Simulation of Path Loss and Link Budget based on Stanford University Interim (SUI), Cost-231 Hata and Ericsson propagation models in 4G LTE and WiMAX system using MATLAB

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Abstract - **In mobile communication system, 4G LTE coverage range is one of the crucial factors that have an effect on the quality of broadband access services. The first step in planning and designing cellular mobile systems is to predict and determine the path loss that suitable for certain environments. This paper focus on the comprehensive study of propagation path loss models in 4G LTE and WiMAX for urban and suburban regions. Simulation process was performed using MATLAB for three selected propagation model such as Cost-231 Hata model, Stanford University Interim (SUI) model and Ericsson model. Two carrier frequency, 1800MHz (1.8GHZ) and 2300MHz (2.3GHz) which are the operating frequency for Malaysian 4G service provider and a variation of distances in the range of 1 to 10 km were selected in the simulation process.**

Keywords—**4G LTE, cellular system, propagation path loss, propagation models.**

I. INTRODUCTION

Predicting and determine the received signal power and signal attenuation or path loss at the particular distance between transmitter and receiver will always a job for propagation models. Propagation models are very useful in estimating the radio coverage area of a transmitter and mobile service provider also use it for planning their network because they allow optimization of the cell coverage while minimizing the intercell interference [6]. A large effort has been made to develop mathematical models to specify path losses in different environments. Propagation path loss model can be categorized into three types such as empirical, statistical and deterministic [5][10][24]. Empirical models use measurement data to model a path loss equation. During the process of formulating these formula, a relationship between the received signal strength and other parameters such as antenna heights and terrain profiles was found through the use of extensive measurement and statistical analysis. The Stanford University Interim (SUI) and Cost-231 Hata are example of this path loss type.

In mobile communication system, radio transmission often takes place over irregular terrain. One of the factor that need to be considered for estimating the path loss is the terrain profile of a particular area and this factor may vary from a simple curved earth profile to a highly curved mountainous profile [6]. There are many propagation models available that share the same goal which is to predict path loss and the difference between them is their approach, complexity and accuracy.

Desired quality of service (QoS) cannot be accomplished by relying on the enhancements just from the perspective of technology. Nowadays, the deployment of cellular network is mostly from their appropriate location in a particular operational area compare to the traditional network having a large number of base and relay stations installed. A design and deployment of cellular system is considered successful if several factor such as the ability to predict minimum value of transmission time in a given frequency, to meet the demand with acceptable quality of service in a predefined coverage area and effect of signal propagation can be met [20]. With all the factor that need to be considered, therefore the understanding and estimating the received signal in different terrain areas with pinpoint accuracy is needed in order to obtain satisfied signal.

This paper provides a comparison of some of the existing models to measure the received signal power in the wireless cellular networks. Differences between the three path loss models are presented in this paper for urban and suburban environment by considering their individual parameters with specific frequency bands such as 1.8GHz and 2.3GHz. These bands are also the proposed carriers for 4G networks that are envisioned by Malaysian mobile operators [26][27].

II. SIMULATION SETUP

The computation was taken out for typical urban and suburban environment. Two frequency bands, 1800MHz (1.8GHz) representing 4G LTE and 2300MHz (2.3GHz) for WiMAX are used in the simulation. The elevation of base stations and receiver antenna height were considered as 45 meters and 1.5 meters respectively. For link budget calculation, different parameter is needed, such as transmitted power, transmitter antenna gain, transmitter losses, miscellaneous losses, receiver antenna gain and receiver loses. The values of these parameters are 43dBm, 18dB, 8dB, 10dB, 18dB and 4dB respectively.

III. PATH LOSS MODEL

Achieving the optimal performance is a critical issue in the wireless cellular networks. From the network planning perspective, one needs to be able to successfully model the impact of radio channel estimation for obtaining the QoS. In wireless communication networks, data transmission between transmitting and receiving antennas is achieved by means of electromagnetic waves. These waves can be affected by several factors, such as distance, reflection, diffraction, free space loss and absorption. Different environments such as urban, suburban and rural can be a reason for signal reduction.

Ensuring the service area is covered by minimal number of infrastructure is one of the benchmark of successful deployment of any wireless network. Therefore, one of the important parameters required to achieve good service network is the received signal power. Predicting path loss and received signal power during planning process was done using propagation model. Propagation behavior differs in different environment and realizing this matter several models have been developed to meet that requirements. These models usually applicable to frequencies below 2GHz. In this section, some relevant propagation models will be introduced and their accuracy to measured data for network deployment in 1.8GHz and 2.3GHz for urban and suburban environment will be compared.

There is no doubt that path loss has a great effect on the development of mobile communication systems. These models is handy in term of specify the location of cell sites and network cost for developing the optimal network performance. The consequences of selecting inaccurate selected models will lead to inappropriate location of cell site.

To predict path loss from two different scenarios such as from base station to mobile subscribers and from base station to relay station links, there are several propagation models that can be implemented for both cases. Calculations have been made for different mobile and relay station links with correction factors for the different heights which is above and below rooftop and street levels in order to reach accurate path loss values.

A. *Stanford University Interim (SUI) Model*

As indicated in the name, Stanford University proposed this model in 2007 implemented for frequencies below 11GHz. The model is categorized into three types of terrains, namely type A applicable for urban environment, type B applicable for suburban and type C applicable for rural environment. For hilly terrain with moderate to heavy foliage densities, type A is more suitable to be implemented while for flat terrain with moderate to heavy tree densities or hilly terrain with light tree densities, type B is the suitable choice. Type C useable for flat terrain with light tree densities and which has a smallest path loss exponent. The basic equation for SUI propagation model with correction factors can be represented as [4][6][9][18][21]:

$$PL = A + 10\gamma \log_{10}\frac{d}{d_0} + X_f + X_h + s \tag{1}$$

for the $d > d_0$ cases:

Here the parameters are: d – distance between receiver and transmitter in meters; d_0 – reference distance which is 100 meters; λ – is the wavelength in meters; X_f – as a correction for frequencies above 2GHz in MHz; X_h – correction factors for receiving antenna height above 2 meters; s – correction for shadowing in dB where the values between 8.2 and 10.6 are considered for shadow fading because of trees and finally γ – as a path loss component. In the equation, parameters A and γ are defined as follows [18][21]:

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \tag{2}$$

$$\gamma = a + bh_b + \frac{c}{h_b} \tag{3}$$

$$X_f = 6.0\log_{10}\left(\frac{f}{2000}\right) \tag{4}$$

where, hb – is the parameter of base station antenna height which can be between 10 and 80 meters. The values of a, b and c depend on the types of terrain (refer Table 1).

Table 1: Parameter values of different terrain for SUI model

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

B. *Cost-231 Hata Model*

Based on previous mathematical Hata-Okumara radio propagation model, emerge a new propagation model called Cost-231 Hata model that are proposed for urban areas. Later this propagation path loss model is adapted and evaluated for rural and suburban areas. The frequency band suggested for this type of radio propagation ranging between 500MHz and 2000MHz. Correction factors are needed for higher frequency application. The basic equation of the Cost-231 Hata model can be expressed as [4][6][9][18][21]:

$$PL = A + B\log_{10} d + C - a(h_r) \tag{5}$$

$$A = 46.3 + 33.9\log_{10} f - 13.82\log_{10} h_b \tag{6}$$

$$B = 44.9 - 6.55\log_{10} h_b \tag{7}$$

$$a(h_r) = (1.1\log_{10} f - 0.7)h_r - (1.56\log_{10} f - 0.8) \tag{8}$$

$$c = \begin{cases} 0\ dB\ for\ medium\ cities\ and\ suburbun\ areas \\ 3\ dB\ for\ metropolitian\ areas \end{cases} \tag{9}$$

Where, PL is a median path loss, calculates in dB, f is frequency of transmission in MHz; h_b is the base station antenna effective height in meter; d is a link distance between transmitter and receiver; h_r is the mobile station antenna effective height; and $a(h_r)$ is the correction factor.

C. *Ericsson Model*

As specified in the name, Ericsson Inc. developed Ericsson path loss model in order to predict the path loss under the network planning software. This model is the modified version of Hata-Okumara model and changes are made to adapt some parameters according to the propagation environment. The path loss equation for this model can be expressed as follows [9][18][21]:

$$PL = a_0 + a_1\log_{10} d + a_2\log_{10}(h_b)$$

$$+ a_3\log_{10}(h_b)\log_{10} d - 3.2(\log_{10}(11.75h_r))^2$$

$$+g(f) \tag{10}$$

Where f is the envisioned frequency band, transmitter ntenna height as a h_b while h_r is the receiver antenna height and the following $g(f)$ can be expressed as [9][18][21]:

$$g(f) = 44.49\log_{10} f - 4.78(\log_{10} f)^2 \tag{11}$$

Values for a_0, a_1, a_2, and a_3 are presented in the Table 2 for the different terrains.

Table 2: Parameter values of different terrain for Ericsson model

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.60	12.0	0.1

The values of parameters a_0 and a_1 for rural and suburban area are based on the Least Square (LS) method.

III. SIMULATION RESULTS

The validity of models is examined by comparing their radio propagation models implemented for different type of environment using MATLAB simulation measurements. In the simulation, parameters as shown in Table 3 were used in the link budget calculation to obtain accurate results. Table 3 shows the summary of parameter that were used in the simulation process.

Table 3: Summary of parameters used in the simulation

Parameter	Value
Transmitted power (Pt)	43dBm
Transmitter antenna gain (Gt)	18dB
Transmitter losses (Lt)	8dB
Miscellaneous losses (Lm)	10dB
Receiver antenna gain (Gr)	18dB
Receiver losses (Lr)	4dB

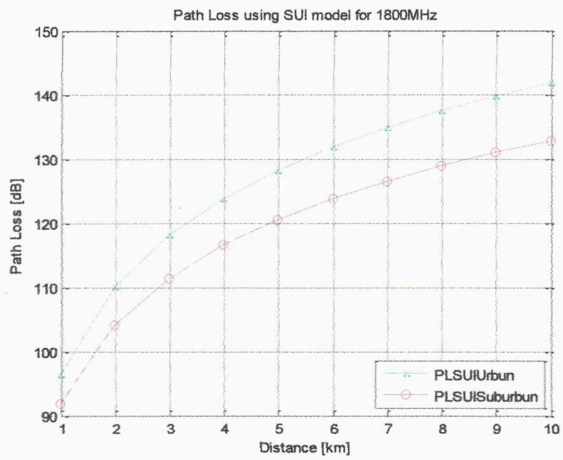

Figure 2: SUI path loss for 1.8GHz

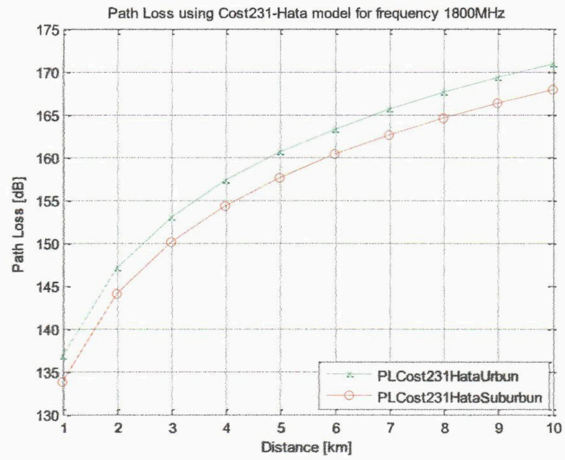

Figure 1: Cost-231 path loss for 1.8GHz

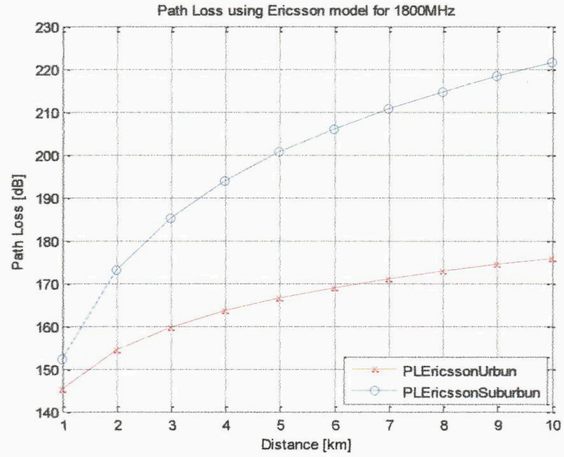

Figure 3: Ericsson path loss for 1.8GHz

In this study, the path loss for two different environments, urban and suburban are estimated and the result is shown in Figure 1 – 6. The distance for 4G LTE and WiMAX cell base station was varied in the range of 1 to 10 km and the carrier frequency was set to 1.8GHz and 2.3GHz. Table 4 provides the comparison between the selected model for 4G LTE while Teble 5 provides the comparison between the selected model for WiMAX.

Table 4: Summary of simulation path loss data measured using 1.8GHz at 10km distance

Propagation environment	Path loss model	Path loss value (dB)
Urban	Cost-231	170.8
	SUI	141.9
	Ericsson	175.6
Suburban	Cost-231	167.8
	SUI	132.8
	Ericsson	221.3

Generally, it is known that lower frequencies produce lower path loss values. As shown in the Figure 1 - 6, the frequency increment leads to proportionally increase of their path loss components. From observations of three propagation models, a path loss method that operating with a frequency of 1.8GHz has lower propagation exponent compare to those operating at 2.3GHz frequency. From Table 4, the path loss values for urbun environment is higher compare to suburban environment for Cost-231 model and SUI model with gap between these two environments is 3dB and 9.1dB respectively. For Ericsson model, the situation is different where the path loss values for urban environment is lower than suburban environment with gap between these two environment is 45.7dB. At 10km distance, SUI model achieves less path loss value compare to other model while Ericsson model achieves high path loss values. Therefore, SUI model is more suitable to be implemented for both urban and suburban region for 4G LTE system.

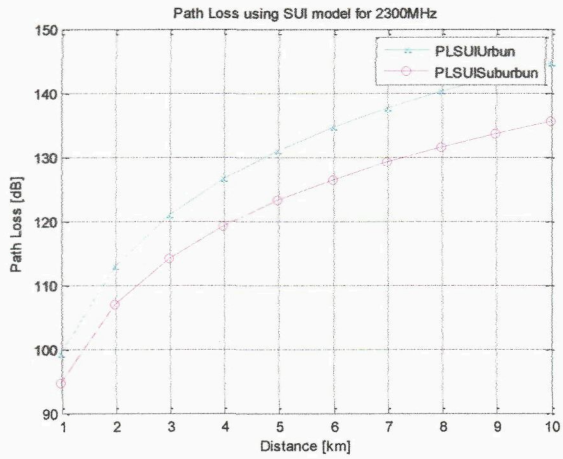

Figure 5: SUI path loss for 2.3GHz

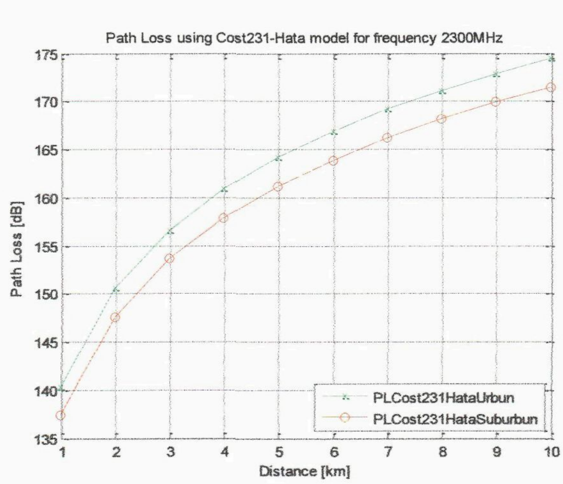

Figure 4: Cost-231 path loss for 2.3GHz

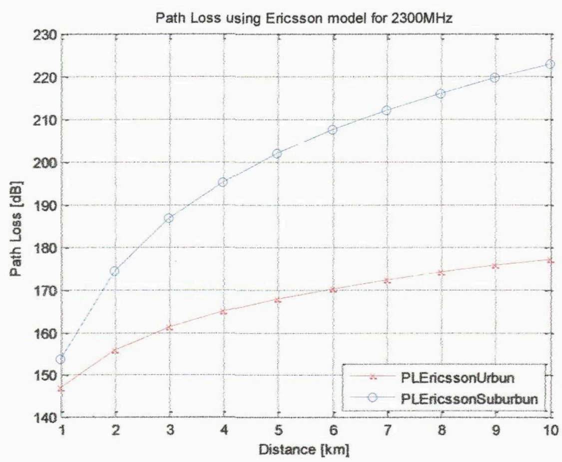

Figure 6: Ericsson path loss for 2.3GHz

Table 5: Summary of simulation path loss data measured using 2.3GHz at 10km distance

Propagation environment	Path loss model	Path loss value (dB)
Urbun	Cost-231	174.4
	SUI	144.6
	Ericsson	177.0
Suburbun	Cost-231	171.4
	SUI	135.5
	Ericsson	222.7

From Table 5, the path loss values for urban environment is higher compare to the suburban environment for Cost-231 model and SUI model with gap between these two environments is 3dB and 9.1dB respectively. For Ericsson model, the situation is different where the path loss values for urbun environment is lower than suburban environment with gap between these two environment is 45.7dB. At 10km distance, SUI model achieves less path loss value compare to other model while Ericsson model achieves high path loss values. Therefore, SUI model is more suitable to be implemented for both urban and suburban region for WiMAX system.

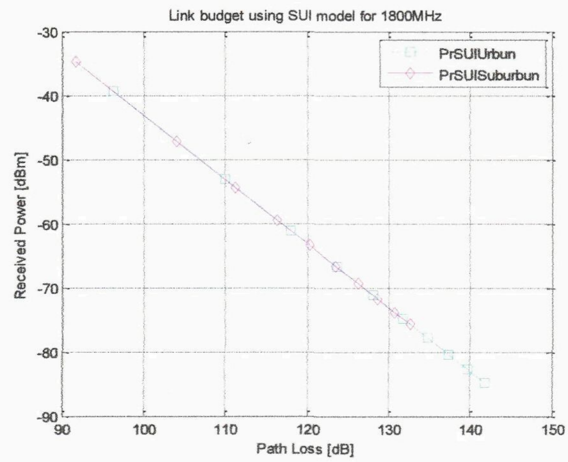

Figure 8: Link budget for SUI model using 1.8GHz

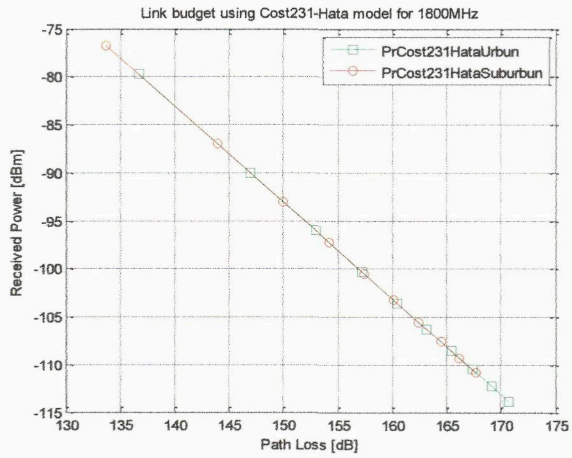

Figure 7: Link budget for Cost-231 model using 1.8GHz

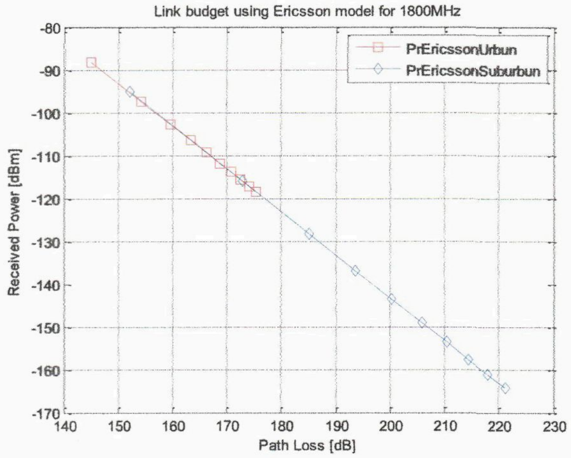

Figure 9: Link budget for Ericsson model using 1.8GHz

Table 6: Summary of received power data measured using 1.8GHz at 10km distance

Propagation environment	Path loss model	Received power value (dBm)
Urban	Cost-231	-113.8
	SUI	-84.87
	Ericsson	-118.6
Suburban	Cost-231	-110.8
	SUI	-75.77
	Ericsson	-164.3

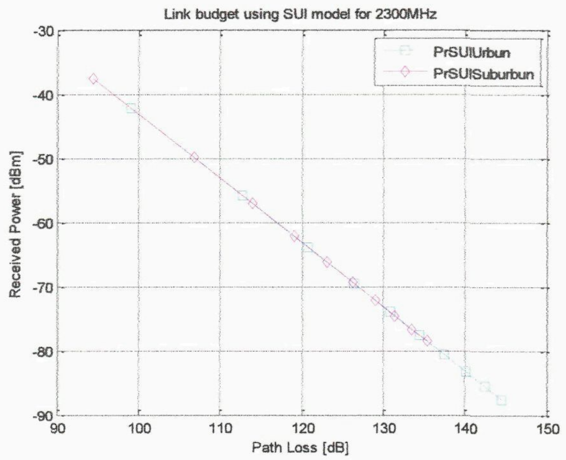

Figure 11: Link budget for SUI model using 2.3GHz

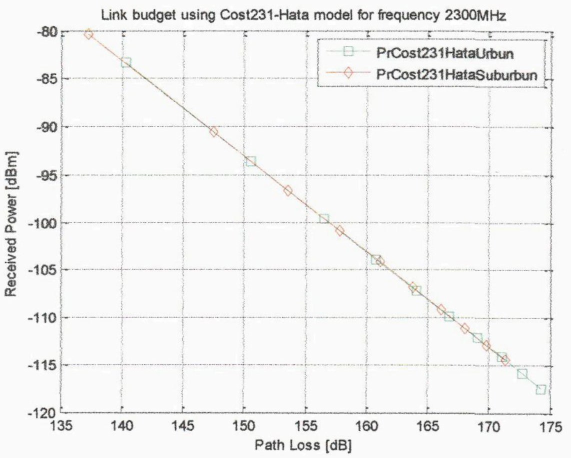

Figure 10: Link budget for Cost-231 model using 2.3GHz

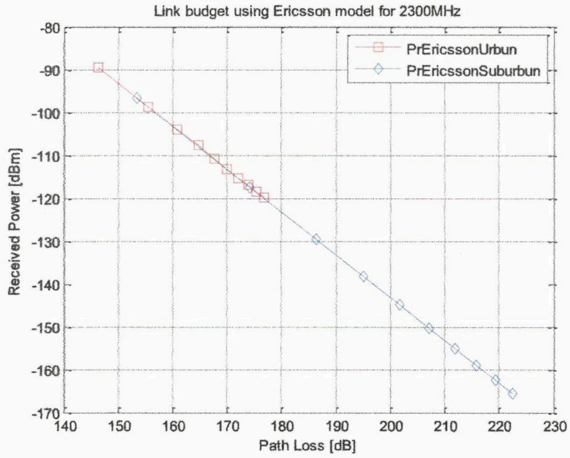

Figure 12: Link budget for Ericsson model using 2.3GHz

Table 7: Summary of received power data measured using 2.3GHz at 10km distance

Propagation environment	Path loss model	Received power value (dBm)
Urban	Cost-231	-117.4
	SUI	-87.64
	Ericsson	-120.0
Suburban	Cost-231	-114.4
	SUI	-78.54
	Ericsson	-165.7

Link budget equation can be expressed as [3]:

$$P_r = P_t + G_t - L_t - PL - L_m + G_r - L_r \quad \textbf{(12)}$$

where PL is the path loss and other parameters are obtained from Table 3.

Link budget is another method to verify the effectiveness of propagation path loss model that being implemented in certain environement by considering the gains and losses in a transmission system. The purpose of calculating link budget is to determine the required power level and for investigating the base station coverage. From Table 6 and 7, SUI model produced higher received power at the distance of 10km compared to other model. Therefore, SUI model can cover large areas when implanted in urban and suburban environment. Cost-231 model and Ericsson model is not a suitable choice 4G LTE and WiMAX as they produce lower received power and cannot cover large area for cellular communications systems.

IV. CONCLUSIONS

This paper presents an overview of the propagation models of 4G wireless networks at 1.8GHz for comparing to 2.3GHz deploy in macro cell urban and suburban areas. For each type of propagation, the model path loss graph was generated and compared among different frequency bands. SUI model shows the lowest path lost in all the terrains while Ericsson model illustrates highest path loss in urban and suburban area. This can be verify by link budget result when SUI model produce high received power at distance 10km compare to the other models.

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