Comparison Among Different Large Scale Path Loss Models for High Sites in Urban, Suburban and Rural Areas

Purno Mohon Ghosh, Md. Anwar Hossain, A. F. M. Zainul Abadin, Kallol Krishna Karmakar

***Abstract*—Radio propagation is essential for emerging technologies with appropriate design, deployment and management strategies for any wireless network. It is heavily site specific and can vary significantly depending on terrain, frequency of operation, velocity of mobile terminal, interface sources and other dynamic factor. Accurate characterization of radio channel through key parameters and a mathematical model is important for predicting signal coverage. Path loss models for macro cells such as Hata Okumura, Walfisch-Ikegami and Lee models are analyzed and compared their parameters. The received signal strength was calculated with respect to distance and model that can be adopted to minimize the number of handoffs. This paper proposes path loss models for high sites in urban, suburban and rural areas.**

***Index Terms*—Cellular mobile, Propagation model, Path loss, Received signal strength.**

I. INTRODUCTION

Propagation model predicts the mean received signal strength for an arbitrary transmitter-receiver separation distances as well as the variability of the signal strength in a close spatial proximity to a particular location are useful in estimating the radio coverage area of a transmitter, since they characterize signal strength over large T-R separation distance (several hundreds or thousands of meter). On the other hand Propagation models that characterizes the rapid fluctuation of received signal strength over very short travel distances are called small scale models. As a mobile moves over very small distances, the instantaneous received signal strength may fluctuate rapidly giving rise to small scale fading. The reason for this is that the received signal is a sum of many contributions coming from different directions. Propagation models are useful for predicting signal attenuation or path loss. This path loss information may be used as a controlling factor for system performance or coverage so as to achieve perfect reception [1]. 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. These models can be broadly categorized into three types; empirical, deterministic and stochastic. Empirical models are those based on observations and measurements alone. These models are mainly used to predict the path loss. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Stochastic models, on the other hand, model the environment as a series of random variables. These models are the least accurate but require the least information about the environment and use much less processing power to generate predictions [2].

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II. PATH LOSS MODELS

Path-loss models play an important role in the design of cellular systems to specify key system parameters such as transmission power, frequency, antenna heights, and so on. Several models have been proposed for cellular systems operating in different environments (indoor, outdoor, urban, suburban and rural). The long distance prediction models intended for macro-cell systems use base station and mobile station antenna heights and frequency. On the other hand, the prediction models for short distance path-loss estimation use building heights, street width, street orientation, and so on. These models are used for micro-cell systems. When the cell size is quite small (in the range of 10 to 100 m), deterministic models based on ray tracing methods are used. Thus, it is essential to select a proper path-loss model for design of the mobile system in the given environment [6]. Several empirical path loss models have been determined for macro cells. Among numerous propagation models, the following are the most significant ones, providing the foundation of mobile communication services. The empirical models are

i. Hata Okumura model
ii. COST 231 Walfisch-Ikegami model
iii. Lee's model

A. Hata-Okumura Model

Okumura analyzed path-loss characteristics based on a large amount of experimental data collected around Tokyo, Japan. He selected propagation path conditions and obtained the average path-loss curves under flat urban areas. Then he applied several correction factors for other propagation conditions, such as:

- Antenna height and carrier frequency
- Suburban, quasi-open space, open space, or hilly terrain areas
- Diffraction loss due to mountains
- Sea or lake areas
- Road slope

Hata derived empirical formulas for the median path loss (L_P) to fit Okumura curves. Hata's equations are classified into three models **[6]:**

1. *Typical Urban*

$$L_{P(urban)} = 69.55 + 26.16\log_{10} f_c + (44.9 - 6.55\log_{10} h_b)\log_{10} d - 13.82\log_{10} h_b - a(h_m)dB$$

where

$a(h_m)$ = correction factor (dB) for mobile antenna height as given by:

- For large cities

$$a(h_m) = 8.29[\log_{10}(1.54h_m)]^2 - 1.1, \qquad f_c \le 200MHz$$

$$a(h_m) = 3.2[\log_{10}(11.75h_m)]^2 - 4.97, \qquad f_c \ge 400MHz$$

- For small and medium-sized cities

$$a(h_m) = [1.1\log_{10}(f_c) - 0.7]h_m - [1.56\log_{10}(f_c) - 0.8]$$

2. *Typical Suburban*

$$L_{SU} = L_{P(URBAN)} - 2[\log_{10}(f_c/28)]^2 - 5.4$$

3. *Rural*

$$L_{P(rural)} = L_{P(URBAN)} - 4.78(\log_{10} f_c)^2 + 18.33\log_{10} f_c - 40.94$$

Where:

f_c = Carrier frequency (MHz)

d = distance between base station and mobile (km)

h_b = Base station antenna height (m)

h_m = Mobile antenna height (m)

The range of parameters for which the Hata model is valid is:

$$150 \le f_c \le 2200MHz$$
$$30 \le h_b \le 200m$$
$$1 \le h_m \le 10m$$
$$1 \le d \le 20Km$$

B. COST-231 Walfisch-Ikegami Model

The COST231 Walfisch-Ikegami model distinguishes between LoS and NLoS propagation. The model is accurate for carrier frequencies in the range $800 \le f_c \le 2000(MHz)$ and path distances in the range $0.02 \le d \le 5(Km)$.

LoS propagation: For LoS propagation in a street canyon, the path loss is

$$L_P(dB) = 42.6 + 26\log_{10}(d) + 20\log_{10}(f_c), \qquad d \ge 20m$$

Where the first constant is chosen so that L_P is equal to the free-space path loss at a distance of 20 m. The model parameters are the distance d (km) and carrier frequency $f_c(MHz)$ **[7].**

C. *Lee's Model*

Lee's path loss model was based on empirical data chosen as to model a flat terrain. Large errors arise when the model is applied to a non-flat terrain, however, Lee's model has been known to be more of a "North American model" than that of Hata. The received signal power in dBm is expressed as

$$\mu_\Omega = 10\log_{10}\left(\mu_{\Omega 0}\left(\frac{d_0}{d}\right)^\beta \left(\frac{f_c}{f}\right)^n \alpha_0\right)$$

Two parameters are initially required to characterize the model: $\mu_{\Omega 0}$ (the power at a 1.6 Km point of interception) and the path loss exponent β.

The following parameters must also be set:

f is the actual carrier frequency

d is the distance between mobile station and base station antennas

α_0 is a correction factor

the parameter α_0 is basically used to account for different BS and MS antenna heights, transmit powers, and antenna gains. For instance, if the actual conditions differ from the nominal ones, then α_0 is computed via:

$$\alpha_0 = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$$

Where

$$\alpha_1 = \left(\frac{new\ BS\ antenna\ hight\,(m)}{30.48\,(m)}\right)^2$$

$$\alpha_2 = \left(\frac{new\ MS\ antenna\ hight\,(m)}{3\,(m)}\right)^\xi$$

$$\alpha_3 = \left(\frac{new\ transmitter\ power}{10W}\right)^2$$

$$\alpha_4 = \frac{new\ BS\ antenna\ gain\ with\ respect\ to\ \lambda_c/2\ dipole}{4}$$

$$\alpha_5 = different\ antenna\ gain\ correction\ factor\ at\ the\ MS$$

The values of n and ξ are also based on empirical data and recommended to take the following values:

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$$n = \begin{cases} 2.0 & for\ f_c < 450\, MHz\ and\ in\ suburban/open\ area \\ 3.0 & for\ f_c > 450\, MHz\ and\ in\ urban\ area \end{cases}$$

$$\xi = \begin{cases} 2.0 & for\ MS\ antenna\ hight > 10\, m \\ 3.0 & for\ MS\ antenna\ hight < 3\, m \end{cases}$$

Finally, the path loss L_P is defined as the difference between the transmitted and received field strengths and can be expressed as:

$$L_P = P_t - \mu_{\Omega 0}\ dBm$$

The path loss obtained from Lee's model can be reduced to,

$$L_P(dBm) = \begin{cases} 89 + 43.5\log_{10}(\frac{r}{1.6\,Km}) + 10n\log_{10}(\frac{f}{900MHz}) - \alpha_0 & Rural \\ 101.7 + 38.41\log_{10}(\frac{r}{1.6\,Km}) + 10n\log_{10}(\frac{f}{900MHz}) - \alpha_0 & Suburbar \\ 110 + 36.81\log_{10}(\frac{r}{1.6\,Km}) + 10n\log_{10}(\frac{f}{900MHz}) - \alpha_0 & Urban \end{cases}$$

Where r is in Km and f is in MHz. It should be apparent that Lee's model is more generic and flexible than that of Hata's **[7]**.

III. RECEIVED SIGNAL STRENGTH

In mobile communication, received signal strength is a measurement of power present in a received radio signal. Signal strength between base station and mobile must be greater than threshold value to maintain signal quality at receiver [4]. Simultaneously signal strength must not be too strong to create more co-channel interference with channels in another cell using same frequency band. Handoff decision is based on received signal strength from current base station to neighboring base stations. The signal gets weaker as mobile moves far away from base station and gets stronger as it gets closer. The received signal strength for various path loss models like Hata Okumura model, Cost 231 Walfisch-Ikegami model and Lee's model are calculated as

Pr= Pt +Gt+Gr-PL - A

where,

Pr is Received signal strength in dBm,
Pt is transmitted power in dBm,
Gt is transmitted antenna gain in dB,
Gr is received antenna gain in dB,
PL is total path loss in dB and
A is connector and cable loss in dB.

IV. LIST OF SIMULATION PARAMETER

Base station transmitter power = 40dBm
Mobile transmitter power = 30dBm
Base station antenna height = 30m
Mobile antenna height = 1m
Transmitter antenna gain = 17.5dB
Threshold level for mobile = -95dBm
Threshold level for base station = -105 dBm
Frequency = 900 MHz
Connector loss = 2 dB
Cable loss =1.5 dB
Duplexer loss =1.5 Db

V. SIMULATION RESULT

Figure 1, 2 and 3 shows the path loss in accordance with distance using Hata, Lee and Walfisch-Ikegami models in urban, suburban and rural areas.

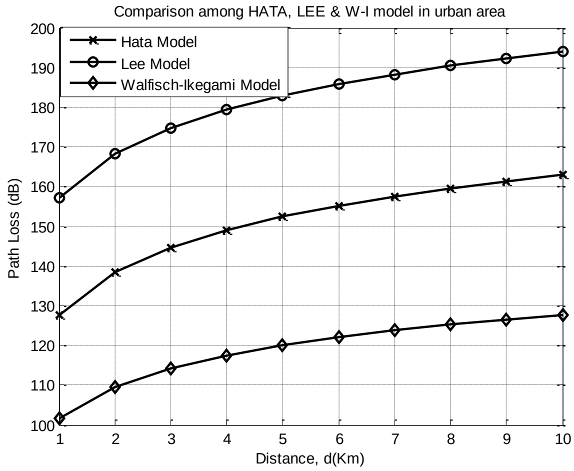

Figure 1: Comparison among Hata, Lee and Walficsh-Ikegami model in urban area.

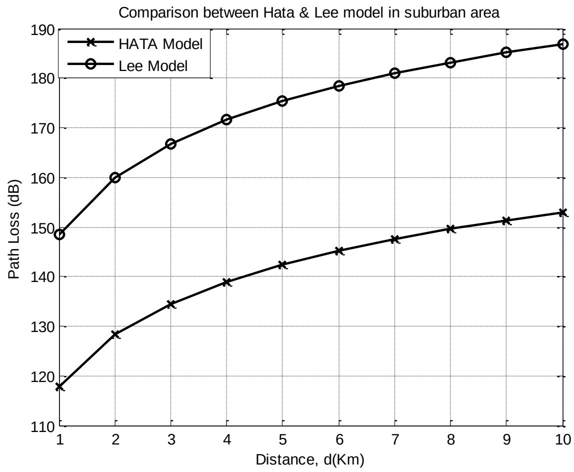

Figure 2: Comparison between Hata and Lee model in suburban area.

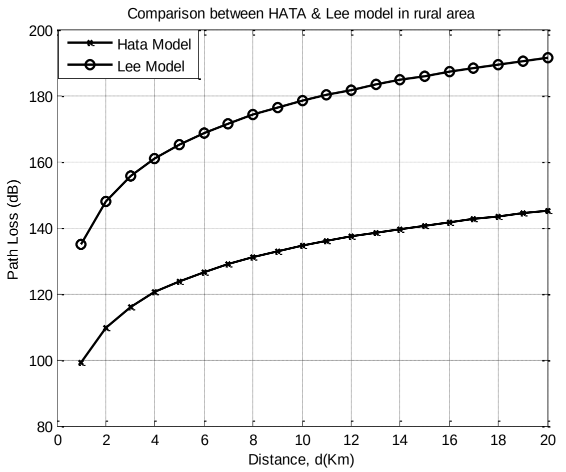

Figure 3: Comparison between Hata and Lee model in rural area.

Figure 4, 5 and 6 shows the received signal strength in accordance with distance using Hata, Lee and Walfisch-Ikegami models in urban, suburban and rural areas.

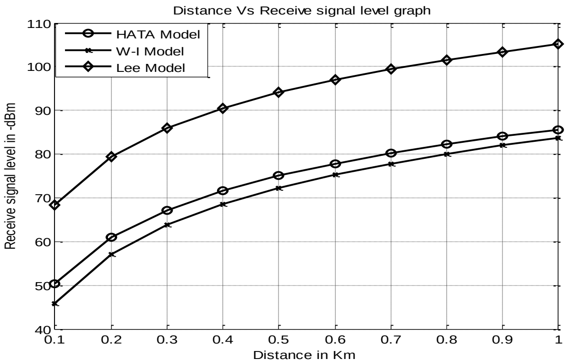

Figure 4: Received signal strength using Hata, Lee and Walficsh-Ikegami model in urban area.

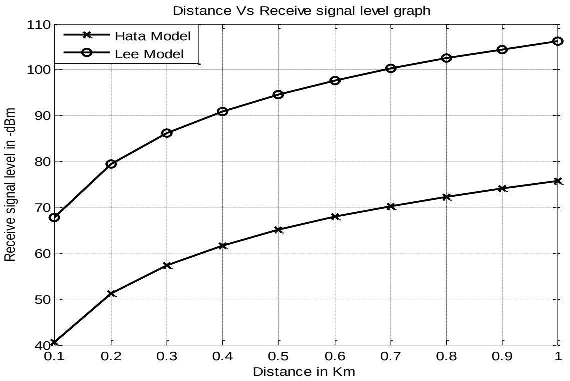

Figure 5: Received signal strength using Hata and Lee model in suburban area.

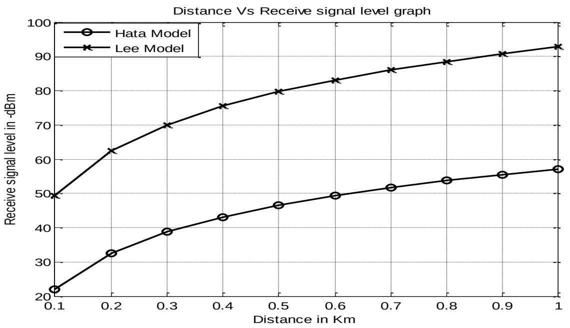

Figure 6: Received signal strength using Hata and Lee model in rural area.

VI. CONCLUSION

In this paper, different path loss models for macro cells in urban, suburban and rural areas were used and compared. Through the MatLab simulation it is observed that in urban area least path loss and maximum received signal at a particular distance is obtained by using Walfisch-Ikegami model. Similarly it is observed that path loss is minimum and received signal strength is maximum in suburban and rural areas using Okumura-Hata model. Therefore, we conclude that Walfisch-Ikegami model is suitable for urban area and Okumura-Hata model is for suburban and rural areas respectively.

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