

Original Research Paper

# Path Loss Measurements for Wireless Communication in Urban and Rural Environments

<sup>1</sup>Yahia Zakaria, <sup>2</sup>Jiri Hosek and <sup>2</sup>Jiri Misurec

<sup>1</sup>Engineering Research Division, National Research Center, Dokki, P.O. 12622, Cairo, Egypt

<sup>2</sup>Department of Telecommunications, Brno University of Technology, Brno, Czech Republic

## Article history

Received: 27-10-2014

Revised: 17-03-2015

Accepted: 15-4-2015

Corresponding Author:

Yahia Zakaria

Engineering Research Division,  
National Research Center, Dokki,  
P.O. 12622, Cairo, Egypt

Email: Yahia.zk82@yahoo.com

**Abstract:** Path loss models are useful planning tools that allow the designers of wireless communication networks to achieve optimal levels for the base station deployment and meeting the expected service level requirements. In this study various propagation models (COST 231 Walfisch-Ikegami W-I, Ericsson and Stanford University Interim SUI) are analyzed and compared with the measurements. The measured data were taken in urban (high density region) and rural (low density region) environments at the operating frequency of 1700 MHz using the spectrum analyzer. As one of the key outputs, It was found that the calculations of SUI model fit with the measured data in urban environment.

**Keywords:** Walfisch-Ikegami Model, Ericsson Model, Stanford University Interim Model, Path Loss, Wireless Communication

## Introduction

In wireless communication system, the losses that occur between transmitter and receiver are known as propagation path loss. Path loss is a major factor in the analysis and design of wireless communication system. Moreover, the electromagnetic waves usually cannot directly reach the receiver due to many obstacles that block the line of sight path. The travelled signal from transmitter to receiver over a lot of reflection paths is called multipath propagation which always causes fluctuations in the receiver signal's phase and amplitude. The description of the main mechanisms that influence the signal propagation is as follows (Rappaport, 1996):

- Reflection
- Diffraction
- Scattering
- Doppler effect

The propagation models are developed to predict the loss of signal strength or coverage in a particular location. Thus, they are mathematical tools used by engineers and scientists to plan and optimize wireless communication systems.

Moreover, path loss can be defined as the ratio between transmitted and received power, usually

expressed as the following form in decibels (Abhayawardhana *et al.*, 2005) Equation 1:

$$PL(d) = PL(d_0) + 10n \log_{10}(d/d_0) \quad (1)$$

Where:

$d$  = The distance

$d_0$  = The reference point at 1 km

$n$  = The path loss exponent

It should be noticed 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.

## Description of Selected Models

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. They are widely used in wireless communication, mainly for conducting feasibility studies and during the deployment. Channel modeling is essential for characterization of the impulse response and to predict the path loss of a propagating channel. Therefore, 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. This research is focused on COST 231 W-I, Ericsson and SU1 propagation models.

### COST 231 Walfisch-Ikegami Model

COST 231 Walfisch-Ikegami (W-I) model is considered as the most appropriate model for rural and suburban environments which have regular building height. Moreover, this model gives more accurate path loss prediction. It identifies various terrains with different parameters. The equation of the model for Non-Line-Of-Sight (NLOS) condition is expressed as (Alam *et al.*, 2014) Equation 2 and 3:

$$PL_{NLOS} = L_{FSL} + L_{rts} + L_{msd} \text{ for suburban and urban} \quad (2)$$

$$PL_{NLOS} = L_{FSL} \text{ when } L_{rts} + L_{msd} > 0 \quad (3)$$

Where:

$L_{FSL}$  = Free space loss

$L_{rts}$  = Roof top to street diffraction

$L_{msd}$  = Multi-screen diffraction loss. Moreover, the Free space loss equation is calculated as (Alam *et al.*, 2014) Equation 4:

$$L_{FSL} = 32.45 + 20\log(d) + 20\log(f) \quad (4)$$

The roof top to street diffraction is computed as (Alam *et al.*, 2014) Equation 5 to 11:

$$L_{rts} = -10\log(w) - 16.9 + 10\log(f) + 20\log(H_{mobile}) + L_{ori} \quad (5)$$

$$L_{rts} = 0 \text{ if } h_{roof} > h_{mobile} \quad (6)$$

Where:

$$L_{ori} = 2.5 + 0.075(\varphi - 35) \text{ for } 35 \leq \varphi \leq 55 \quad (7)$$

$$L_{ori} = -4 - 0.114(\varphi - 55) \text{ for } 55 \leq \varphi \leq 90 \quad (8)$$

$$L_{ori} = -10 + 0.354\varphi \text{ for } 0 \leq \varphi \leq 35 \quad (9)$$

We have to observe that:

$$\Delta h_{base} = h_{base} - h_{roof} \quad (10)$$

$$\Delta h_{mobile} = h_{roof} - h_{mobile} \quad (11)$$

The  $L_{msd}$  (Multi Screen Diffraction Loss) is calculated as (Alam *et al.*, 2014) Equation 12 to 22:

$$L_{msd} = k_a + L_{bsh} + k_d \log_{10}(d) + k_f \log_{10}(f) - 9\log_{10}(B) - 9\log_{10}(f), \text{ For } L_{msd} > 0 \quad (12)$$

$$L_{msd} = 0 \text{ for } L_{msd} < 0 \quad (13)$$

Where:

$$L_{bsh} = 0 \text{ for } h_{base} \leq h_{roof} \quad (14)$$

$$L_{bsh} = -18\log_{10}(1 + \Delta h_{base}) \text{ for } h_{base} > h_{roof} \quad (15)$$

$$k_d = 18 + 15 \left( \frac{\Delta h_{base}}{h_{roof}} \right) \text{ for } h_{base} \leq h_{roof} \quad (16)$$

$$k_d = 18 \text{ for } h_{base} > h_{roof} \quad (17)$$

$$k_a = 54 - 0.8\Delta h_{base} \text{ for } d \geq 0.5 \text{ km and } h_{base} \leq h_{roof} \quad (18)$$

$$k_a = 54 - 0.8\Delta h_{base} \left( \frac{d}{0.5} \right) \text{ for } d < 0.5 \text{ km and } h_{base} \leq h_{roof} \quad (19)$$

$$k_a = 54 \text{ for } h_{base} > h_{roof} \quad (20)$$

$$k_f = -4 + 1.5 \left( \frac{f}{925} - 1 \right) \text{ for urban areas} \quad (21)$$

$$k_f = -4 + 0.7 \left( \frac{f}{925} - 1 \right) \text{ for suburban areas} \quad (22)$$

Where:

$B$  = The building to building distance in meters

$d$  = The distance between transmitter and receiver antenna in meters

$f$  = The frequency in GHz

$\varphi$  = The street orientation angle degree

$w$  = The street width in meters

The equation for Line-Of-Sight (LOS) condition is expressed as (Alam *et al.*, 2014) Equation 23:

$$PL_{los} = 20\log(f) + 42.6 + 26\log(d) \quad (23)$$

### Ericsson Model

The network planning engineers are used a software provided by Ericsson company is called Ericsson model (Milanovic *et al.*, 2007). 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 (Milanovic *et al.*, 2007) Equation 24:

$$PL = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(h_b) \cdot \log_{10}(d) - 3.2 \left[ \log_{10}(11.75h_r)^2 \right] + g(f) \quad (24)$$

Where:

- $f$  = The frequency in MHz
- $h_r$  = The receiver antenna height in meters
- $h_b$  = The transmission antenna height in meters
- $g(f)$  = Defined by the following equation (Milanovic *et al.*, 2007) Equation 25:

$$g(f) = 44.49 \log_{10}(f) - 4.78 \left[ \log_{10}(f) \right]^2 \quad (25)$$

The values of these parameters ( $a_0, a_1, a_2, a_3$ ) for different types of terrain are given in (Milanovic *et al.*, 2007) and (Simic *et al.*, 2001) as the following Table 1.

#### Stanford University Interim (SUI) Model

The frequency band below 11GHz use the channel model which is proposed by Stanford University called SUI model. This model is 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, 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 (Erceg *et al.*, 2001; 1999) as Equation 26:

$$PL = A + 10\gamma \log_{10} \left[ d / d_0 \right] + X_f + X_h + S \text{ for } d > d_0 \quad (26)$$

Where:

- $f$  = The frequency in MHz
- $d$  = The distance between AP and CPE antennas in meters
- $d_0 = 100$  m;  $X_h$  = The correction for receiving the antenna height in meters
- $\gamma$  = The path loss exponent
- $X_f$  = The correction for frequency in MHz
- $S$  = The correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of trees and other

clutters on the propagation path (Abhayawardhana *et al.*, 2005).

The parameter  $A$  is calculated by (Abhayawardhana *et al.*, 2005; Milanovic *et al.*, 2007) Equation 27:

$$A = 20 \log_{10} (4\pi d_0 / \lambda) \quad (27)$$

Also, the pat loss exponent  $\gamma$  is computed by (Anderson, 2003) Equation 28:

$$\gamma = a - bh_b + (c / h_b) \quad (28)$$

Where:

- $\lambda$  = The wavelength in meters
- $h_b$  = The base station antenna height above the ground which measured in meters and its value should be between 10 and 80 m.

The constants  $a$ ,  $b$  and  $c$  depend on the types of terrain which are given in Table 2, also the value of the parameter  $\gamma > 5$  for indoor propagation, for urban environment and for free space propagation in urban environment (Milanovic *et al.*, 2007).

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 in (Abhayawardhana *et al.*, 2005) Equation 29 to 31:

$$\text{terrain type C: } X_h = -20 \log_{10} (h_r / 2000) \quad (29)$$

$$\text{terrain type A and B: } X_h = -10.8 \log_{10} (h_r / 2000) \quad (30)$$

$$X_f = 6 \log_{10} (f / 2000) \quad (31)$$

Where:

- $f$  = The frequency in MHz
- $h_r$  = The receiver antenna height above the ground level in meters.

Table 1. Parameters values of Ericsson model

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	36.20	30.20	12	0.1

Table 2. Parameter values of SUI Model for different types of terrain

Parameter model	Terrain A	Terrain B	Terrain C
$a$	4.6000	4.0000	3.600
$b$ ( $m^{-1}$ )	0.0075	0.0065	0.005
$c$ (m)	12.6000	17.1000	20.000

## Results Comparison and Analysis

Practically, measured data was taken in urban (high density region) and rural (low density region) environments in Egypt at 1700 MHz as more appropriate frequency band in urban area. In this research, selected propagation models are calculated using MATLAB software and compared with the experimental results which were taken in two different environments (urban and rural). The power from transmitter is 43 dBm.

Correction for shadowing is 10.3 dB. Transmitter antenna height is 12 m.

The measured path losses in various environments are shown in Fig. 1. By observing the path loss values, it was clear that the path loss has less value in rural regions than in urban regions.

Related to the results of the predicted and measured path losses, Fig. 2 and 3 show it in urban and rural environments, respectively.

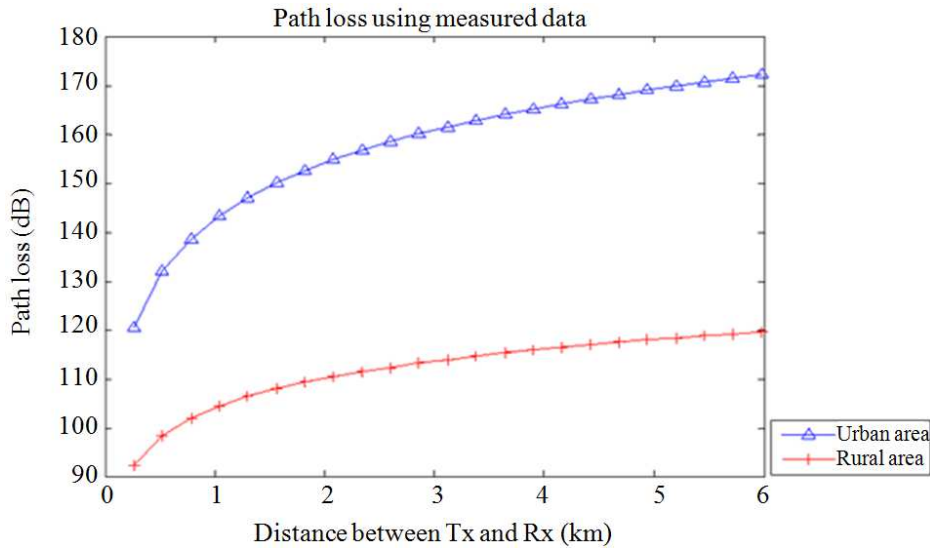


Fig. 1. Measured path loss in different environments

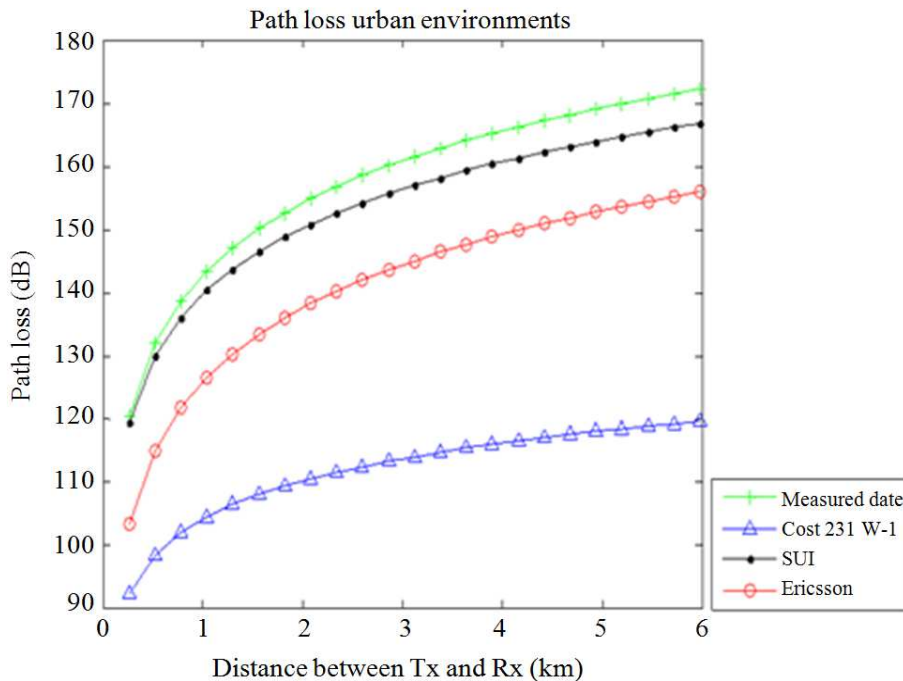


Fig. 2. Comparison of path loss models with measurements in urban environment

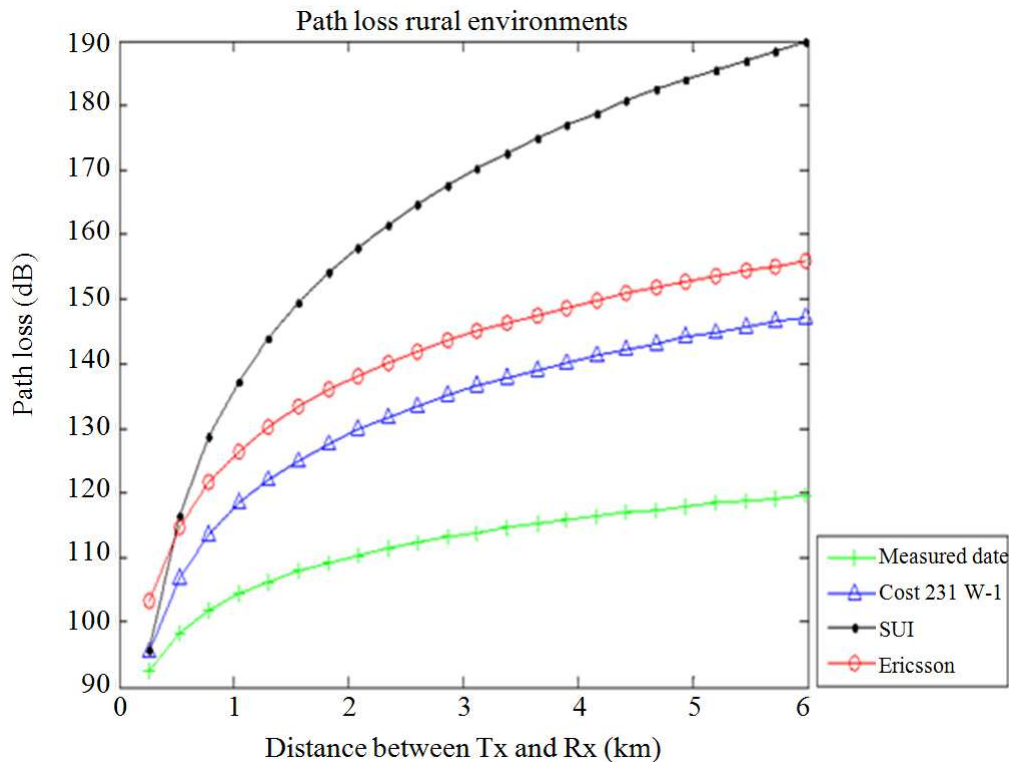


Fig. 3. Comparison of path loss models with measurements in urban environment

By comparing the results in (Chandran and Prabhakara, 2014) with the results of this research, it has been found that the results of Cost 231 W-I model in the mentioned paper stated the highest value (176.22 dB) in urban environment at 4.2 GHz. On the contrary, Free Space model at the mentioned paper showed the lowest value 119.37 dB in urban environment at 3.7 GHz. Also, it was noticed from (Shabbir *et al.*, 2011) that the results of SUI model stated the lowest value (72.17 dB) in urban environment at 1900 MHz.

By comparing the calculated results in (Vyas and Korde, 2014) with these results, it has been found that the results of Free Space model, ECC-33, Cost 231 W-I and Cost 231 Hata in the mentioned paper stated the lowest values (113.5 dB, 149.3 dB, 164.5 dB and 158 dB), respectively in 3m, 6m and 10 m receiver antenna heights in urban environment at 4.5 GHz. On the contrary, Cost 231 W-I model in the mentioned paper stated the lowest value (126 dB) in 3m, 6m and 10 m receiver antenna heights in rural environment at 4.5 GHz.

It was noticed from (Alam *et al.*, 2014) that the results of Ericsson model stated the highest value (174.6 dB) in 3 m receiver antenna height in rural environment at 3.5 GHz. On the contrary, Free Space model stated the lowest value (106.4 dB) at 2.5 GHz in the same environment. Ericsson model showed the highest values (172.6 dB) and (171.2 dB) in 6 m and 10 m receiver antenna heights, respectively in rural environment at 3.5

GHz. Moreover, it was observed from (Shabbir *et al.*, 2011) that the results of Ericsson model stated the highest value (204.79 dB) in rural environment at 2100 MHz. On the contrary, SUI model stated the lowest value (38.20 dB) at 1900 MHz in the same environment.

It was concluded from (Zakaria, 2014) that Ericsson model showed the highest path loss result (183 dB in 4 m receiver antenna height) at the operating frequency of 2.5 GHz as compared with the other models in rural environment. Also, it was mentioned that SUI model showed the lowest path loss result (119 dB in 4 m receiver antenna height) at the same frequency band in all types of the environments.

## Conclusion

The main goal of this research was to analyze the behavior of channel propagation models of wireless communication systems. The simulated and measured path loss values of selected models are analyzed and compared in urban and rural environments at 1700 MHz. It can be concluded that the calculations of SUI model correspond to the measurements. Thus, it is highly recommended for urban environments. On the other hand, the simulated results of Cost 231 W-I model do not fit with the measured results. Furthermore, network planners rely on the signal propagation path loss models for enhancing the wireless communication systems to

achieve an acceptable level of quality of service for the users. Therefore, it is very important to find out a suitable propagation model for all types of the environments to provide guidelines for cell planning of wireless communication systems. Finally, it is necessary to point out that the main goal in the planning phase of wireless communication systems is to predict the loss of signal strength in a specific location.

## Acknowledgement

The support of authors by Brno University of Technology, Czech Republic was acknowledged.

## Funding Information

Research described in this paper was financed by the National Sustainability Program under grant LO1401 and by the project CZ.1.07/2.3.00/30.0005 of Brno University of Technology. For the research, infrastructure of the SIX Center was used.

## Author's Contributions

**Yahia Zakaria:** Participated in conducting and analyzing propagation loss calculations and contributed to writing of the manuscript.

**Jiri Hosek:** Participated in measurement results analysis, propagation model comparison and also contributed to writing of the manuscript.

**Jiri Misurec:** Provided technical consultancy about the obtained results and contributed to writing of the manuscript.

## Ethics

This work has not been published elsewhere so there are no ethical issues know to authors that may arise after the publication of this manuscript.

## References

- Abhayawardhana, V.S., I.J. Wassell, D. Crosby, M.P. Sellars and M.G. Brown, 2005. Comparison of empirical propagation path loss models for fixed wireless access systems. Proceedings of the 61th IEEE Vehicular Technology Conference, May 30-Jun. 1, IEEE Xplore Press, Sweden, pp: 73-77. DOI: 10.1109/VETECS.2005.1543252
- Alam, M.D., S. Chowdhuriz and S. Alam, 2014. Performance evaluation of different frequency bands of Wi-MAX and their selection procedure. Int. J. Adv. Sci. Technol., 62: 1-18. DOI: 10.14257/ijast.2014.62.01

- Anderson, H.R., 2003. Fixed Broadband Wireless System De-sign. 1st Edn., John Wiley and Co., ISBN: 978-0-470-84438-0, pp: 528.
- Chandran, B. and B. Prabhakara, 2014. Design and modeling of propagation models for WiMAX communication system at 3.7GHz and 4.2GHz. Int. J. Elect. Commun., 2: 1-7.
- Erceg, V., K. Hari, M.S. Smith and D.S. Baum, 2001. Channel models for fixed wireless applications. IEEE Tech. Rep.
- Erceg, V., L.J. Greenstein, S.Y. Tjandra, S.R. Parkoff and A. Gupta, *et al.*, 1999. An empirically based path loss model for wireless channels in suburban environments. IEEE J. Selected Areas Commun., 17: 1205-1211. DOI: 10.1109/49.778178
- Milanovic, J., S. Rimac-Drlje and K. Bejuk, 2007. Comparison of propagation model accuracy for WiMAX on 3.5GHz. Proceedings of the 14th IEEE International Conference on Electronic Circuits and Systems, Dec. 11-14, IEEE Xplore Press, Morocco, pp: 111-114. DOI: 10.1109/ICECS.2007.4510943
- Rappaport, T.S., 1996. Wireless Communications. 1st Edn., Prentice-Hall, Upper Saddle River, New Jersey, ISBN-10: 0-13-375536-3, pp: 641.
- Shabbir, N., M. Sadiq, H. Kashif and R. Ullah, 2011. Comparison of radio propagation models for Long Term Evolution (LTE) network. Int. J. Next Generat. Net., 3: 27-41. DOI: 10.5121/ijnngn.2011.3303
- Simic, I.L., Stanic I. and B. Zrnica, 2001. Minimax LS algorithm for automatic propagation model tuning. Proceeding of the 9th Telecommunications Forum, Nov. 20-22, Belgrade, Serbia, pp: 1-5.
- Vyas, P. and M. Korde, 2014. Optimization of empirical path-loss models of WiMax at 4.5 GHz frequency band. IOSR J. Elect. Commun. Eng., 9: 1-8.
- Zakaria, Y., 2014. Performance analysis of propagation models for cellular mobile communication systems at 2.5 GHz. Int. J. Scientific Eng. Res., 5: 426-432.