Comparison between Path-Loss Prediction Models for Wireless Telecommunication System Design

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1. Introduction

For the cell design of mobile communication systems, the path loss prediction models are very important and have been studied for a long time. These models can be classified into theoretical and experimental models. The main experimental models are the Okumura-Hata, Cost231-Hata, and ITU-R model. The problem of these models is that these prediction expressions are based on the qualitative propagation environments such as urban, suburban, and open areas. The Cost231-Walfisch-Ikegami model (Cost231-WI) is a result of the effort to use a quantitative description of the propagation environments. In addition to the height of T_x and R_x antennas, the quasi-uniform building height and width of street are considered in this model. Recently, a mistake in formulating the Cost231-WI from the original Ikegami paper[3] was found[4]. The mistake happened due to the misunderstanding between reflection coefficient and reflection loss. We shortly comment on this in the main paper contents. For the more quantitative understanding of the propagation environment when Oukumura measured path losses near Tokyo, we compared the path losses of Cost231-Hata with those of Cost231-WI based on the same frequency(f=2000MHz, and 1500MHz), T_x and R_x antenna heights(h_b=40m and h_m=1.5m), but changing building height(10~25m) and street widths(20~25m). We also compared Okumura-Hata model with ITU-R model using the similar approach. Through such a parametric study, a quantitative propagation environment based on which Okumura curves were extracted is estimated.

2. Comparison between path-loss prediction models

1) Conversion between path loss and electric field at R_x end

In the far-field, the expression for received power are given by[1]

$$S = \frac{E^2}{Z_0}(W/m^2) \tag{1}$$

$$A_e = \frac{\lambda^2}{4\pi}D = \frac{\lambda^2 G}{4\pi\eta} \tag{2}$$

$$P_r = SA_e = \frac{E^2}{Z_0}\frac{\lambda^2 G}{4\pi\eta} = \frac{E^2 c^2 D}{4Z_0\pi f^2} \approx \frac{19E^2 D}{f^2}(W) \quad \text{(f expressed in MHz)} \tag{3}$$

where P_r, D, E, S, η, Z_0 and A_e are received power, directivity, rms electric field (V/m), power flux density(W/m^2), receiving antenna efficiency, intrinsic impedance(Ω), and antenna effective area(m^2).

P_r in dBw is given as follows

$$P_r(dBw) = 10\log P_r = 10\log\frac{19(E\cdot 10^{-6})^2 D}{f^2} \quad \text{(E expressed in } \mu\text{V)}$$

$$= 10\log 19 + 10\log D - 120 + E(dB(\mu V/m)) - 10\log f^2 \tag{4}$$

Thus, Pr in dBm is given by (5).

$$P_r(dBm) = -77.21 + E(dB(\mu V/m) + 10\log D - 10\log f^2 \tag{5}$$

By equating the general expressions for P_r(6) with (5), we obtain the conversion formula(7) between the path loss and electric field at Rx end assuming D=1.64.

$$P_r(dBm) = P_t G_t(dBm) - L(dB) \tag{6}$$

$$L = PtGt\,(dBm) + 75.06 - E(dB(\mu V/m)) + 20\log f \tag{7}$$

Assuming that the power of 1kW is radiated from a half-wave dipole, the conversion formula become (8).

$$L(dB) = 137.21 - E(dB(\mu V/m)) + 20\log f(MHz) \tag{8}$$

This conversion formula is used throughout the contents of this paper when necessary

2) Comparison between corrected Cost231-WI and Cost231-Hata

The Cost231-Walfisch-Ikegami model(Cost231-WI) presents a path-loss formula that considers diffraction and reflection of urban building groups. The expression used in Cost231-WI model for L_{rts} (Rooftop-to-street loss) is given by

$$L_{rts} = -16.9 - 10\log 10(W) + 10\log 10(f) + 20\log 10(\Delta h_m) + L_{ori} \quad (9)$$

where W, f, Δh_m, and L_{ori} are street width, frequency, difference between last building height and receiver height, and the street orientation factor, respectively. Fig. 1 illustrates these parameters appearing in (9). It was pointed out in [4] that the expression (9) accounting for L_{rts} was erroneously obtained. We shortly review this point as follows.

In the original Ikegami model [3], the received field E_r in Fig. 1 is given by

$$E_r = E_0 + 5.8 + 10\log(1 + \frac{3}{L_r^2}) + 10\log W - 10\log f - 20\log\Delta h_m - 10\log(\sin\Phi) \quad (10)$$

where Φ, E_r, E_0, and L_r is orientation angle, mean field strength received by a mobile antenna in decibel scale, mean field strength at the last rooftop in decibel scale, and reflection loss due to reflection of waves from buildings. Assuming that Φ is 90°, ($E_0 - Er$) is given by (11).

$$L_{E_0 - E_r} = E_0 - E_r = -5.8 - 10\log(1 + \frac{3}{L_r^2}) - 10\log W + 10\log f + 20\log\Delta h_m \quad (11)$$

If L_r is 0.5 in (11), the L_{rts} (9) and $L_{E0\text{-}Er}$ (11) are identical. However, the value of Lr =0.5 is an erroneous use of the definition of L_r in [3]. For the constant reflection loss Lr =6 dB in [3], Lr in (11) is '2' instead of '0.5' because L_r(relfection loss) in linear scale is just the inverse of $|\Gamma|$ (magnitude of reflection coefficient).

The paper also [4] verified mistake of L_{rts} of the Cost231-WI model using Felsen's model[5], in which, the diffraction loss L_F, for the case of w=W/2 (See Fig.1), is given by

$$L_f = -10\log[\frac{1}{r_1} D^2(\theta_1) + \frac{1}{r_2} |\gamma|^2 D^2(\theta_2)] \quad (12)$$

where

$$r_1 = \sqrt{w^2 + \Delta h_m^2} \qquad r_2 = \sqrt{(3w)^2 + \Delta h_m^2} \qquad D^2(\theta) = \frac{1}{2\pi k}(\frac{1}{\theta} - \frac{1}{2\pi + \theta})^2$$

$$\theta_1 = \tan^{-1}(\frac{\Delta h_m}{w}) \qquad \theta_2 = \tan^{-1}(\frac{\Delta h_m}{3w})$$

In above expression, Γ is the reflection coefficient as a function of incidence angle θ_2 and k is the propagation constant.

For the case of $\Delta h_m << w$, assuming $r_1 \approx w$, $r_2 \approx 3w$, $\theta_1 \approx (\Delta h_m/w)$, $\theta_2 \approx (\Delta h_m/3w)$ and $D^2(0) \approx (1/2\pi k\, \theta^2)$, (12) can be represented in the form of (13)

$$L_S = -10\log[\frac{1}{2\pi k}\frac{w}{\Delta h_m^2}(1 + 3|\gamma|^2)]$$

$$= -5.8 - 10\log W + 10\log f + 20\log\Delta h_m - 10\log(1 + 3|\gamma|^2) \quad (13)$$

For the case of $|\Gamma|$=0.5, $L_s = L_{E0\text{-}Er}$. L_S can be termed the simplified version of L_F

In Fig. 2, we plotted the difference of L_S and L_F changing the Δh_m and w to obtain the region of (Δh_m, w) where L_S can be used.

In Fig. 3, it is shown that with the allowable error of 1dB, L_S can be used instead of L_F as long as Δh_m is less than 4w. These regions seem to cover most of urban area.

Therefore, the L_{rts}, expressing the diffraction and scattering loss from the last rooftop to the street, can be finally given by (14)

$$L_{rts} = -8.23 - 10\log W + 10\log f + 20\log\Delta h_m + L_{ori} \quad (14)$$

In Fig. 4, for the case of h_b=50m, h_m=30m, W=50m, building height(h_{roof})=30m, and w=25m, we plotted the path losses as functions of frequency and distance using corrected Cost231-WI. They are 8dB greater than those given by the original Cost231-WI equation(15).

The Cost231-WI expression for overall path loss is given by (15)[2]

$$L_p = L_0 + L_{msd} + L_{rts} \quad (15)$$

where L_0 is the free-space loss, L_{rts} is the roof-to-street diffraction and scatter loss, and L_{msd} is the multi-screen diffraction loss.

The Cost231-Hata (extension of Okumura-Hata to cover frequencies up to 2000MHz) is given by (16) for urban area[2].

$$L = 46.3 + 33.9\log f - 13.82\log h_b - a(h_m) + (44.9 - 6.55\log h_b) \times \log d + 3 \quad (16)$$

In Fig. 5, we compared the path-losses of Cost231-Hata with those of Cost231-WI as a function of the distance d based on the same f=2000MHz, h_b=40m, h_m=1.5m, and W=20m with h_{roof} changing from 10m to 25m. The Cost231-Hata is close to Cost231-WI in case h_{roof}=10~15m.
In Fig. 6, we compared the path-losses of Cost231-Hata with those of Cost231-WI as a function of the distance d based on the same f=2000MHz, h_b=40m, h_m=1.5m, and W=50m with h_{roof} changing from 10m to 25m. The Cost231-Hata is close to Cost231-WI in case h_{roof}=20~25m.
In Fig. 7, we compared the path-losses of Cost231-Hata with those of Cost231-WI as a function of the distance d based on the same f=1500MHz, h_b=40m, h_m=1.5m, and W=50m with h_{roof} changing from 10m to 25m. The Cost231-Hata is close to Cost231-WI in case h_{roof}=25m.
From these parametric study, it is concluded that the Cost231-Hata is close to Okumura-Hata(including Cost231-Hata) when building group height is about the half of street width.

3) Comparison between Okumura-Hata(OH) and ITU-R model
Recently, the WP 3K-1,2 of ITU-R SG3 drafted a new recommendation, named 'Method for point to area predictions for the broadcasting, land mobile and terrestrial maritime mobile services and other applications in the frequency range 30 to 3000 MHz'. This recommendation presents field strength curves for the frequency range of 30MHz~3000MHz and distance range of 1~1000Km. For details can be taken from www.itu.int. These ITU-R curves are compared with OH to check what kind of propagation environment the ITU-R and based on.
In Fig. 8, the ITU-R field strength waves and compared with OH for suburban area in case f=100 MHz, and h_m=10m change h_b from 38m to 300m. They are shown to be in reasonally good agreement. We also performed comparisons for the frequency f=600, 2000MHz and could see that ITU-R curves are based on Okumura's suburban area.

3. Conclusion

After shortly reviewing the mistake that occurred in Cost231-WI, we compared the Cost231-Hata with the corrected Cost231-WI for a quantitative understanding of propagation environment when Okumura measured path losses near Tokyo. Parametric study shows that the Okumura-Hata(including Cost231-Hata) is close to Cost231-WI when building group height is about the half of street width. We also compared Okumura-Hata model with ITU-R model. From various parametric studies, It is shown that ITU-R curves are based on Okumura's suburban area.

Refrerences :

[1] Reinaldo Perez "Handbook of Electromagnetic Compatibility", Academic Press, pp 801-802
[2] Gordon L. Stuber "Principles of Mobile Communication" KAP 1996 pp. 99-101
[3] F. Ikegami, S. Yoshida, T. Takeuchi, and M. Umehira. "Propagation factors controlling mean field strength on urban streets." IEEE Trans Antennas Propagat., vol. 32, pp. 822-829
[4] Dongsoo Har, Alix M. Watson, and Anthony G. Chadney, "Comment on Diffraction Loss of *Rooftop-to-Street in* Cost231-Walfisch-Ikegami Model" IEEE Trans. Veh. Technol., vol pp. 1451-1452, Sep. 1999
[5] L. B. Felsen and N. Marcuvitz, "Radiation and Scattering of Waves". Englewood Cliffs, NJ: Prentice-Hall, 1973 pp. 652-665

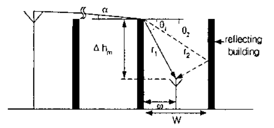

Fig. 1. Geometry for L_{rts}

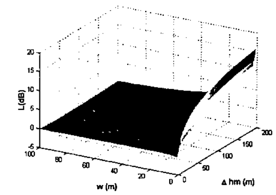

Fig. 2. Error ($|L_S-L_F|$) as functions of Δh_m and w

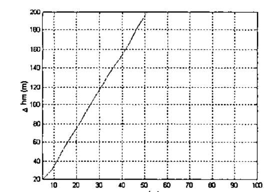

Fig. 3. Region of (Δh_m, w) where $|L_S-L_F|<1$dB

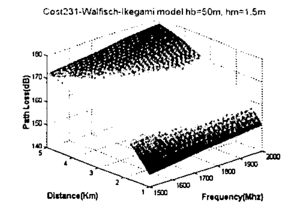

Fig. 4. Path-loss (corrected Cost231-WI) (h_b=50m, h_m=1.5m, h_{roof}=30m, W=25m)

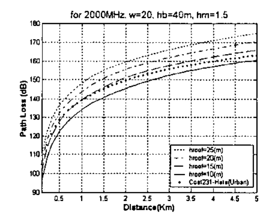

Fig. 5. Path-loss of corrected Cost231-WI and Cost231-Hata (2000MHz, h_b=40m, h_m=1.5m, W=20m)

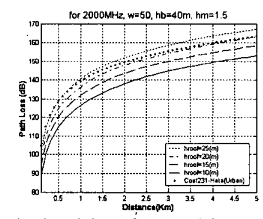

Fig. 6. Path-loss of corrected Cost231-WI and Cost231-Hata (2000MHz, h_b=40m, h_m=1.5m, W=50m)

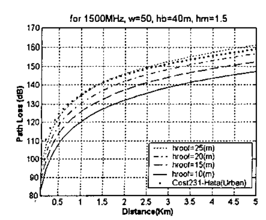

Fig. 7 Path-loss of corrected Cost231-WI and Cost231-Hata (1500MHz, h_b=40m, h_m=1.5m, W=50m)

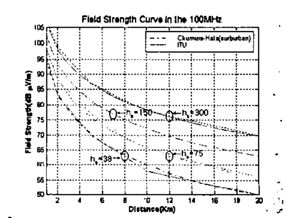

Fig. 8. . Field strength of Okumura-Hata and ITU-R (100MHz, h_m=10m)