Performance analysis for a suitable propagation model in outdoor with 2.5 GHz band

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ABSTRACT

As demand for mobile wireless network services continues to rise, network planning and optimization significantly affect development. One of the critical elements in network planning is predicting pathloss. Thus, propagation models predict pathloss in indoor and outdoor environments. Choosing the appropriate propagation model for the area out of existing models is essential for network planning. Selected propagation models suitable with 2.5 GHz, such as Friis free space propagation model (FSPL), Stanford University Interim (SUI), Ericsson, Okumura, and COST-231 Hata models, are utilized for evaluation and compared with empirical data collected from long-term evolution (LTE) networks in urban areas. The best acceptable model is chosen based on statistical results such as mean, standard deviation, and root mean square errors (RMSE). The analytical results show Cost-231 Hata model fits the empirical pathloss with a minimum RMSE of 5.27 dB.

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1. INTRODUCTION

The revolutionary growth of wireless networks these days influences the development of wireless communication, especially in the quality of services (QoS) that manage telecommunication services' usability, performance, and reliability [1], [2]. Network planning plays a crucial key role in indoor and outdoor environments to obtain better QoS for wireless cellular networks [3], [4]. Also, the deployed devices are supported to optimize the wireless networks. It assists in selecting the optimal parameters such as cell location, transmitting power, the best channel for transmission, and planning to guarantee the new deployed wireless networks the requirements of users and operators [5], [6]. For all considerations to be efficient in the selected area with radio transmission, it's also crucial to pick the best possible propagation model.

In network planning, radio frequency (RF) propagation models are frequently used, mostly for initial deployment and predict pathloss. To improve and optimize the appropriate propagation model for the region, the radio signal coverage should be studied and investigated [7], [8]. Therefore, pathloss is the most important signal property that propagation models have estimated. Different propagation models have been proposed and studied the appropriate one based on various environments, for instance, (dense city, urban, suburban, and rural). Also, the signal is affected by how far the mobile device is from the base station, where the range distance starting from a few meters to a few kilometers [9], [10]. Therefore, the most significant factor for propagation models is the environment for mobile communication and the type of terrain, either flat open area, hilly, or inside building in a dense city. Typically, the specifics of the RF signal environment are not identified. Thus, the most efficient model that is taken into account all the considerations [11], [12].

Various propagation models have been used and classified into: firstly, the empirical models, which depend on the measurement for a specific region, such as log-distance, Okumura models, and Hata models. They are simple expressions representing the effect of obstacles that faced signal while traveling between the transmitter and receiver, and multipath and shadowing propagation models, but lack accuracy [13], [14]. Secondly, the semi-empirical models combine suitable statistical factors with the expression of physical phenomena, such as the two-ray, Cost-231 models [15], [16]. The parameter values can be tweaked to increase the accuracy of these models. Thirdly, the deterministic models that need complete information on the 3D area map to compute the received signal strength at certain points, like the ray-tracing model. These models are complex in mathematics expression and consider all obstacles that are faced by the propagated signal and the environmental situations [17], [18].

This work applies the empirical and semi-empirical propagation models to determine the pathloss for long-term evolution (LTE) cellular networks in an urban environment with a 2,500 MHz frequency range. Moreover, the models that are used for estimation in this article are free space propagation model (FSPL), Ericsson, Stanford University Interim (SUI), Okuomora, and Cost-231 Hata models. The comparison for prediction results between the pathloss from propagation models and the measurement data are presented to pick the most applicable model for this area. Statistical analysis for results such as mean, standard deviation, and root mean square errors (RMSE) are demonstrated. The rest of this article has been divided into five main sections, beginning with the introduction, empirical and semi-empirical propagation models, setup dataset, results and discussion, and the conclusion.

2. METHOD

In this section, the empirical and semi-empirical propagation models have been described in detail. The selected propagation models have been explained mathematically. Also, the dataset used in the evaluation has been explained below.

2.1. Empirical and semi-empirical propagation models

The propagation models, including friis free space propagation model (FSPL), SUI, Okumura, Ericsson, and Cost-231 Hata models, have been described in detail below. In this work, the selected models are based on the frequency band in this area. Also, choosing the optimal model is based on the minimum RMSE in this area.

2.1.1. Friis free space propagation model

It is utilized to determine the signal's pathloss in the free area without obstacles when there is no reflection, diffraction, and attenuation. It is a perfect model for the enormous distance between the transmitter and receiver [19], [20]. Because radio waves expand out according to the inverse square law, FSPL increases with the square of the separation between the sender and receiver. In (1) is a for this model:

$$P_R = P_T \frac{G_T G_R \lambda^2}{4\pi d^2 L} \tag{1}$$

where "P_R and P_T" are received and transmit power in watts, respectively. d is the distance in (Km). "G_T and G_R" transmits and receives antennas, respectively. λ denotes to the length of the wave in meters. L is losses.

2.1.2. Stanford University Interim model

The IEEE 802.16 broadband wireless access introduced it for frequency band 11 GHz, including the channel model designed via Stanford University and named SUI. Moreover, the model modified the frequency beyond the 1,900 MHz of the Hata model, and the correction factors are accepted to expand the SUI model up to a 3,500 MHz band. As a result, the SUI model was declared for the" multipoint microwave distribution system (MMDS)" in 2,500 MHz to 2,700 MHz frequency bands in the United States [20], [21].

The height for the antenna transmitter of this model is around (10 to 80 m), the height for the antenna of the mobile device is from (2 to 10 m), and the range of coverage is from 100 m to 8 km. SUI models have three types of terrains without declaring the specific area. Terrain A is suitable for a hilly area with middle to dense trees, and pathloss is high with this terrain. Terrain B is suitable mainly for the flat area with medium to dense trees or hilly areas with few trees, and the pathloss with this type is moderate. Finally, terrain C is defined for the flat area with little vegetation, and this type has low pathloss. For this model is in (2):

$$PL_{SUI} = A + 10\gamma \log(d/d_o) + X_f + X_h + S \tag{2}$$

$$X_f = 6\log(f/2000) \tag{3}$$

$$X_h = 10.8\log(h_r/2000), \text{for terrain type A and B} \tag{4}$$

$$X_h = -20\log(h_r/2000), \text{for terrain type C} \tag{5}$$

$$A = 20\log(4\pi d_o/\lambda) \tag{6}$$

$$\gamma = a - bh_b + c/h_b \tag{7}$$

The variables definition are " d measures the distance in meters, d_o is the reference distance, X_f and X_h in (3, 4, and 5) are correction factors for frequency higher than 2 GHz and the height of antenna receiver, respectively as. f is frequency in MHz and h_r is the height of antenna receiver. S is shadowing parameters between 8.2 to 10.2 dBm. The parameter A is defined in (6). γ in (7) is exponent for pathloss. h_b is the height of antenna transmitter between 10-80 m. The a, b, and c base on the type of terrains, and terrain B is used in this work with a=4, b=0.0075, and c=17.1" [21].

2.1.3. Okumura model

A well-known and standard model is the Okumura model. It came from massive data measured from Japan, and all recent models are established from the Okumura model. The frequency limit included by this model is 200-1,925 MHz, with a base station height of 30-100 m and a receiver antenna height of 1-3 m. Moreover, the sender and receiver can be separated by up to 100 km [20], [22]. For this model is presented in (8):

$$PL_{ok} = Frris + A_{m,u} - H_{tu} - H_{ru} - G_{Area} \tag{8}$$

$$H_{tu} = 20\log(h_t/200) \tag{9}$$

$$H_{ru} = 10\log(h_r/3) \tag{10}$$

Friis is determined by (1)."H_{tu} and H_{ru} are sender and receiver height correction factors in dB, respectively, and computed by (9) and (10). h_t and h_r are receiver and sender heights, respectively. Am, u is median attenuation". The variable G_{Area} is based on the kind of region and the median attenuation factor.

2.1.4. Ericsson model

The Ericsson company has software for determining pathloss named the Ericsson model. It was basically updated from the Okumura-Hata model to permit space for adjusting factors regarding the environment type. The pathloss for this type is in (11) [23]:

$$\begin{aligned} PL_{Ericsson} =& a_o + a_1\log(d) + a_2\log(h_b) \\ &+ a_3\log(h_b)\log(d) \\ &- 3.2(\log(11.75h_r)^2) + g(f) \end{aligned} \tag{11}$$

whereas h_b and h_r are the antenna's height for transmitter and receiver in meters, respectively. $g(f)$ is expressed in (12):

$$g(f) = 44.49\log(f) - 4.78(\log(f))^2 \tag{12}$$

the values for variables a_o, a_1, a_2, and a_3 depend on the type of environment, and urban environment is used in research with " a_o=36.2, a_1=30.2, a_2=12, and a_3=0.1" [23].

2.1.5. COST-231 Hata model

It is commonly utilized for determining pathloss in cellular networks. It was developed as an expansion for the Hata-Okumura model, operated on a frequency between 500–2,000 MHz, and can work even more than 2,000 MHz. Moreover, this model has correction factors for various environments, for instance, rural, suburban, and urban. For this model is in (13) [24]:

$$\begin{aligned} PL_{Cost-231} =& 46.3 + 33.9\log(f) - 13.82\log(h_b) \\ & - ah_m + (44.9 - 6.55\log(h_b))\log(d) + C_m \end{aligned} \tag{13}$$

whereas h_b is the height of the site in meters, and d is distance in Km. C_m is 0 dbm for open area and suburban and 3 dbm for an urban environment. For ah_m in (14):

$$ah_m = 3.2(\log(11.75h_r))^2 - 4.97\text{,for f¡400 MHz} \tag{14}$$

h_r is the height for the receiver antenna.

2.2. Dataset

The analysis results comparison of various propagation models with data measurement for LTE networks are presented. The LTE data was measured in Cologne, Germany, with a total length route 16 km as shown in Figure 1 and frequency band 2,500 MHz. The data is collected using the driving test (DT) that the operators commonly use to collect, test, and optimize the coverage area and figure out the troubles [25], [26]. DT gathers data at various distances from the base stations starting at l0 m to 2 km. The dataset that uses with propagation models to obtain pathloss is mentioned in Table 1.

Also, the empirical pathloss is computed by utilizing the measured reference signal received power (RSRP) that DT records. RSRP is the power of the LTE reference signals distributed on the entire bandwidth and narrowband [27]. It considers one of the important metrics for the quality of signal in LTE networks.

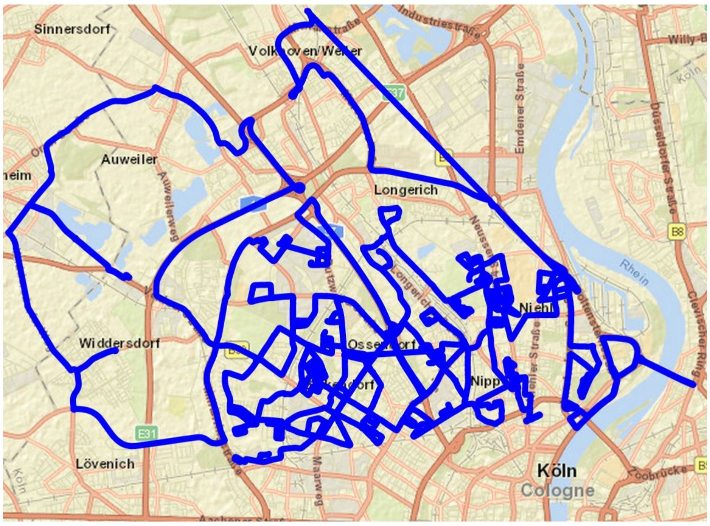

Figure 1. Route map for measured data

Table 1. Parameters for propagation models

Parameters	Values
Cell type	Macro cell
EiRP	40-43 dbm
Base station height	16-36 m
Mobile station	1.5 m
Receiver antenna height	0 dbi
Frequency	2,500 MHz
Distance	10-2,000 m
Area	Urban

3. RESULT AND DISCUSSION

The selected RF propagation models for high frequency described in the second section have been implemented in MATLAB and compared with data measured for the same area. The measured data took place in the urban environment in Cologne, Germany, with a high-frequency band 2.5 GHz. For evaluation, we have used 52 various serving cells in the area for different distances (10-2,000 m). We have calculated the pathloss based on the distance between the cellular phone and the serving site using the data collected in our setup section. In addition, statistical analysis is employed, such as mean, standard deviation, and RMSE.

Figure 2, plots the average pathloss for various distances utilizing only outdoor data measurements. The Figure 2 shows six curves: empirical Pathloss, SUI, Ericsson, FSPL, Okumura, and COST-231-Hata models. We have selected these models because they are appropriate with a high-frequency band 2.5 GHz. According to our evaluation, FSPL, SUI, and Okumura models are underestimated from the empirical data measurements. It is obvious from the Figure 2 Ericsson and Cost-231 Hata models are close to empirical pathloss.

In addition, Figures 3 and 4 present the mean and the STD for all selected propagation models. It is significantly noticed that Ericsson and COST-231 Hata models close the empirical pathloss. The mean and std for Ericsson are 141.69 dB and 12.53 dB, respectively. Also, the mean and std for COST-231 Hata model are 142.01 dB and 14.23 dB, respectively. Whereas the empirical pathloss has 147.28 dB and 14dB for the mean and STD, respectively, as shown in Table 2. Only the RMSE can detect the optimal propagation model for that region. According to the RMSE Figure 5, the COST-231 Hata model provides the optimal prediction model with an RMSE of 5.27 dB for this outdoor area. Additionally, it is worth noticing the Ericsson model is the second-optimal propagation model with an RMSE of 5.67 dB after the winner closely.

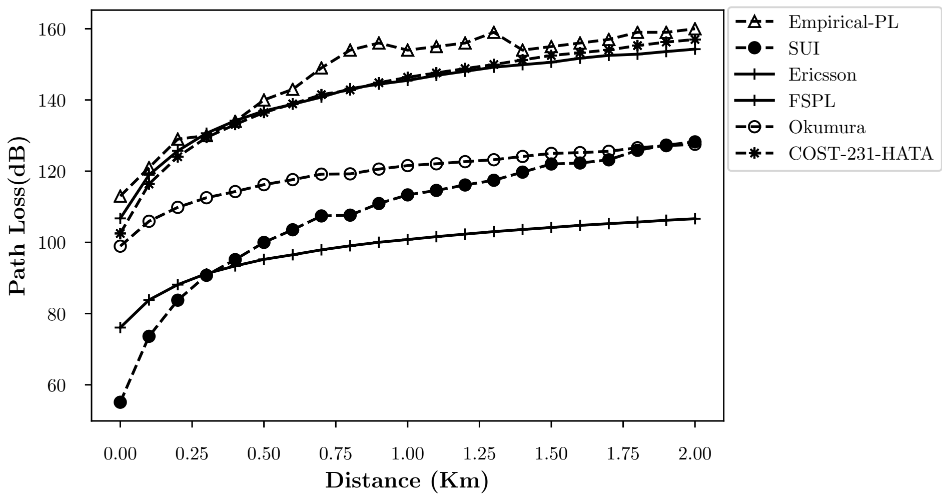

Figure 2. Comparison of selected propagation models with empirical PL

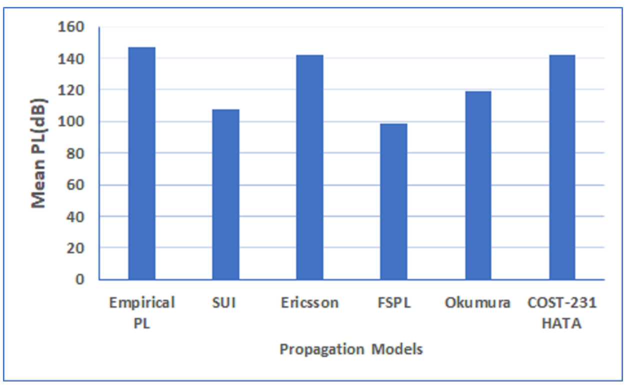

Figure 3. Comparison in mean for propagation models

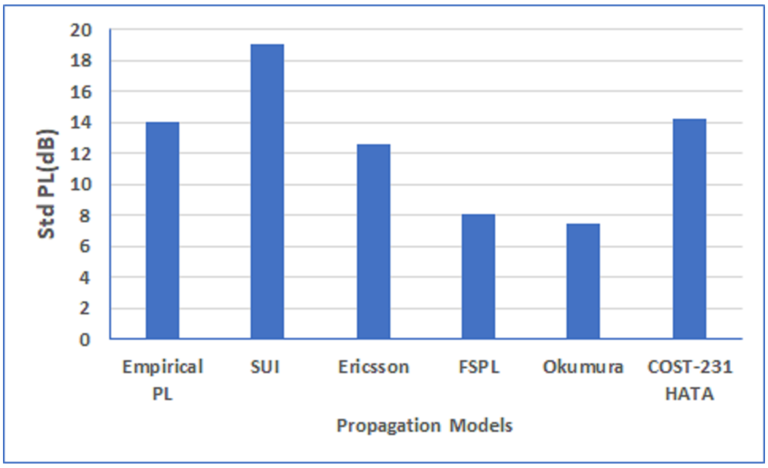

Figure 4. Comparison in Std for propagation models

Table 2. Mean and standard deviation for models

Models	Mean (dB)	Std (dB)
SUI	107.52	19
Ericsson	141.69	12.53
FSPL	98.36	8.04
Okumura	119.28	7.48
COST-231 Hata	142.01	14.23
Empirical PL	147.28	14

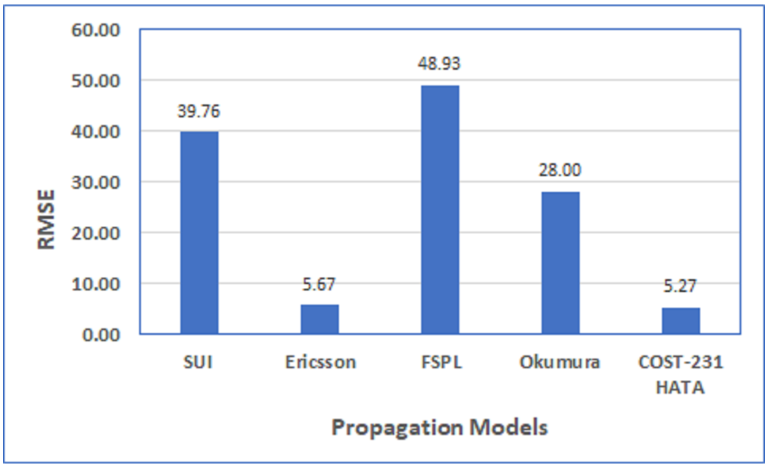

Figure 5. Comparison in RMSE (dB) for propagation models

4. CONCLUSION

In this paper, one of the challenges of network planning, which is selecting the suitable propagation model, has been investigated. The selected appropriate models with 2.5 GHz band LTE networks are Friis, SUI, Ericsson, Okumura, and COST-231 Hata. According to the chosen models' analysis results, the Cost-231 Hata model obtained the lowest RMSE with 5.27 dB. Moreover, the Ericsson model provides the second-best choice with 5.67 dB RMSE for the urban area. All comparisons have been made with empirical pathloss from LTE data measurements for Cologne city, Germany.

We plan to optimize the parameters for future work by using some statistical methods, for instance, least mean square errors (LMSE) and linear least squares method (LLSM), to achieve minimum RMSE. Furthermore, it is intended to investigate enhancing QoS for outdoor and indoor cellular networks by applying machine learning algorithms with different feature selections. A more accurate dataset can be used to compare the results. In addition, it is planned to study the performance analysis for a millimetres wave (60 GHz).

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