Performance Analysis of Propagation Models for Cellular Mobile Communication Systems at 2.5 GHz

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Abstract— In wireless communication systems, transfer of information between the transmitting antenna and the receiving antenna is achieved by means of electromagnetic waves. Furthermore, the interaction between the electromagnetic waves and the environment reduces the signal strength which is sent from transmitter to receiver, that causes the path loss. There are several propagation models which can precisely calculate the path loss. In this paper various propagation models (COST 231 Hata Model, Stanford University Interim (SUI) Model and Ericsson Model) are compared and analyzed. These propagation models have been proposed for operating frequency at 2.5 GHz for different receiver antenna heights in all types of the environments (urban, suburban and rural) by using MATLAB Software. It was noticed from the results of the path loss estimation for 4 m and 8 m receiver antenna heights in suburban area that SUI model showed the lowest path loss result (119 dB in 4 m receiver antenna height) as compared with the other models in suburban environment. On the contrary, Ericsson model showed the highest path loss result (183 dB in 4 m receiver antenna height) as compared with the other models in rural environment. Also, COST 231 Hata model showed the highest path loss result (159 dB in 4 m receiver antenna height) as compared with the other models in urban environment. Moreover, it was mentioned that SUI model showed the lowest path loss result (119 dB in 4 m receiver antenna height) as compared with the other models in all types of the environments (urban, suburban and rural). Furthermore, it can be realized that SUI model is extensively used to predict the path loss in all types of terrain (urban, suburban and rural).

Index Terms— COST 231 Hata Model, Ericsson Model, Path Loss, Stanford University Interim (SUI) Model, Types of terrain.

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1 INTRODUCTION

Wireless communication is a telecommunication technology which enables wireless transmission between the portable devices to provide wireless access in urban, suburban and rural environments. Moreover, attention should be paid to the fact that the propagation models are extensively used to evaluate the path loss in wireless communication for different types of environments. Furthermore, propagation models can be grossly categorized into three types :

1. Empirical Models.
2. Deterministic Models.
3. Statistical Models.

Empirical models are those based on observations and measurements. These models are mainly used to predict the path loss. Also, empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [1], [2]. An example of time dispersive is the Stanford University Interim (SUI) channel models which developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group [3]. On the other hand, COST 231 Hata model is an example of non-time dispersive empirical models [4]. The deterministic models make use of the laws governing the electromagnetic wave propagation to determine the received signal power at a specific location. Deterministic models often require a complete 3-D map of the propagation environment. An example of a deterministic model is a ray tracing model [5]. On the contrary, statistical models behave as a series of random variables. In spite of these models are the least accurate, they require the least information about the environment and use much less processing power to generate predictions. Propagation models play a major role in planning of wireless cellular systems. Moreover, they represent a set of mathematical equations and algorithms that are used for radio signal propagation prediction in specific regions. Path loss calculation is one of the major factor that we have to estimate. Furthermore, path loss can be defined as the ratio of the transmitted to received power, usually expressed as the following form in decibels, [6]:

$$PL(d) = PL(d_0) + 10n\log_{10}(\frac{d}{d_0}) \qquad (1)$$

Where :
d is the distance.
d_0 is the reference point at 1km.
n is the path loss exponent.

We have to note that for free space loss the path loss exponent is equal to two. Moreover, the path loss exponent is valuable since it shows the rate of increasing of the path loss with respect to distance.

2 TYPES OF PROPAGATION MODELS

It is necessary to estimate the propagation characteristic of a system through a medium so that the signal parameters can be more accurate in mobile system. Propagation analysis is very important in evaluating the signal characteristics. For wireless communication system, the system should have the ability to predict the accurateness of the radio propagation behavior. Propagation models have been developed as low cost, convenient, alternative and suitable way. Channel modeling is essential for characterized the impulse response and to predict the path loss of a propagating channel. Path loss models are important to design base stations, that can be estimated us to radiate the transmitter for service of the certain region. Furthermore, It is very important to have the knowledge about the electromagnetic environment where the system is operated, and the location of the transmitter and receiver. Propagation models are used widely in wireless communication, mainly for conducting feasibility studies and during the deployment. There are different types of propagation models which can precisely calculate the path loss in different environments (urban, suburban and rural). This research focused on (COST 231 Hata, SUI and Ericsson) propagation models.

2.1 COST 231 Hata Model

A model that is widely used for predicting path loss in mobile wireless system is the COST 231 Hata model [4,6]. The COST 231 Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz. It was devised as an extension to the Hata-Okumura model [7], [8]. Also, it contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band. The basic equation for path loss in dB is, [6], [9] :

$$PL = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - a h_m + (44.9 - 6.55 \log_{10}(h_b)) \log_{10} d + c_m \qquad (2)$$

Where :

f is the frequency in MHz.
d is the distance between the Access Points (AP) and the Customer Premises Equipment (CPE) antennas in km.
h_b is the AP antenna height above ground level in metres.

Moreover, the parameter cm is defined as 0 dB for suburban or open environments and 3 dB for urban environments. The parameter a h_m is defined for urban environments as [1] :

$$_a h_m = 3.20(\log_{10}(11.75/5hr)^2 - 4.97 \quad \text{for f >400 MHz} \qquad (3)$$

Also, it is defined for suburban and rural (flat) environments as [1] :

$$_a h_m = 1.1(\log_{10}(11.75/5hr)^2 - 4.97$$

$$a h_m = (1.1 \log_{10} f - 0.7) h_r - (1.56 \log_{10} f - 0.8) \qquad (4)$$

Where :

h_r is CPE antenna height above the ground level in meters.

By focusing on (2) to (4), it has been found that the path loss exponent of the predictions which made by COST 231 Hata model is given as :

$$_a h_m = 3.20(\log_{10}(11.75/5hr)^2 - 4.97$$

$$N_{COST\ 231} = (44.9 - 6.55 \log_{10}(h_b))/10 \qquad (5)$$

2.2 Stanford University Interim (SUI) Model

The frequency band below 11GHz use the channel model which is proposed by Stanford University called SUI model. These models are derived for the Multipoint Microwave Distribution System (MMDS) frequency band from 2.5 GHz to 2.7 GHz. The model covers three most common terrain categories. The SUI models are divided into three types of terrains, namely A, B and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities. The basic path loss equation with correction factors is presented in [3], [10] as :

$$PL = A + 10\gamma \log_{10}\{d/d_0\} + X_f + X_h + s\ , \text{ for } d > d_0 \qquad (6)$$

Where :

f is the frequency in MHz.
d is the distance between AP and CPE antennas in meters.
d_0 = 100 m.
X_h is the correction for receiving the antenna height in meters.
γ is the path loss exponent.
X_f is the correction for frequency in MHz.
S is the correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of tress and other clutter on the propagation path [6].

The parameter A is calculated by [6], [11] :

$$A=20 \log_{10}(4\pi d_0\ /\lambda) \qquad (7)$$

Also, the pat loss exponent γ is computed by [1] :

$$\gamma = a - b h_b + (c\ /\ h_b) \qquad (8)$$

Where :

λ is the wavelength in meters.
h_b is the base station antenna height above the ground which measured in metres and its value should be between 10 m and 80 m.

The constants a, b and c depend on the types of terrain which are given in Table 1, also the value of the parameter $\gamma > 5$ for indoor propagation, $3 < \gamma < 5$ for urban environment and $\gamma = 2$ for free space propagation in urban environment [11].

TABLE 1
Parameter values of SUI Model for different types of Terrain [11]

Parameter Model	Terrain A	Trrrain B	Terrain C
a	4.6	4	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The correction factor for receiving the antenna height X_h and the correction factor for operating frequency X_f for the SUI Model are given by [6] :

$$X_h = -20\log_{10}(h_r/2000), \text{ for terrain type C} \qquad (9a)$$

$$X_h = -10.8 \log_{10}(h_r\ /\ 2000)\ , \text{ for terrain type A and B} \qquad (9b)$$

$$X_f = 6\log_{10}(f/2000) \qquad (10)$$

Where :

f is the frequency in MHz.
h_r is the receiver antenna height above the ground level in meters.

2.3 Ericsson Model

The network planning engineers are used a software provided by Ericsson company is called Ericsson model [11]. This model also stands on the modified Okumura-Hata model to allow the room for changing in parameters according to the propagation environment. The path loss calculation of the Ericsson model is done by using the following equation, [11] :

$$PL = a_0 + a_1 . \log_{10}(d) + a_2 . log_{10}(h_b) + a_3 . log_{10}(h_b) . log_{10}(d) - 3.2[log_{10}(11.75 h_r)^2] + g(f) \qquad (11)$$

Where :

f is the frequency in MHz.
h_r is the receiver antenna height in meters.
h_b is the transmission antenna height in meters.
$g(f)$ is defined by the following equation, [11] :

$$g(f) = 44.49\log_{10}(f) - 4.78\ [log_{10}(f)]^2 \qquad (12)$$

The values of these parameters (a_0, a_1, a_2 and a_3) for different types of terrain are given in [11], [12] as the following table :

TABLE 2
Parameters values of Ericsson model [11], [12]

Environment	a_0	a_1	a_2	a_3
Rural	*45.95*	*100.6*	*12*	*0.1*
Suburban	*43.20*	*68.63*	*12*	*0.1*
Urban	*36.2*	*30.2*	*12*	*0.1*

3 SIMULATION RESULTS AND ANALYSIS

In this work, COST 231 Hata Model, Stanford University Interim (SUI) Model and Ericsson Model are analyzed in urban, suburban and rural environments by applying two various receiver antenna heights which are 4 m and 8 m. Also, the operating frequency was fixed at 2.5 GHz. Moreover, Table 3 shows values of the parameters which were applied at this research.

TABLE 3
Parameters of Simulation

Parameters	Values
Operating frequency	2.5 GHz
Distance between TX and RX	3 Km
Transmitter antenna height	25 m
Mobile transmitter power	30 dBm
Correction for shadowing	9 dB
Base station transmitter power	40 dBm
Receiver antenna height	4 m and 8 m

Related to the results for the propagation models for 4 m and 8 m receiver antenna heights, Figures 1 and 2 show it respectively in urban environment.

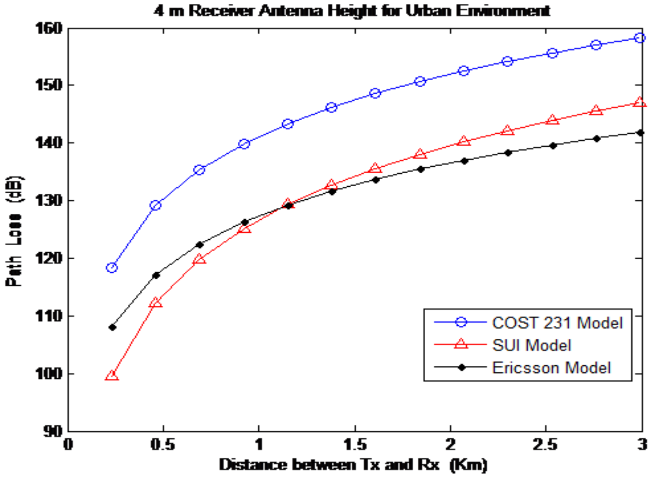

Fig. 1: Path Loss for 4 m Receiver Antenna Height in Urban Environment.

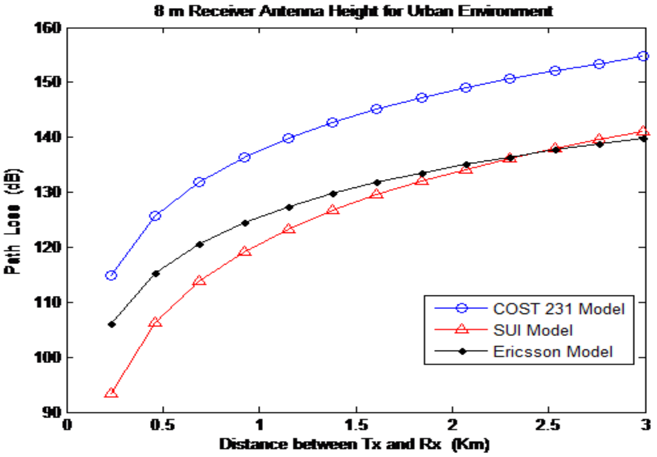

Fig. 2: Path Loss for 8 m Receiver Antenna Height in Urban Environment.

Table 4. shows the summarized values in urban environment.

TABLE 4
Path Loss values in Urban Environment

Model	Path Loss for 4 m receiver antenna height	Path Loss for 8 m receiver antenna height
COST 231 Hata	159 dB	155 dB
SUI	147 dB	140 dB
Ericsson	141 dB	140 dB

It was obvious from the results of the path loss estimation for 4 m and 8 m receiver antenna heights in urban area that COST 231 Hata model showed the highest path loss result (159 dB in 4 m receiver antenna height) as compared with the other models in urban environment. Also, it was observed that SUI and Ericsson models showed the lowest path loss result (140 dB in 8 m receiver antenna height) as compared with the other models in urban environment. Moreover, attention should be paid to the results of the path loss estimation of SUI and Ericsson models which are identical and equal to (140 dB) for 8 m receiver antenna height in urban environment.

Moreover, Figures 3 and 4 show the results for the mentioned propagation models in suburban environment.

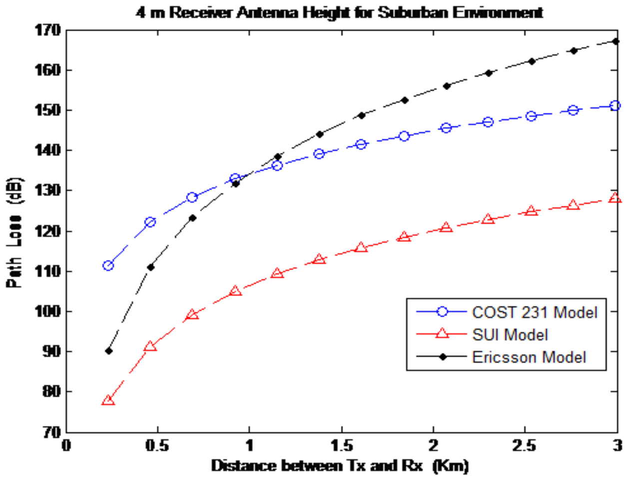

Fig. 3: Path Loss for 4 m Receiver Antenna Height in Suburban Environment.

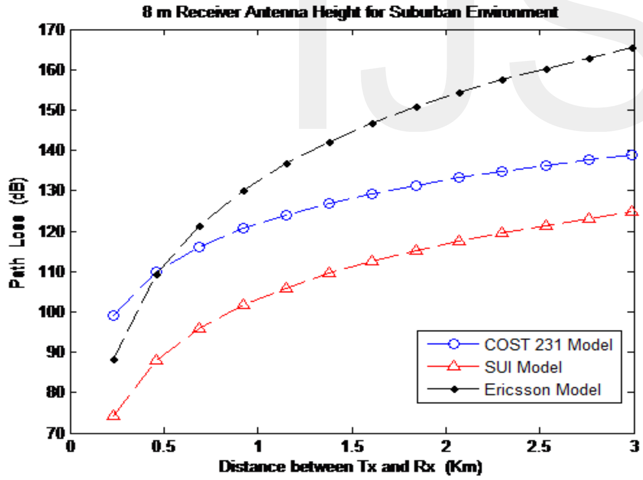

Fig. 4: Path Loss for 8 m Receiver Antenna Height in Suburban Environment.

Table 5. shows the summarized values in suburban environment.

TABLE 5
Path Loss values in Suburban Environment

Model	Path Loss for 4 m receiver antenna height	Path Loss for 8 m receiver antenna height
COST 231 Hata	150 dB	140 dB
SUI	119 dB	125 dB
Ericsson	169 dB	167 dB

It was noticed from the results of the path loss estimation for 4 m and 8 m receiver antenna heights in suburban area that SUI model showed the lowest path loss result (119 dB in 4 m receiver antenna height) as compared with the other models in suburban environment. Moreover, it was observed that Ericsson model showed the highest path loss result (169 dB in 4 m receiver antenna height) as compared with the other models in suburban environment.

Furthermore, Figures 5 and 6 show the results for the mentioned propagation models in rural environment.

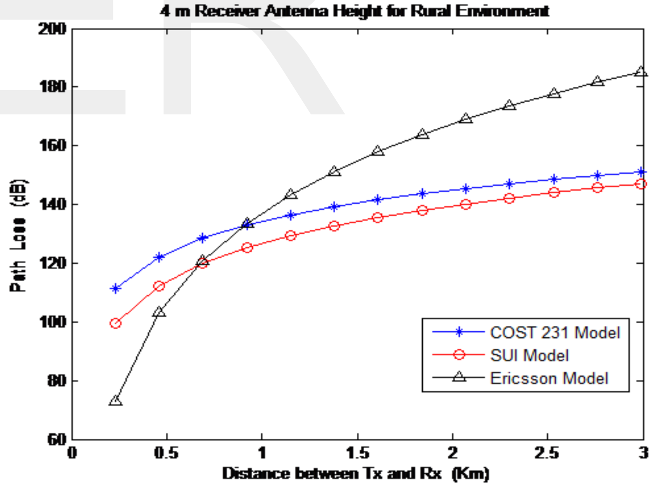

Fig. 5: Path Loss for 4 m Receiver Antenna Height in Rural Environment.

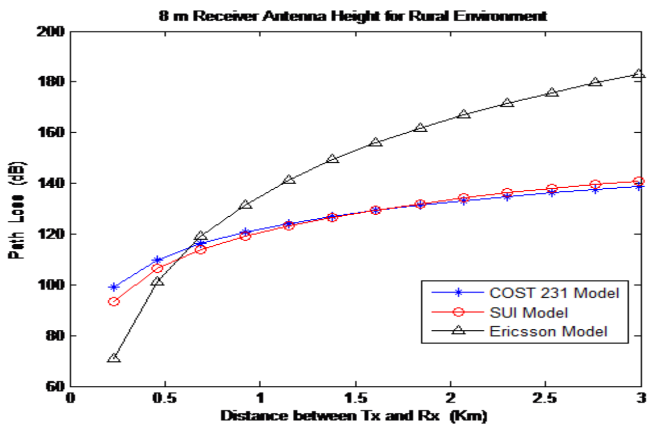

Fig. 6: Path Loss for 8 m Receiver Antenna Height in Rural Environment.

Moreover, the path loss values in rural environment were summarized in Table 6.

TABLE 6
Path Loss values in Rural Environment

Model	Path Loss for 4 m receiver antenna height	Path Loss for 8 m receiver antenna height
COST 231 Hata	150 dB	138 dB
SUI	145 dB	142 dB
Ericsson	183 dB	181 dB

It can be mentioned from the results of the path loss estimation for 4 m and 8 m receiver antenna heights in rural area that COST 231 Hata model showed the lowest path loss result (138 dB in 8 m receiver antenna height) as compared with the other models in rural environment. Moreover, it was observed that Ericsson model showed the highest path loss result (183 dB in 4 m receiver antenna height) as compared with the other models in rural environment.

4 CONCLUSION

It should be noticed that there are various propagation models which are able to predict the path loss value. In this research the path loss estimation was analyzed for various propagation models (COST 231 Hata, SUI and Ericsson) at the operating frequency of 2.5 GHz for different receiver antenna heights in all types of terrain (urban, suburban and rural). It was obvious from the results of the path loss estimation for 4 m and 8 m receiver antenna heights in urban area that SUI and Ericsson models showed the lowest path loss result (140 dB in 8 m receiver antenna height) as compared with the other models in urban environment. On the other hand, COST 231 Hata model showed the highest path loss result (159 dB in 4 m receiver antenna height) in urban environment. Then, as a conclusion in the case examined here, it can be noticed that Ericsson model showed the highest path loss result (183 dB in 4 m receiver antenna height) as compared with the other models in all types of the environments (urban, suburban and rural). It was observed that increasing the receiver antenna heights leads to get better quality signal from the transmitter. Finally, we have to point out that the propagation models have great importance in the development of wireless communication systems.

5 FUTURE WORK

In the future, a suitable path loss model for all types of terrain may be derived. Also, future research should be focused on finding more appropriate parameters for Ericsson model in all types of the environments (urban, suburban and rural).

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REFERENCES

[1] P. Vyas, M. Korde, “Optimization of Empirical Pathloss Models of WiMax at 4.5 GHz Frequency Band,” *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, vol. 9, issue. 1, pp. 01-08, Jan 2014.
[2] M. Kumari, T. Yadav, et al,“Comparative Study of Path Loss Models in Different Environments” IJEST, vol. 3, no. 4, April 2011.
[3] V.Erceg, K V S Hari, et al., “Channel models for fixed wireless applications,” tech. rep., IEEE 802.16 Broadband wireless access working group, Jan 2001.
[4] COST Action 231, “Digital mobile radio towards future generation systems, final report,” tech. rep., European Communities, EUR 18957, 1999.
[5] E.Athanasiadou,A.R.Nix,and L.P.MeGeehan,″A Microcellular ray-tracing propagation model and evaluation of its narrowband and wideband predictions,″ IEEE journal on selected areas in comm..,wireless comm., series,vol.18 pp.322-355, March 2000.
[6] V.S. Abhayawardhana, I.J. Wassell, D. Crosby, M.P. Sellars, M.G. Brown”Comparison of empirical propagation path loss models for fixed wireless access systems” Vehicular Technology Conference, vol. 1, pp. 73 - 77, 2005.
[7] M. Hata, “Empirical formula for propagation loss in land mobile radio services,” IEEE Transactions on Vehicular Technology, vol. VT-29, pp. 317–325, September 1981.

[8] Y. Okumura, "Field strength and it's variability in VHF and UHF land-mobile radio services," Review of the Electrical Communications Laboratory, vol. 16, September - October 1968.

[9] T.S. Rappaport, Wireless communications –Principles and practice, 2nd Edition , Prentice Hall, 2001.

[10] V. Erceg, L. J. Greenstein, et al., "An empirically based path loss model for wireless channels in suburban environments," IEEE Journal on Selected Areas of Communications, vol. 17, pp. 1205–1211, July 1999.

[11] J. Milanovic, S. Rimac-Drlje , K. Bejuk, "Comparison of propagation model accuracy for WiMAX on 3.5GHz," 14th IEEE International conference on electronic circuits and systems, Morocco, pp. 111-114, 2007.

[12] Md. Didarul Alam, S. Chowdhury, et al., "Performance Evaluation of Different Frequency Bands of WiMAX and Their Selection Procedure," International Journal of Advanced Science and Technology, vol. 62, pp. 1-18, 2014.

INTRODUCTION FOR ARTICLE AUTHOR

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