Pathloss Modeling at 2.3Ghz Frequency Band in the Suburbs of Tropical Region

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***Abstract*—before deploying any wireless system, a careful study of the zone that we desire to cover must be carried out. Such analysis is usually developed through simulations that try to model what happens to the transmitted signal along its path. The higher the number of the propagation conditions taken into account by the simulation, the higher the similarity with the real conditions. But the amount of parameters that influence an electromagnetic emission is vast. Besides, the fact that some parameters having stochastic behavior makes it impossible to control all of them, creating therefore the need for more accurate propagation models, in this paper, we aim to simulate the propagation pathloss models using MATLAB software and compare the results with measurements conducted in the suburbs of Johor city , Malaysia.**

Keywords—Propagation ; wireless; pathloss ,

I. INTRODUCTION

Over the past two decades, mobile communication systems underwent extensive development. Today, the demands a mobile system must fulfill are greater than ever before. For good quality and cost effective new services such as very high speed internet system, mobile communication system requires careful approach from early stages in both the network design and implementation. The first step in the process is to determine frequency plan and network topology, both of which are mainly dependent on environmental characteristics. One of the most important characteristics of the propagation environment is the path (propagation) loss [1]. An accurate estimation of the propagation losses provides a good basis for a proper radio design including selection of base station locations and proper determination of the frequency plan as well as improving converge. By knowing propagation losses, one can efficiently predict the field signal strength and provide good quality network coverage.

II. EMPIRACAL PATHLOSS MODELS

Wireless signal suffers degradation due to various phenomenons caused by the different variants of obstacles between the base station and the mobile station. In this section we review the basics of radio propagation and study the factors that mainly affect propagation conditions at 2.3GHz. We will also study the most used existing propagation models at our frequency range all these reviews will be simultaneously accompanied by various computer simulations that concretize the general definitions for our case of study.

A. *Free Space Model*

The most basic effect that attains any form of RF propagation are the losses due to free-space propagation. Such loss is based on the fact that if a radio signal is emitted from a point source it will then propagate radially, i.e. equally in every direction of space in free space propagation, clear and unobstructed line-of-sight (LOS) path is available and the first Fresnel zone is maintained between base station and mobile terminal. Free space path loss can be obtained by getting the logarithmic value of the ratio between received power and transmitting power as expressed in equation (1) Equation (2) and (3) is the simplified free space path loss model for unity antenna gain [2]. Free space path loss is frequency dependent and is increasing against distance. The increase of distance and frequency has similar effect on the path loss, where the path loss increases by 6 dB when either distance or frequency is doubled.

$$PL_{dB} = -10\log_{10}\frac{P_r}{P_t} \tag{1}$$

$$PL_{dB} = -147.56 + 20\log_{10} f_{Hz} + 20\log_{10} d_m \tag{2}$$

$$PL_{dB} = 32.44 + 20\log_{10} f_{MHz} + 20\log_{10} d_{km} \tag{3}$$

Where;

Pr is receiving power, *Pt* is transmitting power, *f* is the frequency and *d* is the distance

B. *COST-231 Hata Model*

The Cost 231 Hata model has been developed based on Hata model [5]. This new model is valid for frequencies between 1,500 MHz and 2,000 MHz [6]. This model is only applicable for situations where the rooftop levels of adjacent buildings are below the base station antenna. It can provide accurate prediction over large cell coverage [7]. Equation 4 indicates that the path loss exponent of Cost 231 Hata model is varying from 3.5 to 4 for base station height 30 m to 200 m [11].

$$\begin{aligned} PL_{dB} &= 46.3 + 33.9\log_{10} f - 13.82\log_{10} h_b \\ &- a(h_r) + (44.9 - 6.55\log_{10} h_b)\log_{10} D + C_m \end{aligned} \tag{4}$$

Where;

Cm = 0 dB for medium-sized city and suburban center with moderate tree density, 3 dB for metropolitan centers

f = 1,500 to 2,000 MHz

hb = 30 to 200 m

hr = 1 to 10 m

D = 1 to 20 km

$$a(h_r) = (1.1\log_{10} f_{MHz} - 0.7)h_r - (1.56\log_{10} f_{MHz} - 0.8) \qquad (5)$$

For

$$a(h_r) = \begin{cases} 8.29(\log_{10} 1.54h_r)^2 - 1.1 & f \le 200MHz \\ 3.2(\log_{10} 11.75h_r)^2 - 4.97 & f \ge 400MHz \end{cases} \qquad (6)$$

C. COST 231-Walfisch-Ikegami Model

The COST 231-Walfisch-Ikegami model (COST 231-WI) has been used extensively in typical suburban and urban environments where the building heights are quasi-uniform. It should be noted that the designers of public mobile radio systems often use this model, The model utilizes the theoretical Walfisch-Bertoni model to obtain multiple screen forward diffraction loss for high base station antenna heights, whereas it uses measurement-based data for low base station antenna heights. This model also takes into account free-space loss, loss due to diffraction down to the street, and the street orientation factor [3].

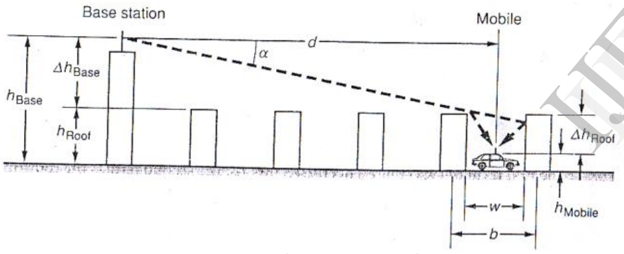

Figure 1: Geometry Of Cost 231 Walfisch- Ikegami

Steep transitions of path loss occur when the base station antenna height is close to the height of the rooftops of the buildings in its vicinity. Therefore, the height accuracy of the base station antenna is especially significant if large prediction errors are to be avoided. Moreover, the performance of the Walfisch-Ikegami model is poor when the base station antenna height is significantly lower than the heights of the rooftops of adjacent buildings. It was claimed, as the expected accuracy of the model, that the mean error is in the range of ±3dB and the standard deviation is about 48dB in the case when the base station antenna height is several meters above the highest rooftops of adjacent buildings within a radius of approximately 150m. However, recently it was found that the loss expression for the diffraction from the last rooftop to the street in the COST 231WI model is over 8dB more optimistic than it is supposed to be [4].

$$PL_{dB} = 42.6 + 26\log_{10} R + 20\log_{10} f \quad R \ge 20m \qquad (7)$$

Where;

f is frequency from 800 MHz to 2000 MHz

R is distance from 0.2 km to 5 km

In non-line of sight (NLOS) situation, Cost 231 Walfish-Ikegami model basically consists of three components that are free space loss component, rooftop-to-street diffraction and scatter loss [8] component, and multiscreen loss component as given in equation 8.

$$PL_{dB} = \begin{cases} L_{fs} + L_{rts} + L_{msd} & L_{rts} + L_{msd} > 0 \\ L_{fs} & L_{rts} + L_{msd} = 0 \end{cases} \qquad (8)$$

Where;

L_{fs} is free space path loss

L_{rts} is rooftop-to-street diffraction loss

L_{msd} is multi-screen diffraction loss

The rooftop-to-street diffraction and scatter loss is given by

$$L_{rts} = \begin{cases} -16.9 - 10\log_{10} w + 10\log_{10} f + 20\log_{10} \Delta h_r + L_{ori} & h_{roof} > h_r \\ 0 & L_{rts} < 0 \end{cases} \qquad (9)$$

Where;

$$L_{ori} = \left| \begin{array}{ll} -10 + 0.354\varphi & 0 \le \varphi < 35^o \\ 2.5 + 0.075(\varphi - 35^o) & 35^o \le \varphi < 55^o \\ 4.0 - 0.114(\varphi - 55^o) & 55^o \le \varphi \le 90^o \end{array} \right.$$

$$\Delta h_r = h_{roof} - h_r$$

$$\Delta h_b = h_b - h_{roof}$$

w=width of road

Where φ is the angle between incidences coming from base station and road, in degrees shown in Figure 2: Definition of Street Orientation angleφ.

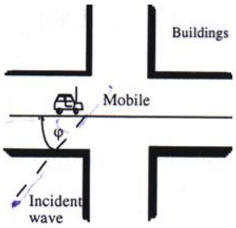

Figure 2: Definition Of Street Orientation Angle φ.

Where;

$$L_{bsh} = \begin{cases} -18\log_{10}(1 + \Delta h_b) & h_b > h_{roof} \\ 0 & h_b \le h_{roof} \end{cases}$$

$$k_a = \begin{cases} 54 & h_b > h_{roof} \\ 54 - 0.8\Delta h_b & R \ge 0.5km, h_b \le h_{roof} \\ 54 - 0.8\Delta h_b \cdot R/0.5 & R < 0.5km, h_b \le h_{roof} \end{cases}$$

$$k_d = \begin{cases} 18 & h_b > h_{roof} \\ 18 - 15 \cdot \Delta h_b / h_{roof} & h_b \le h_{roof} \end{cases}$$

$$k_f = -4 + \begin{cases} 0.7 \cdot \left(f/925 - 1 \right) & suburban \\ 1.5 \cdot \left(f/925 - 1 \right) & urban \end{cases}$$

Cost 231 Walfish-Ikegami model is valid for:

hb = 4 m to 50 m
hr = 1 m to 3 m
b = building separation, 20-50 m, w=b/2

D. Stanford University Interim (SUI)Model

SUI propagation model is an extension of Erceg model and was developed by IEEE BWA group (Institute of Electrical and Electronic Engineers- Broadband Wireless Access Working group). This model can be used in a link distance range of 0.1km to 8km [2]. The height of base station antenna can be from 10m to 80m, with the receiving antenna height of 2m to 10m. SUI models introduce two new components, γ the path loss exponent, s- week fading standard deviation. Both components are random variables through statistical procedure. The Erceg model supported 3 major terrain types. Each terrain in Erceg model was further classified in two types, making a total of 6 types of classifications for SUI model

$$PL = A + 10\,\gamma \log 10\,(d/d0) + s \qquad d>d0 \qquad (10)$$

$$A = 20 \log 10\,(4\,\pi\, d0 / \lambda) \qquad (11)$$

$$\gamma = (a - b\, hb + c / hb) \qquad (12)$$

where λ is the wavelength, γ is the path-loss exponent, hb is the height of the base station for hb between 10m and 8m, d0 is the close-in distance (chosen as 100 m), a,b,c are constants dependent upon the nature of the terrain, s represents the shadowing effect which has a lognormal distribution and has typical values of standard deviation in the range of 8-10dB.

TABLE I. PARAMETERS FOR VARIOUS TERRAIN TYPE

Model Parameter	**Terrain A**	**Terrain B**	**Terrain C**
a	**4.6**	**4.0**	**3.6**
b	**0.0075**	**0.0065**	**0.005**
c	**12.6**	**17.1**	**20**

Table I shows the parameter value for different type of terrain in SUI. For Light to moderate urban areas, Type A are most commonly used. The above model is without the correction terms [2]. Including the terms, it is obtain that the correction factors [9] for the operating frequency and for the receiver antenna height model are as below:

$$Xf = 6.0 \log 10\,(f/2000) \qquad (13)$$

$$Xh = -10.8 \log 10\,(hr/2000) \qquad (14)$$

for Terrain type A and B

$$Xh = -20.0 \log 10\,(hr/2000) \qquad (15)$$

for Terrain type C

Where f is the frequency in MHz and hr is the CPE (Customer Premises Equipment) antenna height above the ground in meters. The SUI model is used to predict the path loss in all three environments, namely rural, suburban and urban by setting the propagation delay for all three environments.

III. EXPERIMENTAL SET UP

Measurements were carried out by transmitting 0dBm Continues Wave (CW) at 2.3 GHz from a signal generator. The output signal from the signal generator was further amplified with 30 dB amplifier to 1 W CW signal. This signal was transmitted using a vertically linearly polarized antenna. The antenna has omni- directional radiation pattern in the horizontal plane and 10° beam-width in the vertical plane. The gain of the antenna is 7.5 dBi the antenna height was 15m from ground level. The same antenna was used at the receiver. The receiver was placed on a vehicle. The receiver antenna was mounted 2.0 m from ground level on the top of the measurement vehicle. The antenna was connected to a spectrum analyzer through preamplifier. A laptop was connected to the spectrum analyzer to acquire peak power reading from spectrum analyzer every second. The reading was time- stamped. A Global Positioning System (GPS) was placed on the car. It was connected to the laptop. The laptop acquired the position from GPS every second and was time-stamped. The separation distance of the receiver and the transmitter was calculated from GPS reading, Figure 3 illustrates the measurement equipment setup and Figure 4 show the measurement vehicle.

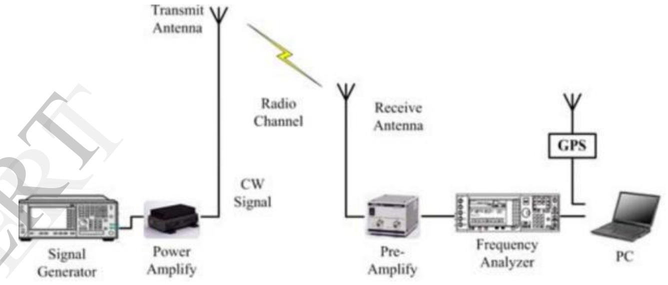

Figure 3: Experimental Measurement Setup

Figure 4: Measurement Vehicle

IV. Measurement Location and Route

The selected measurement site is University of Technology Malaysia (UTM), a suburban area in Taman University area in skudai city. It is located about 20 km from Johor Baharu City it has a mostly suburban terrain profile. The terrain within UTM consists of few flat areas, light to moderate rolling hills with moderate to high tree density, with altitude that varies from 12m to 130m in elevation Figure 5 shows the measurement route within UTM.

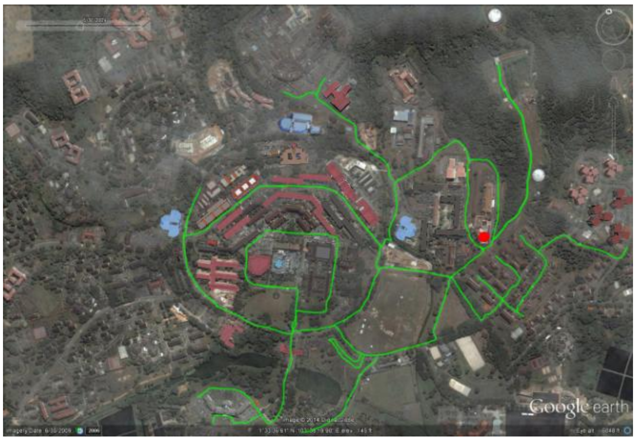

Figure 5: Measurement Route (in green) and base station location (in red)

V. MEASUREMENTS AND ANALYSIS

The measured received signal strength indicator (RSSI) is plotted against transmitter receiver separation distance in Figure 6.

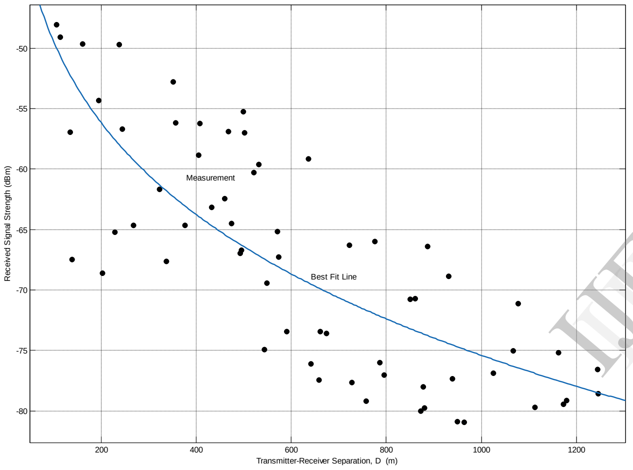

Figure 6: RSSI -2.3ghz

In addition to scattered measured data, averaged data over 50 meter separation is also plotted to better visualize the data trend. The predicted signal power is calculated using

$$Pr = Pt + Gt + Gr - Lt - Lr + PL \qquad (16)$$

Where Gt is transmitter gain, Gr is receiver gain, Lt is transmitter loss, Lr is receiver feeder loss, and PL is the propagation model path loss [10]. By using least square regression analysis we find that the transmitted power can be expressed as

$$RSSI\ (dBm) = -26.57*\log(D) + 4.816 \qquad (17)$$

The measured data show a minimum transmitted power of approximately -48 dBm when the receiver antenna is in close proximity to base station (100m). As the receiver antenna moves away from the base station, the power decreases by 29 dBm at 1.5km distance.

The graph in Figure 7 shows measured data and Best Fit Path loss Model in comparison with free space Path loss model.

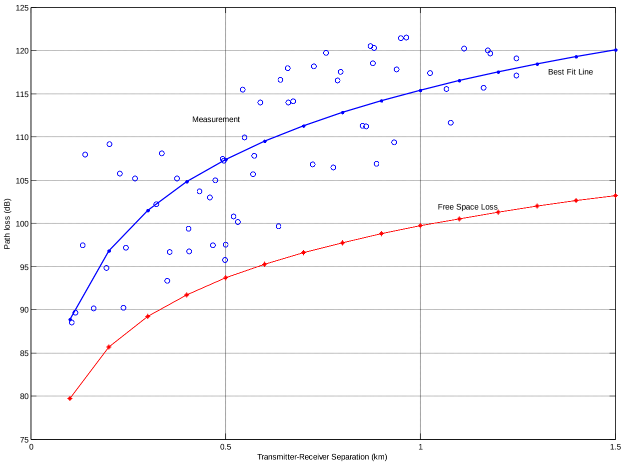

Figure 7: Path Loss Measurement Vs Free Space Pathloss Model at 2.3 GHz

TABLEII. PATHLOSS EXPONENT COMPARISON FOR PATHLOSS PROPAGATION MODELS

Model	**Path loss exponent γ at 2.3GHz suburban/urban environment**
Best Fit Model	**2.648**
Free Space	**2**
SUI	**5.0421**
COST 231-Hata	**3.7191**
COST 231 Walfisch-Ikegami	**3.8004**

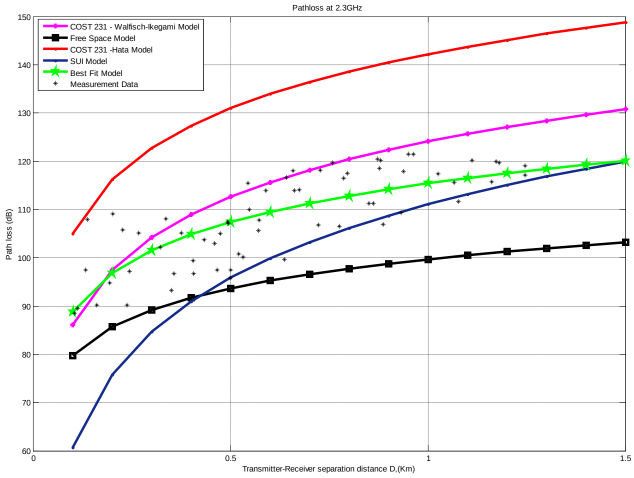

Figure 8: Path Loss Measurement Vs Different Pathloss Models at 2.3 GHz

As we can see from Figure 8 and Table II, the COST 231 Hata Model with pathloss exponent γ 3.71, in general overestimated the path loss, while SUI model with pathloss exponent γ 5.042 tend to underestimated the path loss for any distance below 1.5km, the COST 231-Walsch Ikegami model γ 3.8 shows the closest agreement with the measurement results although it starts to overestimates the path loss for distance above 1km. Using least square regression analysis we find that the pathloss model for the suburbs of Malaysia can be expressed as

$$PL=26.57*LOG(D)+35.68 \quad (18)$$

Which we can also express in the flowing

$$PL(dB)=PL(do)+10\,\gamma\,Log[d/d0] \quad (19)$$

Based on our measurement d0 at 100m reference equals to 106 dBm and the path loss exponent γ =2.648 given that the new measurement based pathloss model can be expressed as

$$PL(dB)=106+26.48\ LOG[d/100] \quad (20)$$

VI. CONCLUSION

Presented in this paper an investigation of the path loss characteristic at 2.3GHz frequency band , measurement based and statistically derived path loss model for microcellular wireless communication systems is also presented for coverage estimation for the suburban environment in Malaysia.

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