bf} and L_{ke} due to the highest building as follows [8]:

$$L_{NLos,2} = L_{bf} + L_{ke}$$

$$L_{ke} = f(h, \lambda, d_1, d_2) \quad (4)$$

where l denotes the length of the path covered by buildings between Tx and Rx. And h is the height of the top of the highest building above the straight line joining the Tx and Rx points, λ the wavelength of the carrier frequency, d_1 and d_2 the distance from Tx to the highest building and from the highest building to Rx, respectively. The radius of the 1st Fresnel ellipsoid at a point between A and B is given as follows [8]:

$$R_1 = \sqrt{\frac{\lambda d_a d_b}{d_a + d_b}} \quad (5)$$

where d_a and d_b are the distance from A to a point and from a point to B, respectively.

Therefore the mixed predicted path loss is expressed as follows:

$$L_{NLoS,3} = \begin{cases} L_{NLoS,1}, & h_{\max} \le h_r + R_{1,\max} \\ L_{NLoS,2}, & \text{else} \end{cases} \quad (6)$$

where h_{max} is the height of the highest building in the buildings existing along the direct path of Tx-Rx pair and $R_{1,max}$ the 1st Fresnel ellipsoid radius at the location of the highest building, respectively.

The existing ITU-R P.1411 model is applied to predict path loss of Tx-Rx pair in the following procedure. For each receiver position, find all building information along the direct path between Tx and Rx such as building height, space between buildings, the width of road, and etc. When considering the building height, Tx antenna height, and Rx antenna height, terrain height is included. And when the ITU-R P.1411 model is applied, the relative heights of h_m and h_b with respect to h_r, specifically Δh_m ($= h_r - h_m$) and Δh_b ($= h_b - h_r$) are used. Then, considering the condition of Eq. (6), path loss components such as L_{bf}, L_{rts}, L_{msd}, and L_{ke} are computed using obtained building information. Figure 1 shows the building information for a certain Rx point in the Yeoui-do area and the applied parameter values for prediction are described in Table 1. In Fig. 1, the dotted line is the 1st Fresnel ellipsoid over a path of length l according to the average building height h_r. The predicted path loss based on $L_{NLoS,1}$ and $L_{NLoS,2}$ are 185.17 dB and 146 dB, respectively. And the measured path loss at this point is 134.5 dB.

The measured and the predicted path losses are shown in Figs. 2(a), 2(b) for about 159 Rx points in the urban type I and in Figs. 2(c), 2(d) for 158 Rx points in the urban type II. Rx positions are randomly selected through the entire area for both types of environments. As shown in Fig. 1, the path loss is overestimated when only $L_{NLoS,1}$ is applied because when there is a very tall building between Tx and Rx, L_{rts} has large value due to the effects of the very tall building on the h_r and on Δh_b. In other words, there are some low build-

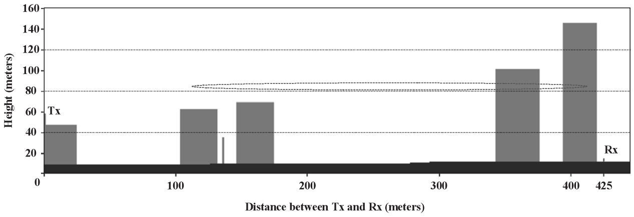


Fig. 1 A building profile between Tx and Rx in Yeoui-do area.

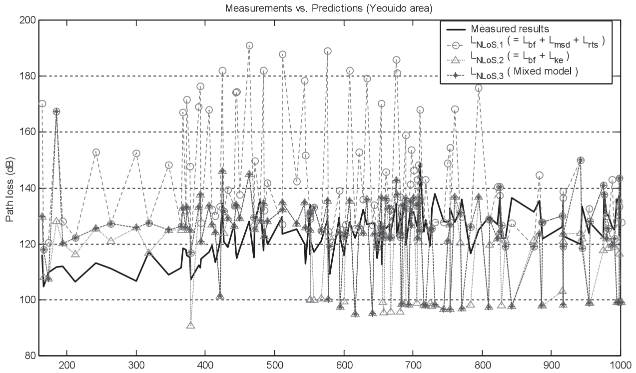
Table 1 The value of applied parameters for prediction.

(a) $L_{NLoS,1}$ model ($= L_{bf} + L_{msd} + L_{rts}$)

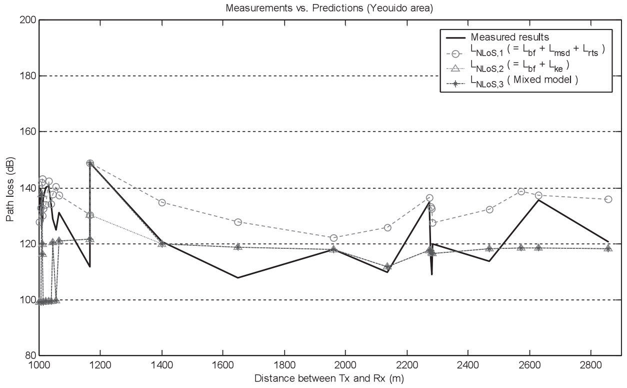
Parameter	d(m)	w(m)	φ(°)	h_b(m)	h_r(m)	h_{max} (m)	h_m(m)	b(m)	l(m)
Value	425	20	72.4	57.7	83.12	146	14.6	72.5	330

(b) $L_{NLoS,2}$ model ($= L_{bf} + L_{ke}$)

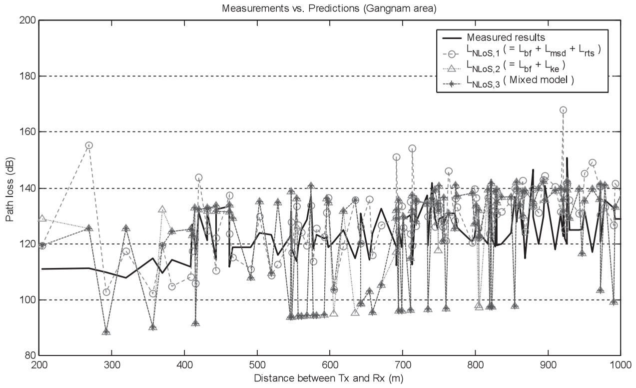
Parameter	d(m)	d_1(m)	d_2(m)	h(m)	v
Value	425	406.6	18.4	129.54	117.43



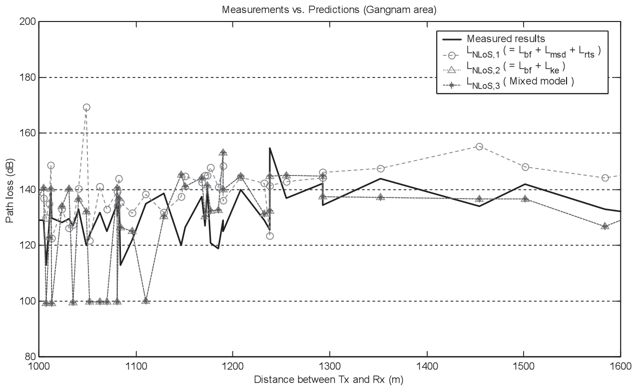
(a) Yeoui-do area (160–1000 m)



(b) Yeoui-do area (1000–2900 m)



(c) Gangnam area (200–1000 m)



(d) Gangnam area (1000–1600 m)

Fig. 2 Comparison of the measured and predicted path losses using existing prediction model.

Table 2 Statistics of prediction error before corrections.

		Average	Standard deviation	Max	Min
Yeoui-do area (Urban type I)	$L_{NLoS,\,1}$	–15.1 dB	19.1 dB	–65.0 dB	0.05 dB
	$L_{NLoS,\,2}$	7.0 dB	17.1 dB	–26.3 dB	0.04 dB
	$L_{NLoS,\,3}$	1.9 dB	17.2 dB	–55.4 dB	0.04 dB
Gangnam area (Urban type II)	$L_{NLoS,\,1}$	–5.7 dB	11.7 dB	–49.5 dB	0.09 dB
	$L_{NLoS,\,2}$	1.5 dB	17.0 dB	–25.5 dB	–0.03 dB
	$L_{NLoS,\,3}$	0.8 dB	16.5 dB	–25.5 dB	–0.03 dB

ings and one very tall building in real situation as Fig. 1, but there seem to exist some tall buildings in predicting the path loss based on $L_{NLoS,1}$. On the other hand, when only $L_{NLoS,2}$ is applied, the path loss is much underestimated. The reason will be commented in Sect. 4.

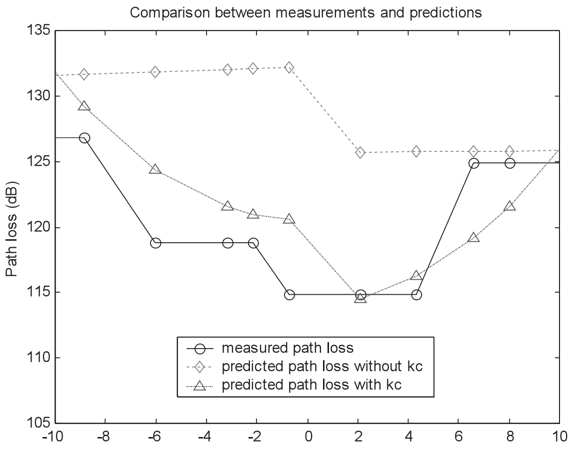
The prediction error statistics of the existing model is shown in Table 2.

4. Correction Factors

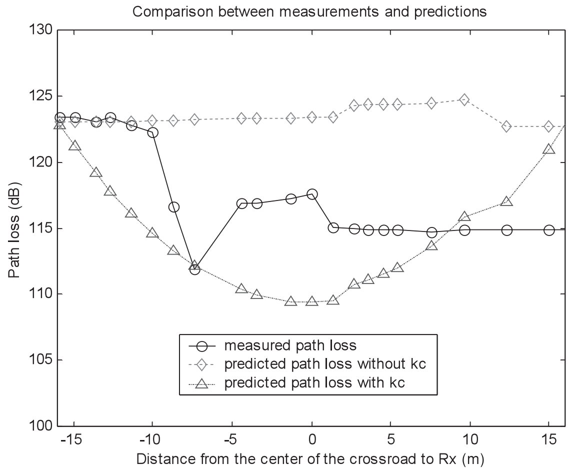
For some Rx positions, the difference between the measured path loss and the predicted path loss with the existing model is excessively large as shown in Fig. 2. Two major reasons for over/underestimation of path loss are identified to develop corresponding correction factors in this paper. For the first reason, when combining $L_{NLoS,1}$ and $L_{NLoS,2}$, building height differences between Tx and Rx is only considered. But the relationship between the Tx antenna height and the heights of the buildings existing between Tx and Rx is not considered. When h_b is larger than h_{max}, the parameter h of L_{ke} is very small or negative, which leads L_{ke} to be excessively underestimated. But in this case, since all low buildings have effects on the path loss, both the L_{rts} and L_{msd} must be considered. When there is only one building between Tx and Rx, the path loss must be predicted as the sum of free-space loss with L_{rts}, not L_{ke}. Therefore the mixed predicted path loss of Eq. (6) is changed as follows:

$$L_{NLoS,3} = \begin{cases} L_{NLoS,1}, & h_{\max} \le \max(h_r + R_{1,\max}, h_b) \\ L_{bf} + L_{rts}, & \text{only one builing is existed} \\ L_{NLoS,2}, & \text{else} \end{cases} \tag{7}$$

For the second reason, predicting the diffraction loss from roof-top of last building to street L_{rts}, only two principal rays were taken into account since other rays have fairly weak power to be neglected [9]. The principal rays are direct-diffracted ray and single-reflected ray by a building across the street. But when Rx is located on the crossroads, more rays having considerable power can reach to Rx from various directions. In example, those can be single-diffracted ray from the corner of buildings near to Rx and



(a) 17 m × 10 m crossroad. ($w_t = 10$ m)



(b) 47 m × 16 m crossroad. ($w_t = 16$ m)

Fig. 3 The effect of k_c.

other single-reflected rays by surrounding buildings. Thus, without considering these rays, the predicted path loss for Rx on the crossroads would be overestimated. Although the crossroad factor was suggested for the limited environment in the literature [10], the simple empirical crossroad factor k_c (dB) is suggested in this paper based on the difference between predictions and measured results. The measured results for Rx positions around crossroads are used in order to obtain the regression fit equation.

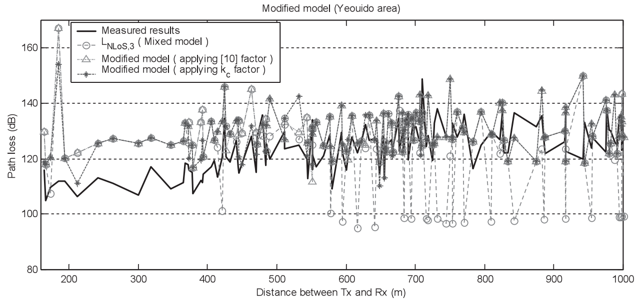
$$k_c = \begin{cases} \alpha d^2 + \beta, & -w_t \le d \le w_t \\ 0, & \text{elsewhere} \end{cases}$$

$$\alpha = -\beta / w_t^2$$

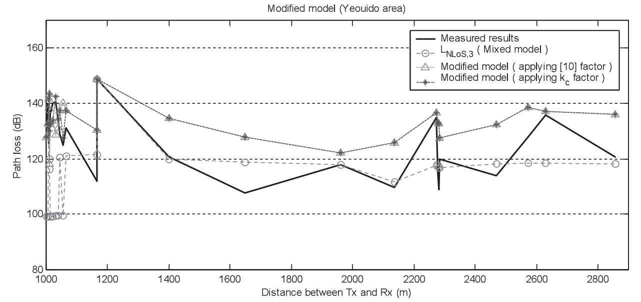
$$\beta = -0.018 \cdot w_t^2 + 0.85 \cdot w_t + 5 \qquad (8)$$

Where w_t ($5\,\mathrm{m} \le w_t \le 45\,\mathrm{m}$) is the width of the transversal street, where the Rx does not travel and d the distance from the center of the crossroad to Rx location, respectively. Figure 3 shows the effect of the correction factor k_c for two crossroads.

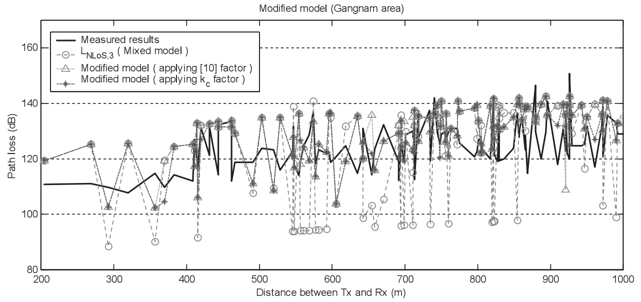
The prediction errors are reduced a lot after applying the modified prediction model as shown in Fig. 4. And the results after applying crossroad factor [10] instead of Eq. (8) are also plotted. Error statistics with the modified model is given in Table 3. Not only the error statistics but also the maximum error is enhanced after applying two correction factors.



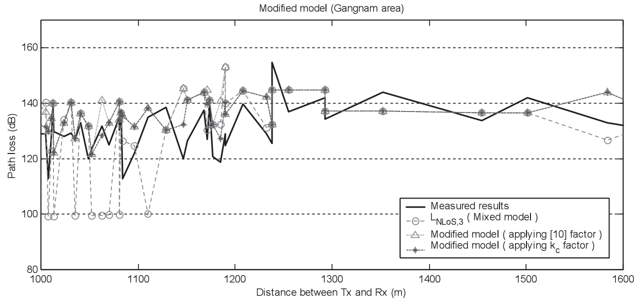
(a) Yeoui-do area. (160–1000 m)



(b) Yeoui-do area. (1000–2900 m)



(c) Gangnam area. (200–1000 m)



(d) Gangnam area. (1000–1600 m)

Fig. 4 Comparison of the existing and the modified path loss prediction model.

After applying the modified model to other Rx locations (about 3000) in the same area, the total average and standard deviation of errors are −5.36 dB and 12.4 dB, respectively.

Table 3 Statistics of prediction error after corrections.

		Average	Standard deviation	Max	Min
Yeoui-do area (Urban type I)	Only 1st correction factor	–7.3 dB	9.5 dB	–55.4 dB	–0.05 dB
	Only 2nd correction factor	3.4 dB	16.2 dB	–42.4 dB	0.04 dB
	Both two correction factors	–5.8 dB	8.7 dB	–42.4 dB	–0.05 dB
Gangnam area (Urban type II)	Only 1st correction factor	–5.7 dB	9.5 dB	–25.5 dB	–0.03 dB
	Only 2nd correction factor	2.0 dB	16.4 dB	–24.0 dB	–0.03 dB
	Both two correction factors	–4.4 dB	8.8 dB	–24.0 dB	–0.03 dB

5. Conclusion

In order to deploy wireless communication systems or to analyze the interference by other systems, the prediction of path loss between Tx and Rx is very important. ITU-R P.1411 model produces considerable prediction errors for some urban environment, although it works very well for simple urban environments. Therefore two correction factors for ITU-R P.1411 model are suggested to improve prediction accuracy of the path loss in non-uniform urban environment. The errors are improved on the standard deviation by about 8 dB.

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