Comparative Study of Path Loss Models for Wireless Mobile Network Planning

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ABSTRACT

Standard propagation models are based on extensive measurements and observations over a particular terrain. There is the need to examine the prediction error variations of the models over other environment in order to be useful in such areas. In this paper, the COST-231 Hata, Lee and COST-231 Walfisch-Ikegami path loss models were used as basis to analyze coverage prediction using signal strength measurement from a GSM network. This was conducted in the semi urban environment of Kano, Nigeria for nine base stations. The analysis of the data was used to obtain the prediction error statistics of the models. The results gave mean prediction error values of -5.2dB - 12.3dB and 4.3 dB for COST-231 Hata, Lee and COST-231 Walfisch-Ikegami path loss models respectively. These results show that on the average, the COST-231 Hata and Lee models under-predict the path loss. The COST-231 Walfisch-Ikegami models over-predict the path loss, but provide the best results for this urban environment.
Keywords: *Wireless mobile, GSM Network, path loss models.*

INTRODUCTION

Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds and optimization of radio resources. Empirical and semi-empirical propagation models have found favour in both research and industrial communities owing to their limited reliance on detailed knowledge of the terrain (Godara, 2002). Empirical propagation models predict path loss as a function of antenna height, gain, mobile station height, distance between transmitter and receiver etc. Semi-empirical path loss models on the other hand, considers in addition base station parameters and provides values for path loss due to radio wave propagation impairments. However, these models are formulated based on extensive studies and observations in different terrains. The effect of radio wave propagation impairments varies from one area to another (Mishra, 2004). There is the need to examine the path loss prediction error over other environments. This is even more important in urban areas where there are a lot of environmental clutters that affect signal propagation. The study of the path loss prediction behaviour will aid effective network planning and optimization of radio resources. The aim of this study is to determine the path loss prediction error statistics of an urban environment using the COST-231 Hata, Lee and COST-231 Walfish-Ikegami path loss models. The two empirical propagation loss models to be used in this analysis are the COST-231 Hata and Lee models, while the semi-empirical propagation loss model is that of the COST-231 Walfisch-Ikegami model.

COST-231 Hata Model is a popular model for predicting the path loss of mobile wireless systems of not more than 10km between the transmitter and receiver. The model was first described by Okumura et. al. (1968) and Hata (1980) for the prediction of path loss of land mobile radio of not more than 1500 MHz. It was later modified by the COST-231 project to include predictions of path loss up to 2000MHz and the provision of correction factors for urban, suburban and rural areas (Lee and Miller, 1998). The basic equation for path loss in dB is (Mishra, 2004):

$$L_P = 46.3 + 33.9\log(f_c) - 13.82\log(h_{bs}) - a(h_m)$$
$$+ [44.9 - 6.55\log(h_b)]\log(d) + C_m \quad \text{.......................................(1)}$$

$$a(h_m) = 3.2[\log(11.75h_m)]^2 - 4.97 \quad \text{.......................................(2)}$$

Where, f_c is the carrier frequency in MHz, is the distance between the base station and mobile station antennas in km. C_m is the area type correction factor defined as dB for urban areas.

Lee Model is another widely used empirical path loss prediction model in mobile wireless systems. It was first described using a base station height of 30.4m, carrier frequency of 900MHz, mobile station height of 3m, maximum distance between transmitter and receiver of 1.6km (Okumura et. al., 1968). The model provided correction factors that enabled other parameters to be included for path loss prediction. The set of equations that define this path loss model are (Lee 1980; Lee and Miller, 1998):

$$L_P = 124 + 30.51\log\left(\frac{d}{1.6km}\right) + 10n\log\left(\frac{f_c}{900MHz}\right) - \alpha_o \quad \text{..............................(3)}$$

Where, $\alpha_o = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$ ....(4)

$$\alpha_1 = \left[\frac{NewH_{BS}(m)}{30.48m}\right]^2 \quad \text{.......................................(5)}$$

$$\alpha_2 = \left[\frac{NewH_{MS}(m)}{3m}\right]^3 \quad \text{.......................................(6)}$$

$$\alpha_3 = \left[\frac{NewTransmitterPower(W)}{10W}\right]^2 \quad \text{.......................................(7)}$$

$$\alpha_4 = \left[\frac{NewBSG_A}{4}\right] \quad ....(8)$$

$$\alpha_5 = \text{New mobile station gain} \quad ....(9)$$

Where, H_{BS} and H_{MS} are the heights of base station and mobile station respectively in meters, BSG_A is the base station antenna gain in dBi and is defined as $3dB$ for f_c > 400MHz. d is the distance between the transmitter and receiver in meters, f_c is the carrier frequency in MHz and α_o is the correction factor.

COST-231 Walfisch-Ikegami Model is a semi-empirical path loss prediction model for mobile wireless systems of not more than 5km between the transmitter and receiver. The model consists of inputs from publications made by Walfisch *et al* (1988) which provided for the multiscreen diffraction loss and Ikegami *et al.* (1984) who considered an approximation for the roof top to street diffraction loss. The model was later modified by the COST-231 project to include correction factors for antenna heights. It can be used for path loss prediction of mobile wireless systems up to 2000MHz. The equations that define this path loss model are (Lee and Miller, 1998):

$$L_P = L_o + L_{rts} + L_{msd} \quad ....(10)$$

Where L_o is the path loss due to free space, L_{rts} is the rooftop to street diffraction and scatter loss and L_{msd} is the multi screen diffraction loss.

$$L_o = 32.44 + 20\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{d}{Km}\right) \quad ....(11)$$

$$L_{rts} = -16.9 - 10\log\left(\frac{w}{m}\right) + 10\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{h_{roof} - h_m}{m}\right) + L_{ori} \quad ....(12)$$

$$L_{msd} = L_{bsh} + K_a + K_d \log\left(\frac{d}{km}\right) + K_f \log\left(\frac{f_c}{MHz}\right) - 9\log\left(\frac{b}{m}\right) \quad ....(13)$$

Where, L_{ori} is the path loss due to the orientation angle and is defined as:

$$L_{ori} = \begin{cases} -10 + 0.354\frac{\varphi}{\deg} & 0^0 \le \varphi < 35^0 \\ 2.5 + 0.075\left(\frac{\varphi}{\deg} - 35\right) & 35^0 \le \varphi < 55^0 \\ 4.0 - 0.114\left(\frac{\varphi}{\deg} - 35\right) & 55^0 \le \varphi \le 90^0 \end{cases} \quad ....(14)$$

d is the distance between the transmitter and receiver in metres and f_c is the carrier frequency in MHz. *b*, *w* and h_m are the average buildings separation, average width of street and height of mobile station respectively in metres. $K_a = 54$ and $K_d = 18$.

$$L_{bsh} = -18\log(1+\Delta h_{bs}) \quad \text{..............................(15)}$$

$$K_f = -4 + 1.5\left(\frac{f_c}{925} - 1\right) \quad \text{..............................(16)}$$

MATERIALS AND METHOD

The signal strength measurement was carried out in Kano, Nigeria. The area consists of buildings whose average height is about nine floors (30m). The signal strength measurement was collected through drive tests with the aid of Ericsson Test mobile system (TEMS) around nine base stations of a GSM network at 900MHz. The height of the receiver was about 1.5m. The peak transmitter power of the base stations was approximately 47dBm (Ogundapo, 2008) The Path loss for each base station was computed using the COST-231 Hata, Lee and COST-231 Walfisch-Ikegami Path loss models. The mean differences between predicted and measured results was used to obtain the mean prediction errors (μ_e) for each base station. The standard deviation (σ_e) was computed using the mean prediction errors (μ_e).

RESULTS AND DISCUSSION

The results of the analysis are presented in the plots of Figures 1 to 9 for each base station (Ogundapo, 2008). It shows the comparison of the prediction errors for the three models examined. The plots in Figures 1 to 9 shows that the path loss models predicted slightly different values of path loss at some instances when compared to measured results, while providing large differences at other locations. This is due to the different radio wave propagation impairments at the base stations. The mean prediction error values of -0.7dB, -4.2dB and 8.9dB was obtained for the COST-231 Hata, Lee and COST-231 Walfisch-Ikegami path loss models respectively (Ogundapo, 2008). This indicates that on the average when compared to measured results, the COST-231 Hata and Lee path loss models generally under-predicts the path loss for this environment. The COST-231 Walfisch-Ikegami path loss model, on the other hand over-predicts the path loss for the environment when compared to the average measured results.

Table 1: Prediction Errors for Base Station 1

Base Stat	COST-231 Hata Model		Lee Model		COST-231 Walfisch-Ikegami Model	
1	-8.2	12.5	-14.8	18.3	-1.3	8.9
2	-8.3	7.2	-10.2	12.5	3.2	7.7
3	7.1	7.4	-7.3	10.0	6.3	10.6
4	13.2	15.8	5.8	9.0	25.0	28.2
5	-3.3	8.3	-10.7	13.2	8.7	12.6
6	-3.7	7.1	-11.4	13.5	7.9	10.9
7	-0.9	12.1	-6.8	13.3	12.5	19.0
8	8.8	10.7	1.5	4.0	20.5	23.6
9	-9.7	11.6	15.9	17.9	-2.9	6.2
Ave.	-0.7	10.3	-4.2	12.4	8.9	14.2

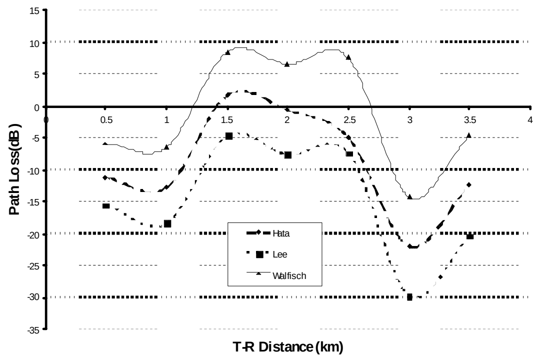

Figure 1: Prediction Errors for Base Station 1

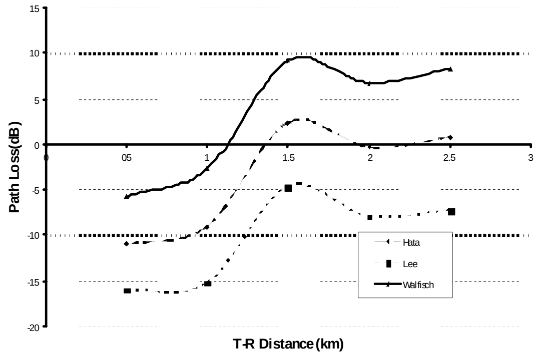

Figure 2: Prediction Errors for Base Station 2

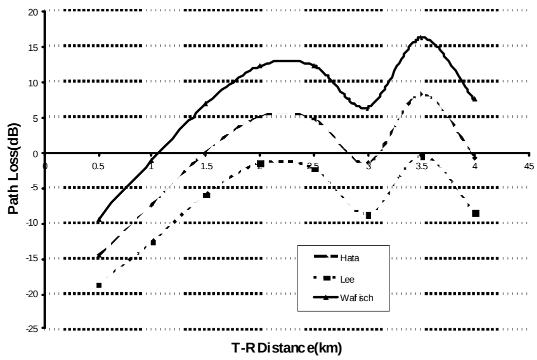

Figure 3: Prediction Errors for Base Station 3

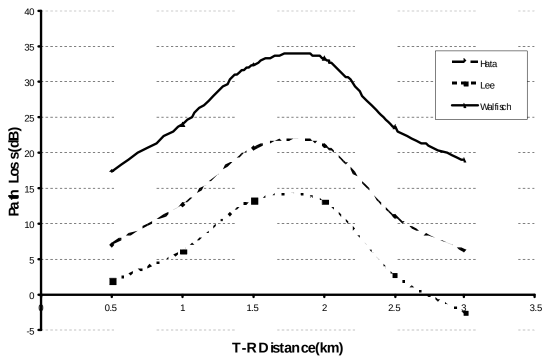

Figure 4: Prediction Errors for Base Station 4

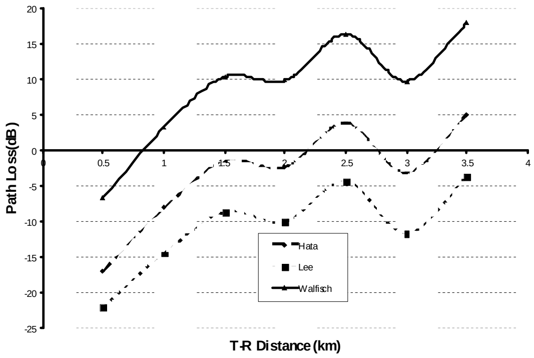

Figure 5: Prediction Errors for Base Station 5

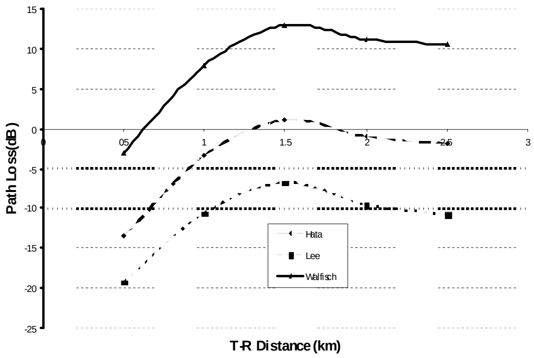

Figure 6: Prediction Errors for Base Station 6

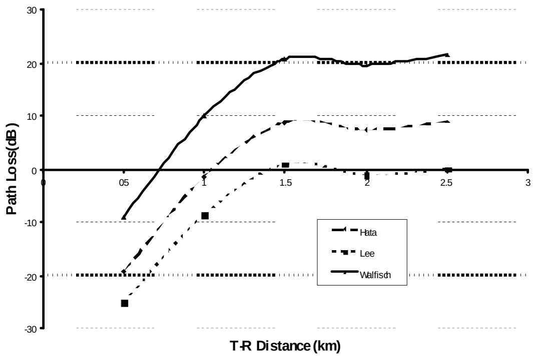

Figure 7: Prediction Errors for Base Station 7

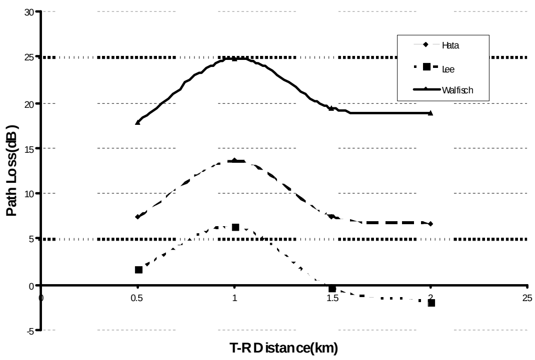

Figure 8: Prediction Errors for Base Station 8

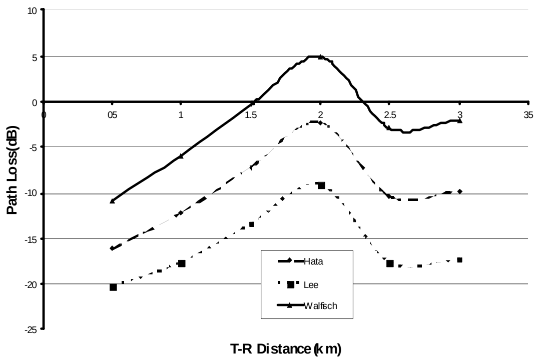

Figure 9: Prediction Errors for Base Station 9

CONCLUSION

This study was designed to determine the path loss prediction error statistics of an urban environment using the COST-231 Hata, Lee and COST-231 Walfish-Ikegami path loss models. The two empirical propagation loss models used in this analysis are the COST-231 Hata and Lee models, while the semi-empirical propagation loss model is that of the COST-231 Walfisch-Ikegami model. It provided the path loss prediction error variation of the two empirical and one semi-empirical path loss models over an urban environment. The path loss obtained from measurement result was compared against predictions made by the COST-231 Hata, Lee and COST-231 Walfisch-Ikegami respectively. On the average, the COST-231 Hata Model provided gives a better prediction of the environment.

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