

## RESEARCH PAPER

# Comparison Between Measured and Empirically Predicted Radio Wave Pathloss in Rural Environment

<sup>1</sup> Sevan Siyyah Abdullah, <sup>2</sup>Sattar Othman Hasan

<sup>1&2</sup>Physics Department, College of Education, Salahaddin University-Erbil, Kurdistan Region, Iraq.

### ABSTRACT:

In this study a comparative analysis of various empirical models for estimating radio wave propagation path losses with those measured experimentally for the rural area in Erbil city is presented. In Gazna village near the center of the Erbil city, one of the Korek telecommunication towers is selected for the purpose of comparative analysis and seven different empirical models were utilized. The implemented models are free space model, Electronic Communication Committee (ECC-33), Stanford Interim University (SUI), Optimization Cost-231, Okumura-Hata, Egli, and Ericson models. The data were collected at operating frequencies of 1800 MHz and 2100 MHz using drive test equipment with Sony-Ericson mobile phone to measure received signal strength. Generally, the analyzed results, which are based on the Mean Absolute Percentage Error (MAPE) values, shows that the Egli and ECC-33 overestimated while both FSPL and Okamura-Hata are underestimated path loss values. In addition, the SUI and Optimized-Cost-231 models are providing minimum MAPE path loss values which are 0.49 and 0.55 at 1800 MHz and 0.07 and 0.16 at 2100 MHz, respectively. Therefore, in order to improve network performance and accurate estimation of financial feasibility, these two models especially SUI model can be used successfully and confidently in the design of the wireless communication system in the rural area of Erbil city in Kurdistan region of Iraq.

KEY WORDS: Network planning: path loss: received signal strength: radio wave propagation.

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### 1.INTRODUCTION:

Erbil town is the capital city of Kurdistan region in Iraq. It is an urban city characterized by sites placed near to moderate and tall mountains, commercial and residential buildings as well as small size industries with large offices. Here, the access to Global System for Mobile Communication (GSMC) has become an active area of interest since 2005 up to now.

The GSM service providers in the town are Asia cell, Korek Telecom, and Zain operating at 900MHz, 1800 MHz and 2100MHz, but the quality of their services is poor due to several factors such as high-rise building, trees, location and height of the antenna towers. The investigation and specification of the possible factors and proper treatments through scientific research became necessary towards solving problems faced by the customers (Singh, 2012). One of the main factors that makes the mobile communication systems to provide their services with a suitable quality and with a high data rate capacity, is accurate estimation of the signal strength in the region under consideration.

In wireless communication systems, the signals are transferred between transmitter and receiver antennas using electromagnetic waves. The propagated signals usually reduced in its strength

#### \* Corresponding Author:

Sevan Siyyah Abdullah

E-mail: [sevan.abdullah@su.edu.krd](mailto:sevan.abdullah@su.edu.krd)

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with distance away from the transmitting tower due to terrain factors such as buildings height, mountain, tall trees and location of the antennas (Singh, 2012). This reduction in radio wave power signals as it propagates from transmitter to the receiver is called path loss (Singh, 2012), (Akande et al., 2017). The factors that lead to path losses in radio wave propagation are mainly due to free space, absorption, diffraction, scattering and multipath signal losses as well as type of environment (urban, sub-urban and rural), height of transmitter and receiver antennas and carrier frequencies (Omolaye et al., 2015). Basically, the path loss is defined as the ratio of the transmitted power  $P_t$  to the received power  $P_r$  and mathematically is expressed as:

$$PL(\text{dB}) = 10 \log \frac{P_t}{P_r} \quad (1)$$

Estimation of radio wave path losses are very important in predicting signal strength power at the receiver, link budget design analysis, interference optimization analysis and cell size estimation. There is different model for path loss estimation and for different types of environments such as urban, suburban, and rural.

Generally, the evaluation of radio wave propagation path losses is determined by different models, such as deterministic, stochastic and empirical models (Akande et al., 2017) and (Mardeni & Priya, 2010). In deterministic model all the objects in the mediums must be defined accurately and then the physical laws of Maxwell equations is implemented to specify the mechanisms of radio wave propagation in a particular location (Akinwole & J.J, 2013). The accuracy of deterministic models is very high but it needs high computation complexity due to requirement of 3D data about the propagation environment. In Stochastic models the environment is considered as a series of random variables that are least accurate but require few information about the area of wave propagation and employ less processing power to generate predictions (Ghosh et al., 2012). On the other hand, empirical models which is based on the observed and extensive measurements data are usually used in practice than statistical and deterministic propagation models for estimating path loss. Generally, empirical models are simple

in nature, low cost and require less calculation effort to predict path losses with acceptable accuracy (Akinwole & J.J, 2013).

Different empirical prediction models have been adapted to different environment and at different frequency operation. The classification of these models for use into urban, suburban and open (rural) areas has been addressed in (Kamboj et al., 2011) and (Sharma, 2011). These models include the free space model, Stanford University Interim (SUI), COST 231, Okumura Hata, Lee, Walfish-Ikegami, ECC-33 model and others. Some wireless network providers use the COST 231-Hata and Okumura-Hata models for radio wave propagation network designing. However, the accuracy of the available models is limited when they are used for an environment of different geographical characteristic formation from that for which they have been proposed. Therefore, the network performance is mostly relying on the accuracy of the prediction model that implemented for the planning designation (Imoize & Oseni, 2019).

Free space and Okumura - Hata models has been employed to estimate broadcasting radio wave signal strength for a television station in Akure Ondo State, Nigeria. This work reveals that the performance of Okumura-Hata model is reliable for good signal prediction in the Akure metropolis (Imoize & Oseni, 2019). Moreover, the modified Ericson model which is proposed by (Akande et al., 2017) at 2100MHz for the Alagbado axis of Lagos, Nigeria showed best performance in compare to the measured path loss data. On the other hand, there are a lot of researches on radio wave propagation path loss measurements and channel modeling, especially for rural environments but we are not been able to decide which of them is suitable for the prediction of radio wave path losses in the environment of Erbil city.

Therefore, this work is established to investigate different empirical path loss models against measured radio wave propagation path loss in rural environment of Erbil city. For this purpose, one of the Korek telecom cellular sites operating at frequencies 1800 MHz and 2100 MHz is selected and various empirical models have been tested. This site is located at Gazna village which is a small size village located near to the center of the city under consideration. The

procedure of the measured and calculated results is described in the following sections.

## 2. EMPIRICAL MODELS

As previously mentioned, the radio wave propagation path loss greatly affected on the quality of services delivered by mobile communication systems. Therefore, accurate estimation of radio wave propagation path loss may lead to the development of efficient design and operating at high quality with high-capacity network. There are a lot of empirical path loss models employed by previous researchers which are helpful in the planning of best Global System for Mobile Communication (GSM) networks.

This work is established to predicting radio wave propagation path loss in rural area of Erbil city in Kurdistan region of Iraq by comparing measured data with those estimating by the different available empirical models. For this,

$$PL_{\text{FSPL}} = 32.45 + 20 \log_{10}(d) + 20 \log_{10}(f_c) \quad (2)$$

$d$ : Transmitter to receiver distance in km,

$f_c$ : operating frequency in MHz.

### 2.2 OKUMURA –HATA MODEL

The Okumura-Hata model is a set of empirical formula obtained on the bases of signal power measurements and data extrapolations from curves derived by Okumura and is valid between 150 MHz to 1500 MHz. In this model the profile terrain, such as hills or other obstacles between

seven models have been utilized namely, free space, ECC-33, Stanford Interim University (SUI), Optimized Cost-231, Okumura-Hata, Egli and Ericson models (Akande et al., 2017). A brief description for each of these models are presented in the following subsections.

### 2.1 FREE SPACE PATH LOSS MODEL

The free space path loss is a theoretical estimation for the prediction of RF signal strength at a particular distance away from the transmitting tower neglecting losses which need to be accounted for while estimating the signal at a location. However, the Free Space Path Loss (FSPL) is a reliable approximation for predicting the signal losses as propagating through the space and is expressed mathematically as (Akande et al., 2017):

the transmitter and receiver are neglected. This assumption is considered by Hata and Okumura due to the fact that the transmitter would normally be placed on hills (Oluwafemi & Femi-Jemilohun, 2018). Okumura-Hata's equations for rural environment is expressed as:

$$PL(\text{dB}) = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_t) + (44.9 - 6.55 \log_{10}(h_t)) \log_{10}(d) - 4.78(\log_{10}(f_c))^2 + 18.33 \log_{10}(f_c) - 40.94 - (1.1 \log_{10}(f_c) - 0.7)h_r - (1.56 \log_{10}(f_c) - 0.8) \quad (3)$$

Generally, in all models, the following parameter symbols have the same meaning and are as follows (P. Akinyemi et al., 2015):

$h_t$ : height of transmitter antenna in m,

$d$ : Transmitter to receiver distance in km,

$h_r$ : height of receiver antenna in m,

$f_c$ : operating frequency in MHz.

### 2.3 ELECTRONIC COMMUNICATION COMMITTEE (ECC-33) MODEL

The ECC-33 path loss model is developed by Electronic Communication Committee (ECC) which is based on Okumura model and is regarded as one of the most suitable models for estimating path losses. This model has been extended to be

applicable for predicting path losses for the frequencies up to 3.5 GHz by the International Telecommunication Union (ITU). In this model path loss is given by (Akinyemi et al., 2015) and (Khan & Kamboh, 2012) and the terms are defined as:

$$PL(\text{dB}) = A_{fs} + A_{bm} - G_t - G_r \quad (4)$$

where,  $A_{fs}$ : attenuation due to free space attenuation [dB],  $A_{bm}$ : basic median path loss [dB],  $G_t$ : transmitter antenna gain factor,  $G_r$ : receiver antenna gain factor.

The mathematical formula for each of these parameters is given by (Sharma, 2011) and (Chebil et al., 2013) and are expressed as:

$$A_{fs} = 92.4 + 20 \log_{10}(d) + 20 \log_{10}(f_c) \quad (5)$$

$$A_{bm} = 20.41 + 9.83 \log_{10}(d) + 7.894 \log_{10}(f_c) + 9.56[\log_{10}(f_c)]^2 \quad (6)$$

$$G_t = \log_{10}\left(\frac{h_t}{200}\right)(13.958 + 5.8[\log_{10}(d)]) \quad (7)$$

$$G_r = [42.57 + 13.7 \log_{10}(f_c)][\log_{10}(h_r) - 0.585] \quad \text{for rural and medium city} \quad (8)$$

$$G_r = 0.759(h_r) - 1.862 \quad \text{for large city} \quad (9)$$

## 2.4 STANFORD INTERIM UNIVERSITY (SUI) MODEL

This model is proposed by the IEEE 802.16 which is an extension of the Hata model by taking into account a correction parameter for frequencies above 1900 MHz. The SUI model is developed as a solution for network planning of the WiMAX at 3.5 GHz band. This model is applicable for base station antenna height between 10 m to 80 m, receiving antenna height between 2 m to 10 m (Bola & Saini, 2013) and (Chebil et al., 2013). In this model different mathematical

equation are proposed for predicting path losses in different propagation environments. The hilly areas with moderate or dense vegetation is considered as an urban, while a hilly area with low vegetation and heavy trees densities is regarded as a sub-urban and a flat area with light vegetation and low-density trees is assumed as a rural terrain.

Generally, the path loss formula that are proposed by this model for each mentioned environment along with its correction factors are expressed as:

$$PL(\text{dB}) = A + 10 \gamma \log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + s \quad \text{for } d > d_o \quad (10)$$

where, ( $d_o$ ) is the reference distance ( $d_o = 100 \text{ m}$ ), ( $d$ ) is the distance between transmitter and receiver antennas in meters, ( $X_f$ ) is the frequency correction factor for frequency above 2 GHz, ( $X_h$ ) is the correction factor for receiving antenna height and ( $s$ ) is a parameter used to account for tree and clutter shadowing and its values are between 8.2 dB to 10.6 dB (Mardeni & Priya, 2010).

$$X_f = 6.0 \log_{10}\left(\frac{f_c}{2000}\right) \quad (11)$$

$$X_h = -10.8 \log_{10}\left(\frac{h_r}{2000}\right) \quad \text{for Terrains 1 and 2} \quad (12)$$

$$X_h = -20.0 \log_{10}\left(\frac{h_r}{2000}\right) \quad \text{for Terrain 3} \quad (13)$$

The parameter ( $\gamma$ ) is called path loss exponent and its values is determined by the equation:

$$\gamma = a - b h_t + \frac{c}{h_t} \quad (14)$$

where,  $a$ ,  $b$  and  $c$  are constants and their values are given in Table 1 which are vary according to the types of the environments (Milanovic et al., 2007). The value of the exponent parameter is ( $\gamma = 2$ ) for LOS propagation area, ( $3 < \gamma < 5$ ) for urban NLOS environment and ( $\gamma > 5$ ) for indoor propagation medium (Sharma & Singh, 2010). Finally, the parameter  $A$  in the above equation is called as the intercept factor and is expressed as:

$$A = 20 \log_{10} \left( \frac{4\pi d_0}{\lambda} \right) \quad (15)$$

where,  $(\lambda)$  is the wavelength in (m),

**Table 1:** Parameter values in different environments for SUI model (Milanovic et al., 2007).

Model Parameter	Terrain 3	Terrain 2	Terrain 1
a	3.6	4.0	4.6
b (m <sup>-1</sup> )	0.0050	0.0065	0.0075
c (m)	20.0	17.1	12.6
s	8.2	9.6	10.6

## 2.5 OPTIMIZED COST-231 MODEL

The Optimization COST 231-Hata model is the extension of Cost-231 and it considered as an improvement version of the Hata model restricted to the frequency ranges from 1500 MHz to 2000 MHz, transmitter antenna height of 30 m

to 200 m, receiver antenna height is between 1 m to 10 m and the distance between them is 1 km to 20 km. Mathematically, the Optimization Cost-231 model as given by the (Akande et al., 2017) is expressed as:

$$PL(\text{dB}) = 41.42 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_t) - a(h_r) + [44.9 - 6.55 \log_{10}(h_r)] \log_{10}(d) + C_K \quad (16)$$

where,

$$a(h_r) = (1.11 \log_{10}(f_c) - 0.7) h_r - (1.56 \log_{10}(f_c) - 0.8) \quad \text{in dB} \quad (17)$$

The value of the correction factor ( $C_K$ ) is (0 dB) for medium city and suburban areas whereas its values for urban or large cities is (3 dB) (Shebani et al., 2013).

## 2.6 EGLI MODEL

Egli model is also an empirical model that is used for estimating radio wave propagation path losses and is suitable for use in the frequency bands of 3 MHz to 3 GHz. This model is normally

applicable when there is Line of Sight (LOS) between the base station transmitting antenna and mobile receiving antenna (Chebil et al., 2013). Egli path loss is calculated using the following equations (Mardeni & Priya, 2010) and (Imoize & Ogunfuwa, 2019):

$$PL(\text{dB}) = 20 \log_{10}(f_c) + P_o + 76.3 \quad h_r \leq 10 \quad (18)$$

$$PL(\text{dB}) = 20 \log_{10}(f_c) + P_o + 83.9 \quad h_r > 10 \quad (19)$$

where,  $P_o(\text{dB}) = 40 \log_{10}(d) - 20 \log_{10}(h_t) - 10 \log_{10}(h_r) \quad (20)$

## 2.7 ERICSON MODEL

The Ericson model also based on the modification of Okumura-Hata model which allow the change in parameters according to the

radio wave propagation terrain. The calculation of the path loss values according to this model is obtained by the use of the following equations (Mardeni & Priya, 2010) and (Imoize & Ogunfuwa, 2019).

$$PL(\text{dB}) = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_t) + a_3 \log_{10}(h_t) \cdot \log_{10}(d) - 3.2 [\log_{10}(11.75 h_r)^2] + g(f_c) \quad (21)$$

Where,

$$g(f_c) = 44.49 \log_{10}(f_c) - 4.78 [\log_{10}(f_c)]^2 \quad (22)$$

The values of the parameters ( $a_0, a_1, a_2$  and  $a_3$ ) for different types of terrain environments are presented in Table 2 (Zakaria et al., 2015).

**Table 2:** Parameter values of ( $a_0, a_1, a_2$  and  $a_3$ ) for different environment area (Zakaria et al., 2015).

Environment	$a_3$	$a_2$	$a_1$	$a_0$
Urban	0.1	12.0	30.20	36.20
Rural	0.1	12.0	100.6	45.95
Suburban	0.1	12.0	68.93	43.20

## 3. MATERIALS AND METHOD

In order to predict the path loss model of cellular transmission, actual data measured on site is required. Here, a downlink data was collected on a given site of the Korek telecom transmitter antennas located at Gazna village near center of the Erbil city which is characterized by desert land region with small sized building and low population. The materials that are used for this study included Ericsson Test Mobile System (TEMS) investigator software, mobile phone handset complete with charger and other require equipment with a laptop. Moreover, the signals frequencies operating in 1800 MHz and 2100 MHz were taken into consideration in this work. The experimental data were obtained by locating the drive tests on the mentioned sites located in rural environment near the Erbil city. The procedure for measuring signal strength for both

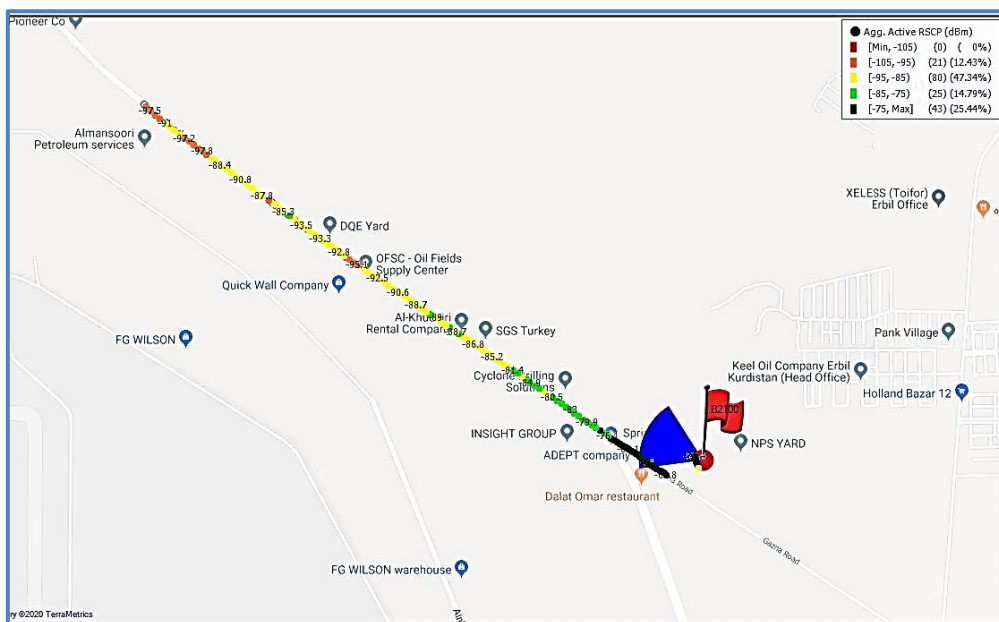
GSM operation frequencies were obtained through these drive tests

conducted along a given selected route in the mentioned village and is topographically shown in Figure 1.

The mobile phone handset was used to identify the signal strength during the data collection steps. The received power signal strength was recorded starting from a distance of 250 m from the mobile base station and along the displayed route from the site up to a distance of about two kilometers. The equipment for the drive test was placed in a vehicle maintained at an average speed of  $30 \frac{\text{km}}{\text{h}}$  and mobile antenna height of the order of 1.5 m. The measured signal power is transferred to the TEMS log file in the laptop by using Ericsson mobile phones. Measurement was conducted in the company of Korek telecom technique team in November 2019. The coordinate for the tower site with its height, transmitting power as well as its antenna type are presented in Table 3.

**Table 3:** Simulation parameters of the selected Korek tower site.

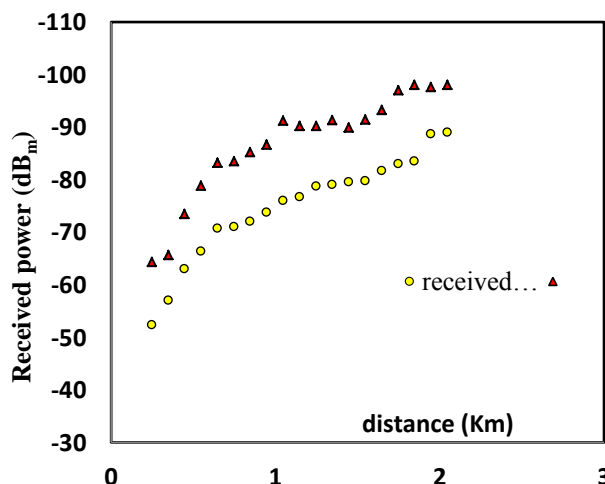
Parameters	Antenna type	Tower location	Operation frequency ( $f$ )	Mobile antenna height ( $h_r$ )	Transmitter antenna height ( $h_t$ )	Base station transmitter power ( $P_t$ )
Specification	K-80010485	Gazna-B	1.8 GHz 2.1 GHz	1.5 m	23 m	43 dBm



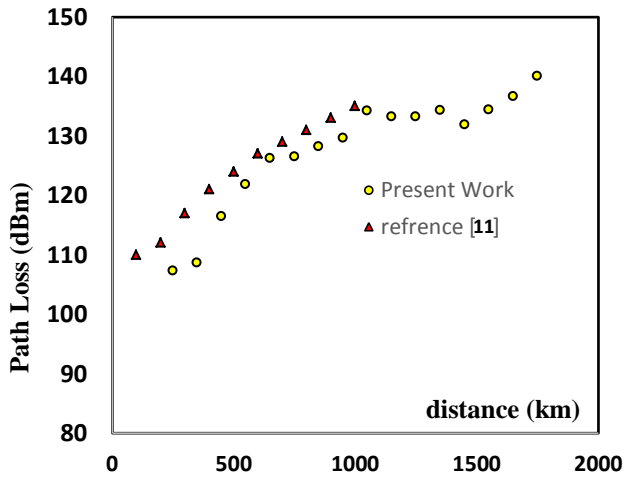
**Figure 1.** Log file representing the received signal level distribution in Gazna area.

**4.RESULTS**

The measured received signal strength values during the drive test in the mentioned environment and at both operating frequencies are presented in Figure 2. On the other hand, the signal path loss values was also evaluated through the measured received signal strength power using eq.(1) and the results are displayed in Figure 3. In addition, the path loss value that is measured by (Akinyemi et al., 2015) in Nigeria for the similar environment are also presented on the same figure.



**Figure 2.** Measured signal strength versus distance from the transmitting tower of height  $h_t = 23$  m.



**Figure 3.** Variation of measured path loss with distance away from the base station at frequency operation of 2100 MHz

Moreover, specification of the suitable employed empirical model also has been performed by comparing their predicted pathloss to those measured practically. For this purpose, all of the mentioned models with their formula equations have been unified together in a MATLAB computer program. The computed

$$RMSE = \frac{1}{n} \sum_{t=1}^n \sqrt{(P_{mt} - P_{Rt})^2} \tag{24}$$

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{(P_{mt} - P_{Rt})}{P_{mt}} \right| \times 100\% \tag{25}$$

where:  $P_{mt}$  is the mean value of measured data,  $P_{Rt}$  is the mean value of predicted path loss values and ( $n$ ) is the number of data points (Fesseha,

values for the mentioned path loss prediction models were identified using equations (2), (3), (4), (10), (16), (18) and (21). The computation results of the path loss values estimated by these models and those measured practically by equation (1) are determined through a developed MATLAB code simulation and are shown together on the path loss distributed graph as shown in Figures 4a and 4b for frequency operation of 1800 MHz and 2100 MHz, respectively.

Furthermore, the most accurate identification of the reliable model for predicting path loss in this environment can be identified more accurately by calculating the root means square error (RMSE) and mean absolute percentage error (MAPE) for each model against measured values. These two parameters were evaluated by using the following mathematical expression as given by (Erceg et al., 1999). and the results of the comparison are presented in Table 4.

2018). The computed results of these two parameters are also displayed in the form of histogram as shown in Figures 5.

**Table 4:** Performance of different path loss models at operating frequency of [1.8 and 2.1] GHz

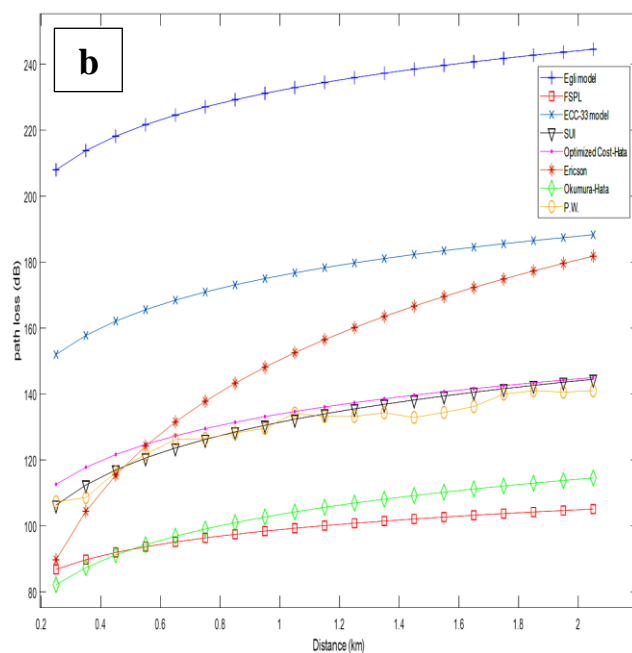
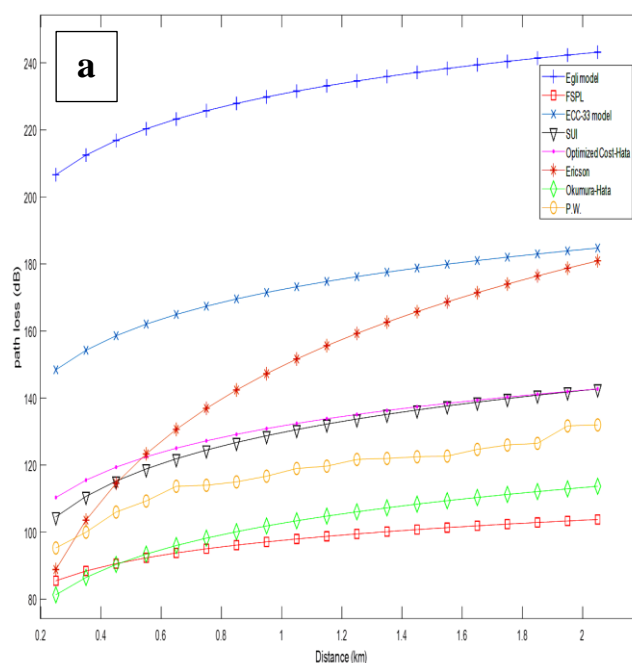
No.	Model	[1.8] GHz		[2.1] GHz	
		RMSE	MAPE	RMSE	MAPE
1.	FS-Model	39.65	1.31	29.04	0.95
2.	ECC-33	37.91	1.27	29.48	0.97
3.	SUI	12.06	0.49	1.85	0.07
4.	Opt. Cost231	14.00	0.55	4.31	0.16
5.	Okumura - Hata	15.30	0.74	26.4	1.33
6.	Egli	112.71	2.56	102.10	2.31
7.	Ericson	31.28	1.17	20.20	0.78



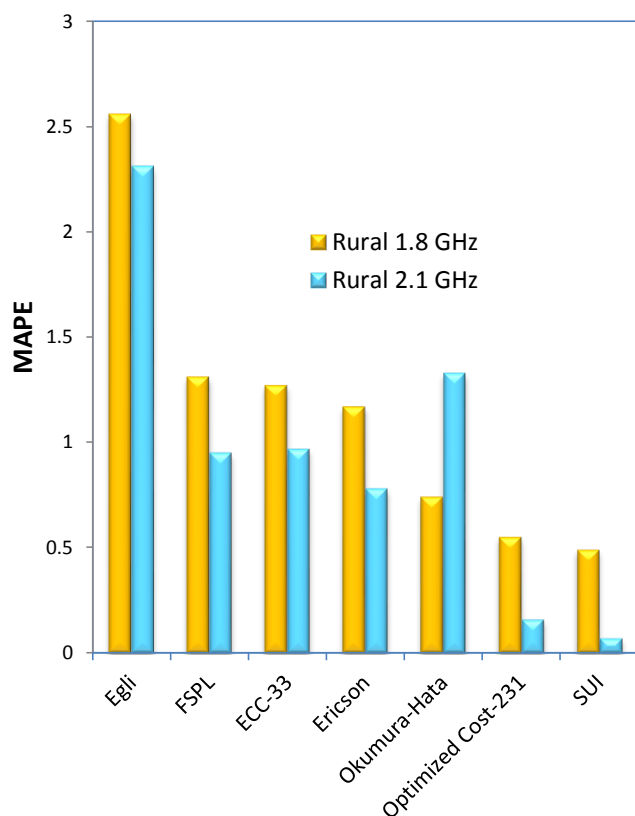
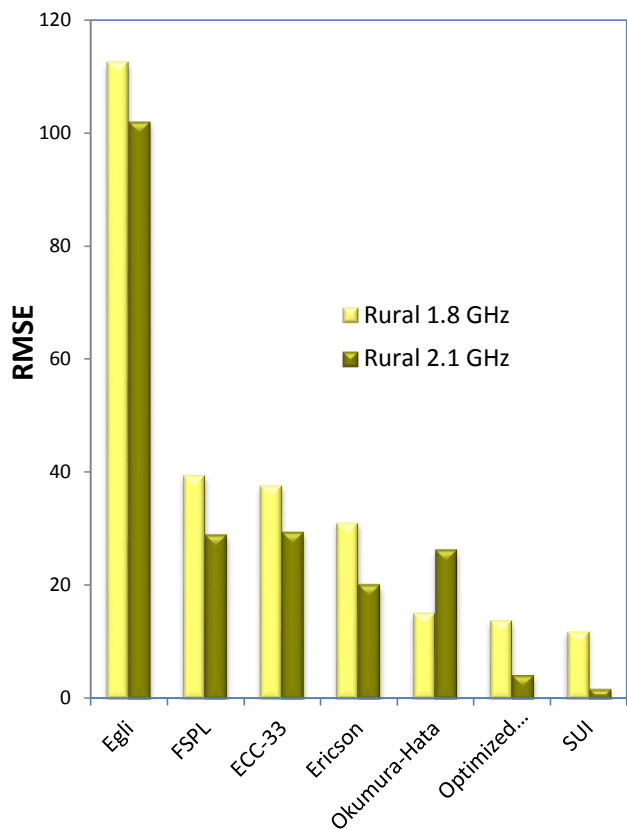
## 5.DISCUSSION

The results of figures 2 and 3 indicate that the signal strength power and path loss values decrease with increasing distance from the tower and also with increasing frequency of operation. In addition, it is evident to note from these two figures that there was no signal reception beyond 2 km. In addition, the comparison of the measured path loss values in our region and those measured by (Akinyemi et al., 2015) at the operation frequency of 2100 MHz indicate the accuracy of our measurement procedure.

Figures 4a & 4b, display that the path loss is seen to increase with distance away from the base station and with the use of all investigated models but in different behavior. Generally, the computed results presented in these two figures implies that the path loss that estimated by Egli and ECC-33 models are overestimated while those obtained by Okamura-Hata and FSPL models are underestimated compare to path loss values measured experimentally. Moreover, it is clearly seen from Figure 4 that the path loss values obtained with SUI and Optimized-Cost-231 followed by Ericson models are very close to those measured experimentally at both operating frequencies. From the results presented in Table 4, and those shown in Figure 5, one clearly observes that the SUI and Optimized-Cost-231 are provide the lowest percentage error values at both operational frequencies regarded in this investigation. In addition, the Egli models followed by free space model showed the highest RMSE and MAPE value. Hence the SUI model which provide minimum error percentage can be considered as a best candidate and most reliable model for use in rural environment of Erbil city in the Kurdistan region of Iraq for planning and designation of any network system for such areas.



**Figure 4.** Comparison between measured and different empirical path loss model calculation versus distance from the transmitting tower antenna operating at: (a) 1.8 GHz and (b) 2.1 GHz.



**Figure 5.** Histogram representation of RMSE and MAPE with the use of different path loss models and at 1800 MHz and 2100 MHz

### 6.CONCLUSIONS

It was clearly seen from the results of this investigations that the radio wave propagation path loss increases with increasing distance away from the base station and operational frequencies. In addition, the measurement results indicate that the signal strength is dropped completely beyond about 2 km far from the base station. It is also evident from the computed results that the path loss values that predicted by SUI followed by Optimized-Cost-231 were in good agreement with those measured experimentally. Since, the MAPE values provided by SUI are 0.49 and 0.07, while for Optimized-Cost-231 are 0.55 and 0.16 at operation frequencies 1800 MHz and 2100 MHz, respectively. In addition, the computed results indicate that the Egli followed by ECC-33 models are generally overestimated path losses while FSPL and Okamura-Hata models are underestimated path loss values.

Therefore, it can be said that the SUI followed by Optimized-Cost-231 are best candidate models for predicting signal path loss successfully and

can be employing them confidently in the network planning and designing problems for wireless communication system in rural area of the city under consideration.

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### Conflict of Interest

There is no any conflict of interest and any funding sources of this research

### 7.REFERENCE

Singh, Y., 2012. Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss

- and Signal Strength. *International Journal of Computer Applications*, pp.37-41.
- Akande, A.O., Semire, F.A. & Adeyemo, Z.K., 2017. Performance Analysis and Optimization of Cost-231 - Hata Model for Mobile Communication in Nigeria. *International Journal of Computer Applications*, 173(6), pp.4-9.
- Omolaye, O.P., Igwue, G.A., Akpakwu, G.A., 2015. Okumura-Hata: A Perfect Model For Driving Route UHF Investigation, *American Journal Of Engineering Research*, 4(9), pp.139-147.
- Mardeni, R. & Priya, T.S., 2010. Optimised Cost-231 Hata Models for WiMAX Path Loss Prediction in Suburban and Open Urban Environments. *Modern Applied Science*, 4(9), pp.75-89.
- Kamboj, V., Gupta, D.K. & Birla, N., 2011. Comparison Of Path Loss Models For Wimax In Rural Environment At 3.5 GHZ. *International Journal of Engineering Science and Technology*, 3(2), pp.1432-37.
- Akinwale, B.O.H. & J.J, B., 2013. Comparative Analysis of Empirical Path Loss Model for Cellular. *American Journal of Engineering Research (AJER)*, 02(08), pp.24-31.
- Ghosh, P.M., Hossain, M.A., Abadin, A.Z., Karmakar, K.K., 2012. Comparison Among Different Large Scale Path Loss Models for High Sites in Urban, Suburban and Rural areas, *International Journal of Soft Computing and Engineering (IJSCE)*, 2(2), pp. 287-290.
- Sharma, P.K., 2011. Comparative Study of Path Loss Models Depends on Various Parameters, *International Journal of Engineering Science and Technology*, 3(6), pp.4683-4690.
- Imoize, A.L. & Oseni, A.I., 2019. Investigation And Path loss Modeling Of Fourth Generation Long Term Evolution Network Along Major Highways In Lagos Nigeria. *Ife Journal Of Science*, 21(1), pp.039-60
- Oluwafemi, I.B. & Femi-Jemilohun, O.J., 2018. Suburban Area Path Loss Propagation Prediction and Optimization at 900 and 1800 MHz. *Journal of Engineering and Applied Sciences*, 13(9), pp.2521-29.
- Akinyemi, P., Azi, S.O., Ojo, J.S. & Abiodun, C.I., 2015. Evaluation for suitable propagation model to mobileCommunications in South-South Nigeria urban terrain. *American Journal of Engineering Research (AJER)*, 4(4), pp.1-5.
- Khan, I. & Kamboh, S.A., 2012. Performance Analysis of Various Path Loss Models for Wireless Network in Different Environments. *International Journal of Engineering and Advanced Technology (IJEAT)*, 2(1), pp.161-65.
- Bola, G.S. & Saini, G.S., 2013. Path Loss Measurement and Estimation Using Different Empirical Models For WiMax In Urban Area. *International Journal of Scientific & Engineering Research*, 4(5), pp.1421-28.
- Chebil, J., Lawas, A.K. & Rafiqul Islam, M.D., 2013. Comparison Between Measured and Predicted Path Loss for Mobile Communication in Malaysia. *World Applied Sciences Journal (Mathematical Applications in Engineering)*, 21, pp.123-28.
- Milanovic, J., Rimac-Dirlje, S. & Bejuk, K., 2007. Comparison of Propagation Model Accuracy for WiMax on 3.5GHz. 14th IEEE International Conference on Electronic Circuits and Systems, 8(7), pp.111-14.
- Sharma, P.K. & Singh, R.K., 2010. Comparative Analysis of Propagation Path loss Models with Field Measured Data. *International Journal of Engineering Science and Technology*, 2(6), pp.2008-2013.
- Fesseha, N., 2018. Fine-tuning of Cost-231 Hata Path Loss Model for LTE Network: The Case of 4 Kilo Area. Ethiopia: Addis Ababa University.
- Erceg, V., Greenstein, L.J. & Tjandra, S.Y., 1999. An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments. *IEEE Journal On Selected Areas In Communications*, 17(7), pp.1205-11.
- Shebani, N.M., Mohammed, A.E., Mosbah, M.A. & Hassan, Y.A., 2013. Simulation and Analysis of Path Loss Models for WiMax Communication System. In Conference: The 3rd International Conference on Digital Information Processing and Communications. Dubai, UAE, January 2013. SDIWC.
- Imoize, A.L. & Ogunfuwa, T.E., 2019. Propagation Measurements of a 4G LTE Network in Lagoon Environment. *Nigerian Journal of Technological Development*, 16(1), pp.1-9.
- Oudira, H., Djouane, L. & Garah, M., 2019. Optimization of Suitable Propagation Model for Mobile Communication in Different Area. *International Journal of Information Science & Technology*, 3(3), pp.10-19.
- Zakaria, Y., Hosek, J. & Misurec, J., 2015. Path Loss Measurements for Wireless Communication in Urban and Rural Environments. *American Journal of Engineering and Applied Sciences*, 8(1), pp.94-99.