Signal Strength Estimation and Comparison with Measured Signal Strength for Mobile Cellular Communication

Tilotma Yadav[1], Partha Pratim Bhattacharya[2]

***Abstract*— In wireless communication systems, path loss models are used to find out the path loss between transmitter and receiver. In this paper, Okumura, Cost-231, Hata, ECC 33 and SUI propagation models are discussed. Path losses are estimated using these models in urban, suburban and rural areas. The signal strength are then estimated in all the three environments and also compared with practical data. Comparison is done to find the best model which shows the closest value to the measured practical data.**

***Index Terms*— Propagation path loss models, mobile communication system.**

I. INTRODUCTION

Path loss models illustrate the signal attenuation between a transmitter and a receiver as a function of the propagation distance and other parameters. Some models consider details of the terrain profile to estimate the signal attenuation, whereas others just consider carrier frequency and distance. Antenna height is another essential parameter [1]. There is large scale, medium scale shadowing and small scale fading models on the variability of the signal strength. Large scale propagation models predict the mean signal strength for an uninformed transmitter-receiver (T-R) separation distance. These models are also useful in estimating the radio coverage area of a transmitter since they distinguish signal strength over large T-R separation distance. The propagation models that describe the rapid fluctuations of the received signal strength over very short travel distances or short time durations are called small scale models [2]. In this models field strength variations occur if the antenna is displaced over distances larger than a few tens or hundreds of meters are known as medium scale shadowing models.

II. PRPAGATION MODELS FOR COMMUNICATION

Few popular and effective propagation models are discussed below:

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A. Okumura Model

The Okumura model is an empirical model which works at several frequencies having the range of 150 MHz to 1920 MHz [2]. It is the most broadly used model in large urban macro cell for signal prediction over distances of 1 km to 100 km and it is extrapolated up to 3000 MHz [3]. The range of base station antenna heights is 30 m to1000 m and a mobile antenna height of 5 m. Path loss is expressed as:

$$L_{50}(dB) = L_f + A_{mu}(f,d) – G(h_{te}) – (h_{re}) - G_{area} \quad (1)$$

where L_{50} is the 50th percentile value of propagation path loss. L_f is the free space propagation loss and given by the formula:

$$L_f = 20*\log(\lambda /4\pi d) \quad (2)$$

Where, d is the distance between transmitter and receiver, A_{mu} is the median attenuation relative to free space, $G(h_{te})$ is the base station antenna height gain factor, $G(h_{re})$ is the mobile antenna height gain factor and G_{area} is the gain due to the type of environment. To determine the path loss using Okumura model, firstly free space path loss between the points of interest is determined [4]. The values of G_{area} and A_{mu} are obtained from empirical plots. $G(h_{te})$ and $G(h_{re})$ are given by the formula as below :

$$G(h_{te})= 20*\log(h_{te}/200) \qquad 1000\text{ m} > h_{te} > 30\text{ m} \quad (3)$$

$$G(h_{re})=10*\log(h_{re}/3) \qquad h_{re} < 3\text{ m} \quad (4)$$

$$G(h_{re})=20*\log(h_{re}/3) \qquad 3\text{ m} < h_{re} <10\text{ m} \quad (5)$$

Furthermore, it is found by Okumura that $G(h_{te})$ varies at a rate of 20dB/decade and $G(h_{re})$ varies at a rate of 10dB/decade for receiver antenna heights less than 3 m.

Correction factors concurrent to terrain are also developed [4] that increase the model accuracy. Okumura model has a 10-14 dB standard deviation between path loss predicted by the model. This model is entirely based on the measured data and does not give any analytical explanation. This model served as a base for the Hata model. The major negative aspect of this model is its slow response to quick changes in terrain therefore the model is best in urban and suburban areas, but not as good in rural areas.

B. Hata Model

Hata model is the tentative formulation of path loss data provided by the Okumura model. It is based on the Okumura's test field results. It is generally liked in Europe and North America and developed by the Y. Okumura and M. Hata at Japan in 1968 [5]. This model is used up to the frequency range of 150MHz to 1500 MHz. The standard formula for median path loss is as follows in urban areas:

$$L_{50}(urban)(dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9-6.55 \log h_{te})(\log d) \quad (6)$$

where, f_c is the frequency in MHz from 150 MHz to 1500 MHz, h_{te} is the effective transmitter (base station) antenna height in meters in between 30 m to 200 m, h_{re} is the effective receiver (mobile) antenna height in meters ranging from 1m to 10 m, d is the distance between the transmitter and receiver in km and $a(h_{re})$ is the correction factor for effective mobile antenna height based on the coverage area size.

Hata equations for path loss are classified in three modes:

1. Rural area: open space and no tall buildings or obstacles in path.
2. Suburban areas: village highway with trees and not very congested, some obstacles around house.
3. Urban areas: built up city and large area with buildings and houses [5].

Now the correction factor is given for different areas:

For small to medium sized city:

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8) \text{ dB} \quad (7)$$

For a large city it is defined for two frequency ranges.
For $f_c \leq 300$MHz, it is defined as

$$a(h_{re}) = 8.29(\log 1.54h_{re})^2 - 1.1 \text{ dB} \quad (8)$$

and

for $f_c \geq 300$MHz, it is given as

$$a(h_{re}) = 3.2(\log 11.75h_{re})^2 - 4.97 \text{ dB} \quad (9)$$

The path loss is defined for two different areas as follows:
For suburban area, the path loss is given by

$$L_{50}(dB) = L_{50}(urban) - 2[\log (f_c/28)]^2 - 5.4 \quad (10)$$

and for open rural areas, it is given by

$$L_{50}(dB) = L_{50}(urban) - 4.78(\log f_c)^2 + 18.33\log f_c - 40.9 \quad (11)$$

Hata model gives the best results for first generation cellular systems but not for personal communication system It does not propagate well in cellular systems having smaller size [6]. Hata's model does not supply for any of the path specific correction factors as available in Okumura model [7].

C. Cost – 231 Model

It is the PCS extension to the Hata model which is developed by the European cooperative for scientific and technical research (EURO-COST) and extended Hata model up to 2 GHz. It is mostly used for determining the path loss in mobile wireless system in frequency range from 500 MHz to 2000 MHz. Although its frequency range is outside that of the measurements, its simplicity and presence of correction factors has been used for path loss prediction [8]. The path loss equation is given as:

$$PL(dB) = L_{50}(urban) = 46.3+33.9 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9-6.55 \log h_{te}) \log d + c_m \quad (12)$$

Where, $a(h_{re})$ is defined for urban areas as:

$$a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.97 \text{ dB} \quad (13)$$

f being the frequency in MHz between 1500 MHz to 2000 MHz, d is the separation between AP and CPE antennas in km ranging from 1 km to 20 km, h_{te} is the AP antenna height above ground level in meters from 30 m to 200 m and h_{re} is the CPE antenna height in meters from 1 m to 10 m.
The parameter c_m is defined for two environments as follows:

c_m = 0 dB for suburban areas

= 3 dB for urban areas (14)

This model has a limitation that it requires the base station antenna is higher than the all adjacent rooftops.

D. ECC-33 model

The model is developed from original measurements by Okumura and given by the Electronic Communication Committee is known as ECC-33 path loss model. In this its assumptions are modified so that it closely represents a fixed wireless access system [8]. The path loss for the model is given as:

$$PL(dB) = Af_s + Ab_m - G_t - G_r \quad (15)$$

where Af_s is the free space attenuation, Ab_m is the basic median path loss, G_t is the base station antenna height gain factor, G_r is the received antenna height gain factor.
These parameters are individually defined as,

$$Af_s = 92.4 + 20 \log (d) + 20 \log (f) \quad (16)$$

$$Ab_m = 20.41 + 9.83 \log (d) + 7.894 \log (f) + 9.56 [\log f] \quad (17)$$

and

$$G_t = \log (h_b/200) [13.98+5.8 (\log d)^2] \quad (18)$$

For median city environments, G_r is given as

$$G_r = [42.57+13.7 \log f] [\log h_m - 0.585] \quad (19)$$

Where, f is the frequency in GHz, d is the distance between base station and mobile station in km, h_b is the base station antenna height and h_m is the mobile station antenna height in meters.

For European cities the medium city model is more appropriate. It is to be noted that the predictions formed by the ECC-33 model do not lie on straight lines when plotted against distance having a log scale [8].

E. SUI Model

After developing the standards for fixed wireless access systems by IEEE working group 802.16 at forefront of developing technical standards for frequency bands above 11 GHz, they paid a little attention towards the frequency bands below 11 GHz. They proposed the channel models for frequency band below 11 GHz and the models are known as SUI (Stanford University Interim) models as name indicates that the models developed by the Stanford University [9]. These models are derived for Multipoint microwave distribution system (MMSD) in the frequency range from 2.5 GHz to 2.7 GHz [3]. These SUI models are categorized into three types of terrains namely terrain A, terrain B and terrain C. Terrain A is the hilly area with medium to very large tree densities in which the path loss is maximum. Terrain C is the flat or open area with light tree densities having minimum path loss category. Terrain B is categorized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities [10]. The basic path loss equation is given as:

$$PL= A+10\,\gamma \log_{10}[d/d_0] + X_f + X_h + s \quad \text{for } d > d_0 \tag{20}$$

Where, d is the distance between access points and customer premises equipment antennas in metres, d_0 is 100 m, s is a log normally distributed factor that is used to account for the shadow fading owing to trees and other clutter and has a value between 8.2 dB and 10.6 dB. The other parameters are as follows:

$$A= 20 \log_{10} (4\pi\, d_0 / \lambda) \tag{21}$$

And

$$\gamma= a- bh_b+ c/h_b \tag{22}$$

where, h_b is the base station height above ground in meters and the range is from 10 m to 80 m. The constants used for a, b and c are given in table 1.

Table 1: Numerical values for SUI model parameters

Model parameter	Terrain A	Terrain B	Terrain C
A	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The correction factors for the operating frequency and for the CPE antenna height for the model are given as:

$$X_f = 6.0 \log_{10}(f/2000) \tag{23}$$

and

$$X_h = -10.8 \log_{10}(h_r/2000) \quad \text{for terrain types A and B} \tag{24}$$

$$= -20.0 \log_{10} (h_r/2000) \quad \text{for terrain type C} \tag{25}$$

Where, f is the frequency in MHz and h_r is the CPE antenna height above ground in meters. The SUI model is suitable for determining the path loss in all three environments namely rural, suburban and urban.

III. PATH LOSS ESTIMATION AND COMPARISON WITH PRACTICAL DATA

Path loss are estimated at 950 MHz for different path loss models like Okumura, Hata, ECC 33, Cost-231 and SUI models in urban, suburban and rural.

The transmitted power is considered as 43 dBm. The measured data is taken from three different areas namely Shakti Nagar, Rewari (urban), Kanina Town, Mohindergarh (suburban) and Duloth Ahir, Mohindergarh (rural). The practical received signals are taken upto 4.5 km. The antenna heights are taken as 35 meters for rural area, 37 meters for suburban area and 25 meters for urban area. Measured data are taken with the help of TEMS software.

The signal strength obtained from the propagation models are compared with practical data for all above environments. The variation of signal strength with distance is shown in figures below and comparison also shown.

From figure 1, it is shown that practical data has the highest signal strength and Hata model lie near to it. There is a slight variation of signal strength in between Hata and Cost-231 model but Hata model has the highest signal strength. So, it is concluded that in urban area, Hata model gives best results nearest to the practical value.

Figure2 shows the signal strength comparison in rural area. It is seen from the figure that Hata model has the highest signal strength nearest to the practical data.

The signal strength comparison with practical data in suburban area is shown in figure 3. It shows the highest signal strength of Hata model closely to the practical data. So, it is concluded that Hata model gives the best results.

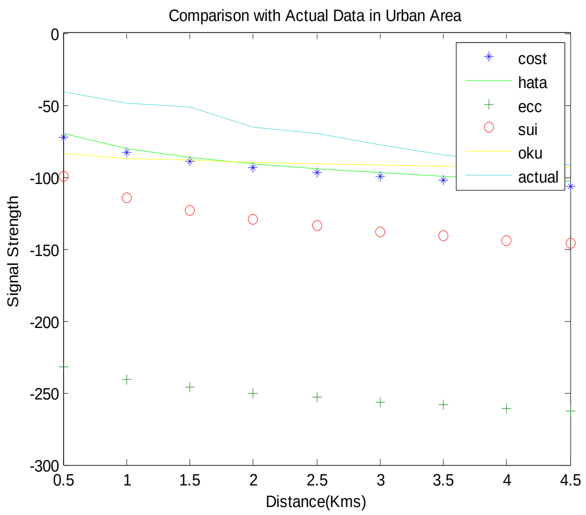

Fig. 1 Signal Strength Comparison in Urban Area

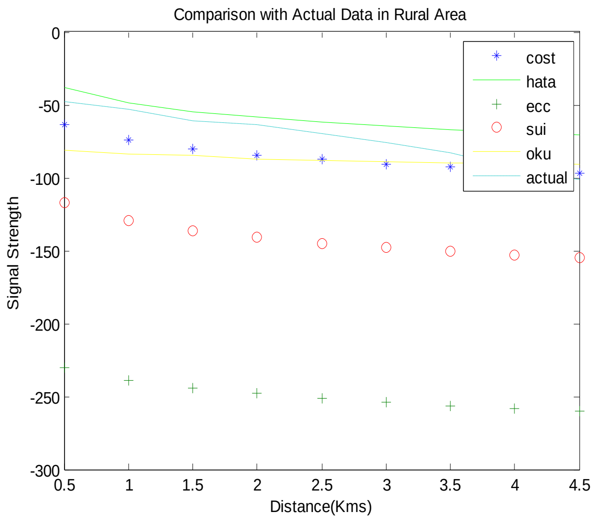

Fig. 2 Signal Strength Comparison in Rural Area

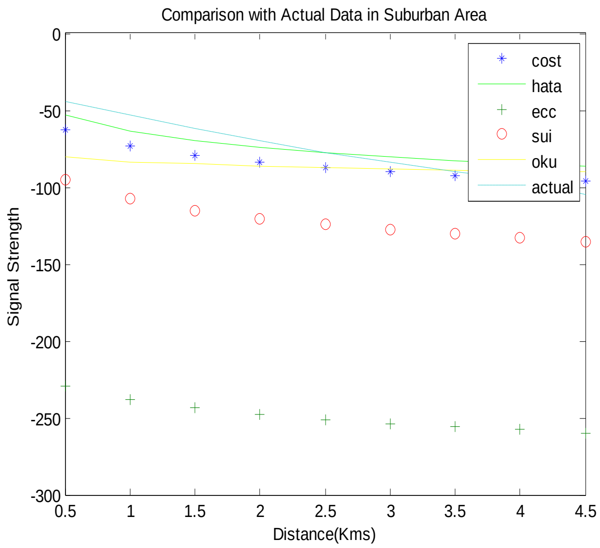

Fig. 3 Signal Strength Comparison in Suburban Area

III. CONCLUSION

In this paper, different path loss models are discussed. Path loss and signal strength are estimated at 950 MHz and compared with practical data. From the results, it can be concluded that Hata model closely estimates practical data in urban, rural and suburbanareas. So, it is the most suitable model for signal strength prediction in all environments.

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