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Optimized Suitable Propagation Model for GSM 900 Path Loss Prediction

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Abstract

This paper present how COST-231 Hata model is chosen and optimizedfor path loss prediction in suburban area of Tarakan, Indonesia in the GSM 900 MHz system.Thispredicted and optimized path loss model is based on the empirical measurement collected in the GSM system on Tarakan City. It is developed by comparing the calculatedpath loss from collected measurements with the well-known path loss models within applicable frequency range of GSM system, such as COST-231 Hata, Ericsson, SUI, Walfish, ECC-33, and Lee Model. The COST-231 Hata model was chosen based on the closest and smallest mean error ascompared to the measured path loss. This optimized COST-231 Hata model is implemented in the path loss predictionduring the validation process. Thus, this optimized model is successfully improved and would be more reliableto be applied in the TarakanGSM900 MHz system for path loss prediction.

Keywords*: path loss prediction, optimization, COST-231 Hata, propagation models, GSM*

1. Introduction

In mobile radio systems the obstacles between the base station (BS) and the mobile station (MS) significantly influences the strength of the mobile signal. The attenuation of the radio signal is referred as path loss. The path loss prediction models have a major role in the radio frequency coverage optimization, interference analysis and efficient utilization of the available network resources [1]. The efficiency of radio network planning to produce a Cost-effective deployment of GSM network foroptimal network coverage largely depend on the degree of accuracy of the propagation prediction modelemployed in characterizing the unique features of the propagation environment where the network is to bedeployed. Thus, the choice of an adaptable radio propagation path loss model plays a pivotal role in obtaining anoptimal network performance [2]. It is required toaccurately estimate the channel characteristics in order to maintain the interference at a minimum level. Since the terrain conditions vary to a large extent, the path loss prediction models cannot be generalized. This drawback can be overcome by adjusting the model parameters to suit the desired environment.

The performance of any wireless communication systems depends on the propagation characteristics of the channel. Channel characteristics have an impact on the design of thetransmission strategy. Received signal and path loss prediction models play an important role in the RF coverage optimization and efficient use of the available resources. These models can differ in their properties with locations due to different terrain environment. Therefore, extensive study on the effects ofradio propagation path-loss had drawn a considerable attention.

Surajudeen *et al.* [3] studied comparatively three propagation models, Hata, COST 231, and the Lee path loss model for GSM 1800 and WCDMA System in Urban area of Nigeria based received predicting signal level swings for varying sites and frequency and was found to be optimum forGSM 1800 and very high for WCDMA. Syahfrizal, in [4] also presented using Okumura-Hata propagation model to path loss determination at 900 MHz GSM systems for Tarakan city, where Okumura-Hata model was adopted and modified. Similar work was carried out by Julie *et al* in [5] whereby they modified Okumura-Hata and COST-231 Hata model to path loss prediction at GSM 900 and 1800 MHz for Port Harcourt and Enugu, Nigeria, where Root Mean Square Error (RMSE) was agree with the acceptable International range. Abraham Deme,

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in [6] the applicability of the COST 231 Hata Model to the metropolis of Maiduguri, Nigeria, is tested by computing variations between the COST 231 Hata predictions and predictions based on the Least Squares function, being the best fit curve through measured data points and RMSE was found to be 5.33dB, which is acceptable, the acceptable maximum being 6dB. Isabona, in [7] was optimized path loss prediction using Okumura-Hata model for the CDMA 800 MHz system for urban area in Benin City, Nigeria.

In this paper, the data collectedexperimentally at 900 MHz band for three base stations, located in the suburban region of Tarakan city, Indonesia are used for path loss analysis. Data collected are used to compare the most widely used propagation models for the purpose of comparison and finding the most suitable model for the two technologies that will assist Engineers in carrying out effective planning for improved service. This work is different from the aforementioned research work because data collected from drive tests are in comparing the chosen propagation models such us COST-231 Hata, Ericsson, SUI, Walfish, ECC-33, and Lee Model. Based on the smallest mean error as compared to the measured path loss, COST-231 Hata model is found to be the best suited path loss prediction model for optimizing. The accuracy of optimized path loss thismodel is enhanced by adjusting its parameters, in order to achieve minimum RMSE between the predicted and the measured values.

2. Empirical Propagation Path Loss Models

In this paper, we studied a number of path loss models for predicting and optimizing the propagation loss for GSM 900 MHz systems. In all models, f_C is the carrier frequency in MHz except for the ECC-33 model inGHz, d is the distance between the transmitter GSM Cell BS and the receiver MS user in km for all models except for Ericsson model in meters (which is fixed to 2.5 km in our simulation), the reference distance d_0 is 100 m, the BS antenna height h_{BS} is equal to 30m for all models, the MS antenna height h_{MS} is equal to 1.5 m for all models, G_{BS} and $G_{MS}$are BS and MS height antenna gain factors chosen to be 18dB, $a\ (h_{MS})$ is the MS antenna correction factor. The shadowing margin s is chosen as 10 dB and added in the path loss to all models in our simulation.

2.1. Simplified Model

The simplified Model is used for free space path loss. Free space path loss (PL_{FS}) is conveniently expressed in dB, as follows [3, 8, 11]:

$$PL_{FS} = 32.45 + 20\ log_{10}(d) + 20\ log_{10}(f_c) \quad (1)$$

Where d is in km and $f_c$is in MHz.

2.2. COST-231 Hata Model

This model is derived by modifying the Hata model, and isused in urban, suburban, and ruralenvironments [1-2], [4], [7-9], [11]. Path loss equation for suburban area as follows:

$$PL_{COSTSU} = PL_{COSTU} - 2\ (log_{10}\ (f_c / 28))^2 - 5.4 \quad (2)$$

$$PL_{COSTU} = 46.3 + 33.9\ log_{10}\ (f_c) - 13.82\ log_{10}\ (h_{BS}) + (44.9 - 6.55\ log_{10}\ (h_{BS}))\ log_{10}\ (d) + s - a\ (h_{MS}) \quad (3)$$

MS antenna correction factors $a(h_{MS})$ for all is:

$$a(h_{MS}) = (1.11 \log_{10}(f_c) - 0.7)h_{MS} - (1.56 \log_{10}(f_c) - 0.8) \quad (4)$$

2.3. Ericsson Model

The planning network engineers use this model to predict the path loss in suburban area, as follows [8]:

$$PL_{Ericsson} = 43.2 + 68.93 log_{10}\ (d) + 12 log_{10}\ (h_{BS}) + 0.1 log_{10}\ (h_{BS}) log_{10}\ (d) - 3.2 (log_{10}\ (11.75\ h_{MS})^2) + G(f_c) \quad (5)$$

$$G(f_c) = 44.49log_{10}(f_c) – 4.78(log_{10}(f_c)) \quad (6)$$

2.4. Stanford University Interim (SUI) Model

Stanford University Interim (SUI) channel model is developed for IEEE 802.16 broadband wireless access working group based on research results of Stanford University [1]. This model covers three common terrain categories. Category A is the maximum path-loss category, which represents a hilly terrain with moderate to heavy tree densities. Category B is the intermediate path-loss category suitable for flat terrains. The minimum path-loss category for flat terrains with less tree densities is Category C. The basic path loss equation for SUI model with correction factors is given in [1-2], [7], [10-11] as follows:

$$PL_{SUI} = S + 10\gamma log_{10}(d/d_0) + \Delta L_{fc} + \Delta L_{hBS} + s \quad (7)$$

Where d is in m, d_0=100m, γ is the path-loss exponent, $\Delta L_{fc}$is the correction factor for the frequency, ΔL_{hBS} is the correction factor for the receiver antenna height and s is the log normally distributed shadow factor due to the trees and other obstacles, having a value between 8.2 dB and 10.6 dB [1]. The term S, the path loss exponent and the correction factors in the above equation are given as

$$S = 20\ log_{10}(4\pi d_0/\lambda) \quad (8)$$

$$\gamma = u - vh_{BS} + (w/h_{MS}) \quad (9)$$

$$\Delta L_{fc} = 6\ log_{10}(f_c/2000) \quad (10)$$

$$\Delta L_{hBS} = \begin{cases} -10.8\ log_{10}\left(\frac{h_{MS}}{2}\right) & Categories\ A, B \\ -20\ log_{10}\left(\frac{h_{MS}}{2}\right) & Categories\ C \end{cases} \quad (11)$$

Where λ is the wavelength (m), f_c is the frequency (MHz), h_{BS} is the height of the base station (m), h_{MS} is the height of the receiving antenna (m). The parameters u, v, and w are standard values that depend on the type of terrain. Since the terrain is categorized as suburban, an intermediate path loss (CategoryB) is chosen for analysis. The values of constants u, v, and w are 4, 0.0065, and 17.1 respectively.

2.5. Walfish Model

The Walfish Model is used for free space, large and medium cities [8]. Path loss equation for suburban area as follows:

$$PL_{Walfish} = PL_{Walfish\_FS} + PL_{rts} + PL_{msd} \quad (12)$$

Scenario 1: Free Space Path loss.

$$PL_{Walfish\_FS} = 32.4 + 20log_{10}(d) + 20log_{10}(f_c) + s \quad (12a)$$

Scenario 2: Free Space in a deep valley Path loss.

$$PL_{Walfish\_FS} = 42.6 + 26log_{10}(d) + 20log_{10}(f_c) + s \quad (12b)$$

Where $PL_{Walfish\_FS}$ is the free space loss, $PL_{rts}$is the roof-to-street diffraction and scatter loss, and PL_{msd} is the multi screen diffraction loss.

$$PL_{rts} = - 16.9 - 10log_{10}(w) + 10log_{10}(f_c) + 20log_{10}(h_{roof} – h_{MS}) + PL_{ori} + s \quad (12c)$$

$$h_{roof} = 3n_{floor} + roof\ (m) \quad (12d)$$

$$PL_{ori} = 4 – 0.114\ (\Phi - 55) \quad (12e)$$

Where w is the width of the street in m and equal $b/2$, b is the building separation equal to 40 min our simulation, Φ is the road orientation with respect to the direct radio path in degrees and equal to 90^o in the simulation, roof height is 3 m and number of floors is 3. The formula for the multi screen diffraction loss is as follows:

$$PL_{msd} = PL_{hBS}+k_a+k_d log_{10} (d) +k_f log10 (f_c) – 9log_{10} (b) \quad (12f)$$

$$PL_{hBS}= -18 \; log_{10} (1 + \Delta h) \quad (12g)$$

$$k_f= -4 + 0.7(f_c/925 - 1) \quad (12h)$$

Where k_a is the account for the increase in path loss when the BS antennas are below the rooftops of adjacent buildings, and equal to 54, while k_d which equal to 18 and k_f are to control the dependency of the multi-screen diffraction loss on the distance and frequency.

2.6. ECC-33 Model

The ECC-33 model developed by the ElectronicCommunication Committee (ECC) is appropriate for suburban and small urban areas [8, 10].

$$PL_{ECC} = PL_{FS}+ PL_{bm}– G_{BS\_ECC} – G_{MS\_ECC} \quad (13)$$

$$PL_{FS}= 92.4 + 20 \; log_{10} (d) + 20 \; log_{10} (f_c) \quad (13a)$$

$$PL_{bm} = 20.41+9.83log_{10}(d)+7.894log_{10}(f_c)+9.56(log_{10} (f_c))^2 \quad (13b)$$

$$G_{BS\_ECC}=log_{10}(h_{BS}/200)(13.98 + 5.8 \; (log_{10}(d))^2) \quad (13c)$$

$$G_{MS\_ECC}= (42.57 + 13.7 \; log_{10} (f_c))(log_{10}(h_{MS}) - 0.585) \quad (13d)$$

Where PL_{FS} and $PL_{bm}$are the free space path loss and the basic median path loss.

2.7. Lee Model

Lee's Model is used to predict the path loss in urban, suburban, rural and free space areas [8]. Path loss equation for suburban area as follows:

$$PL_{Lee}= 99.86 +38.4 \; log_{10} (d) +10n \; log_{10} (f_c) –(h_{BS}/30.48)^2 – (h_{MS}/3)^2– (P_t/10)^2 – (G_{BS}/4) – G_{MS} \quad (14)$$

Where n is an experiment value chosen to be 3. In our simulation, the parameter values of P_t, G_{BS}, and G_{MS} are 43 dBm, 18 dBm, and 18 dBm respectively.

3. Materials and Method

3.1. Description of the Area under Investigation

Tarakan city is located within tropical rainy region. Its terrain clutter is characterized by the availability of tropical rainy forest, houses mostly below 20 meters and an average road with of about 20 meters. Attenuation is caused by multiple reflections, absorption and multiple diffractions off roof tops, trees, cars etc. The concrete ground and tarred roads have very relative poor electrical conductivity, and therefore, cause attenuation by absorption. Ground reflected waves are blocked by buildings and trees.

3.2. Measurement Procedure

Measurements were taken from three different Base Stations of a mobile network service provider in GSM 900 MHz Network, situated within the terrain. The testing tool used in the measurement was GSM test phone handset in the Net Monitor mode capable of measuring signal strength (P_r) in decibel milliwatts (dBm), in conjunction with a Digital Global Positioning System receiver antenna to determine distance (d) from the Base Station (BS). Readings were taken within the 900MHz frequency band at intervals of 0.2 km, after an initial separation of

0.1km away from the Base Station up to 2.5 km fixed length. Base Station parameters obtained from GSM 900 MHz Network Provider such us mean transmitter height (h_{BS}) is 30 m, mean Effective Isotropically Radiated Power (*EIRP*)is 43 dBm, transmitting frequency for BS1, BS2, and BS3 are 902.5, 903.2, and 904.5 MHz respectively. Received power (P_r) values were recorded at various distances from each of the three BS named BS1,BS2, and BS3. For every received power value, the corresponding path loss measured was computed using the formula:

$$PL_{Measured} = EIRP - P_r \quad (15)$$

3.3. Path Loss Model Optimization

Several existing path loss models was explained in Section 2 are chosen for comparison with measurement data path loss. The best existing path loss model with smallest mean error to the measured path loss data will be chosen as a reference for the development of the optimized path loss model. The optimized path loss model will be tested during the validation process by comparing the RMSE calculated path loss to the measured path loss in Tarakan CityGSM 900 MHz system.

Path loss model optimization is a process in which a theoretical propagation model is adjusted with thehelp of measured values obtained from test field data. The aim is to get the predicted field strength as close as possible to the measured field strength. Propagation path loss models optimized for different wireless technologies and environments are abundant in [7].

In order to optimize and validate the effectiveness of the proposed model, the Mean error (μ_e), and RMSE (ρ_e) were calculated between the results of the proposed closest model and the measured path loss data of each area. These mean error (μ_e), and root mean square error, RMSE (ρ_e) are defined by the expression in (16), and (17) respectively.

$$\mu_e = (1/N)\ \Sigma\ (PL_{Measured} - PL_{Predicted}) \quad (16)$$

$$\rho_e = \sqrt{\frac{\mu_e^2}{N}} \quad (17)$$

Where $PL_{Measured}$ is measured Path loss (dB), $PL_{Predicted}$ ispredicted path loss (dB), and N is number of measured data points.

4. Results and Analysis

Figure 1 show that BS transmitter antenna height increased caused path loss decreased. The path loss of COST-231 Hata model shows decreasing trend with respect to transmitter antenna height and increasing trend with respect to transmission distance. In Figure 2, increasingly of frequency in mobile network system that caused path loss increased. The fluctuations of the signal levels as the results of fading. As we drove from the starting point of the drive test, the receiver power changes significantly. This is because of multipath fading; meaning transmitted signal takes multiple paths to the receiver. The received signal amplitude at the mobile changes with its position. Both defects the same pattern as we moveaway from the transmitter, the received signal amplitude degrade. Same results were obtained for all the BTSs examined throughout the drive test. Except for some exceptional cases where, the signal amplitude decrease with increase in distance and later increase for short distance as a result of line of sight between the BS and MS, possibly due to valley in between or we drove high the hill and then descend.

The measured signal strength (P_r) results of three BS (BS1, BS2, and BS3) in this study were presented graphically in Figure 3. The values of the predicted path loss and the measured path loss were plotted against the distance of separation between the Base Station (BS) antenna and the Mobile Station (MS) antenna. Figure 4 presents the result of the path loss predictions as compared with the path loss measured on BS1 propagation environment. The result of the drive test carried out within the coverage area of the cell reported a mean path loss of 120.23 dBm. Mean path loss values of 115.80 dBm, 145.13 dBm, 91.38 dBm, 154.81 dBm, 126.60 dBm, 157.52 dBm, and 145.98 dBm were predicted by COST-231 Hata model, Ericsson model, Free Space model, SUI model, Walfish model, ECC-33 model, and Lee model respectively.

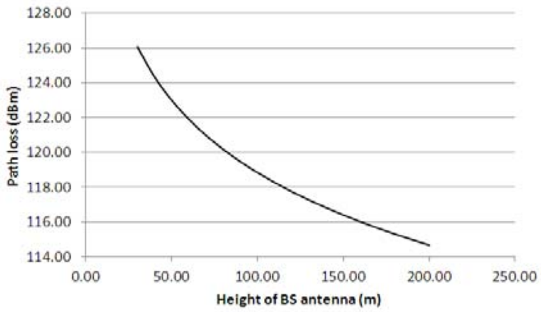

Figure 1. Path loss of COST-231 Hata modelwith respect to height of BS1 transmitter antenna

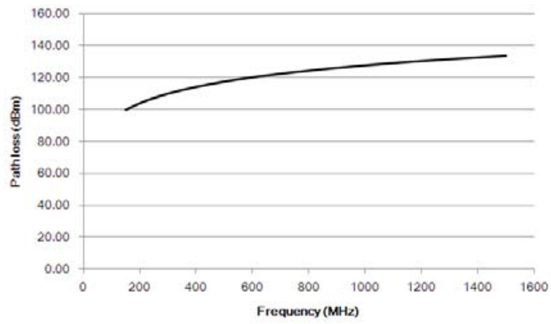

Figure 2. Variation of COST-231 Hatapath loss model with frequency

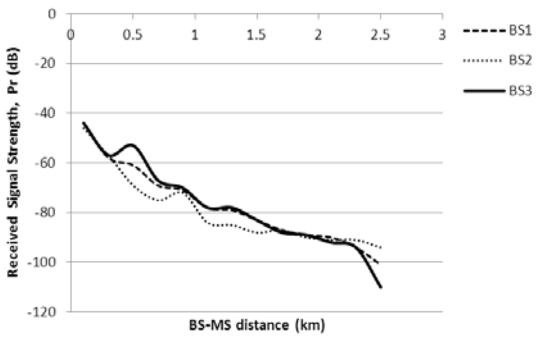

Figure 3. Measured received power (P_r) in BS1, BS2, and BS3

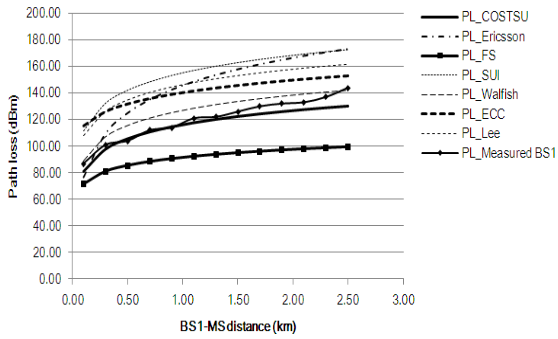

Figure 4. Comparison of measured and predicted path loss for BS1

Figure 5 show the path loss of thetransmitted signal in the terrain covered by BS2. COST-231 Hata model, Ericsson model, Free Space model, SUI model, Walfish model, ECC-33 model, and Lee model predicted mean path loss values of 115.84 dBm, 145.15 dBm, 91.41 dBm, 154.85 dBm, 126.65 dBm, 140.76 dBm, and 146.02 dBm respectively. The mean path loss obtained from the propagation environment within the radio coverage of the BS2 was 122.15 dBm.

The analysis of the drive test data of the BS3 as presented in Figure 6 reported that the mean path loss calculated by the mobile users in that area covered is 120.15 dBm. The predictions of COST-231 Hata model, Ericsson model, Free Space model, SUI model, Walfish model, ECC-33 model, and Lee model gave mean values of 115.86 dBm, 145.16 dBm, 91.42 dBm, 154.86 dBm, 126.67 dBm, 140.78 dBm, and 146.04 dBm respectively.

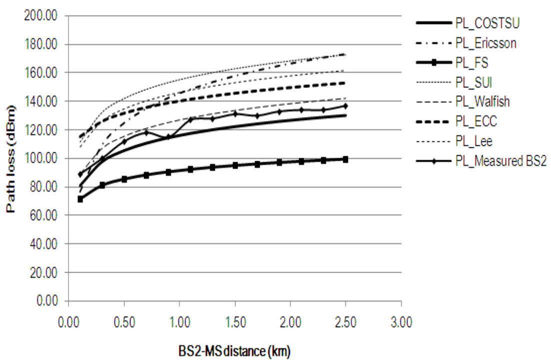

Figure 5. Comparison of measured and predicted path loss for BS2

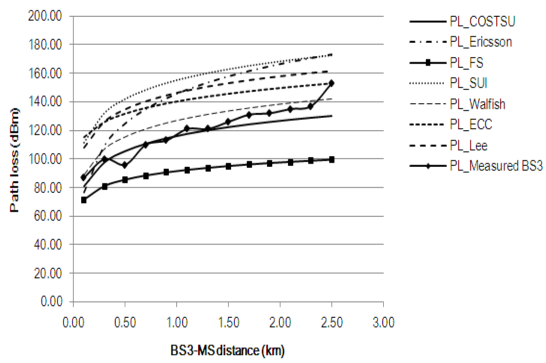

Figure 6. Comparison of measured and predicted path loss for BS3

The findings of this research showed that all the seven empirical propagation prediction models investigated under the measured path loss of GSM 900 MHz deployed in this area. COST-231 Hata model has mean error path loss values with smallest and closets from the actual path loss measured on the 'live' GSM 900 network deployed in the area. Path loss estimated by Cost-231 Hata model matches with the measured path loss in a much better way, compared to other prediction models. Similar results are observed for other base stations. Selection of best path loss prediction model for optimizing that is required to identify the best prediction model, so that this model can be adjusted to achieve minimum RMSE with themeasured data. By using Equation (16), the mean error of all the seven empirical propagation path loss model to measured path loss has calculated in Table 1. The smallest mean errors for BS1, BS2, and BS3 with the predicted COST-231 Hata model are4.43dBm, 6.31dBm, and 4.29dBm respectively. From the results of Table 1, it is observed that the average mean error for COST-231 Hata model is the least, compared to other models. This indicates that path loss isbest predicted by COST-231 Hata model. Based on this result,COST-231 Hata model is selected as the suitable model for optimizing process.

Path loss model optimization is a process in which an empirical propagation model is adjusted with thehelp of measured values obtained from test field data. The aim is to get the predicted path loss as close as possible to the measured path loss. Propagation path loss models optimized for different wireless technologies and environments are abundant in [7].

The calculated RMSE with the field measured data throughout the three coverage area investigated by using Equation (17). The RMSE function computation of this residual is calculated based on the least squared algorithm which is used to determine the residual minimum values. Similar to the work by [4] and [7], the RMSE is then subtracted from the Equation (2) of COST-231 Hata model to obtain optimized path loss models for all BS sites in the location of study as given in Equation (18). Figure 7-9 below illustrates how measured path loss models have been optimized with COST-231 Hata model in this paper. Here, the optimized path loss model for each operator was applied for path loss calculation for other base stations in all the study location, to verify the accuracy and the suitability of this optimized path loss models. In Table 2 shown that all the base stations fit into the optimized model with lower average RMSE was about 4.87 dB and still in the acceptable range is up to 6 dB [4]. From these results as depicted in Figure 7-9, it is shown that the optimized model does show a good agreement for the entire studied BS sites compared with COST-231 Hata model. Thus the optimized model is successfully developed with proper optimized procedure.

Table 1. Comparison of mean error (μ_e)

Base Station	COSTSU	Ericsson	FS	SUI	Walfish	ECC-33	Lee
BS1	4.43	24.90	28.85	34.57	6.37	37.28	25.75
BS2	6.31	23.00	30.75	32.69	4.50	18.61	23.87
BS3	4.29	25.01	28.73	34.71	6.52	20.63	25.89
Average	5.01	24.30	29.44	33.99	5.80	25.51	25.17

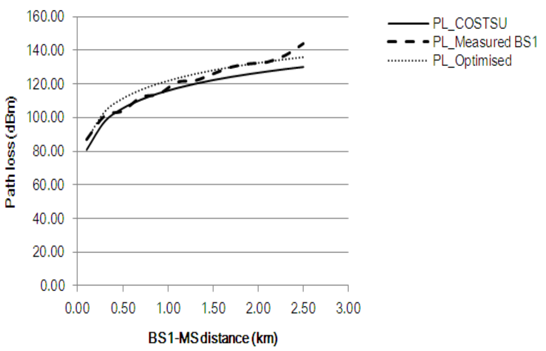

Figure 7. Optimized and predicted path loss for BS1

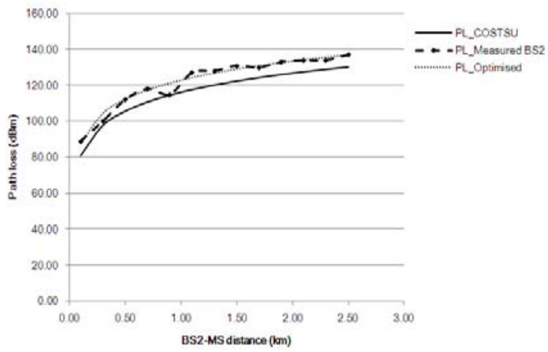

Figure 8. Optimized and predicted path loss for BS2

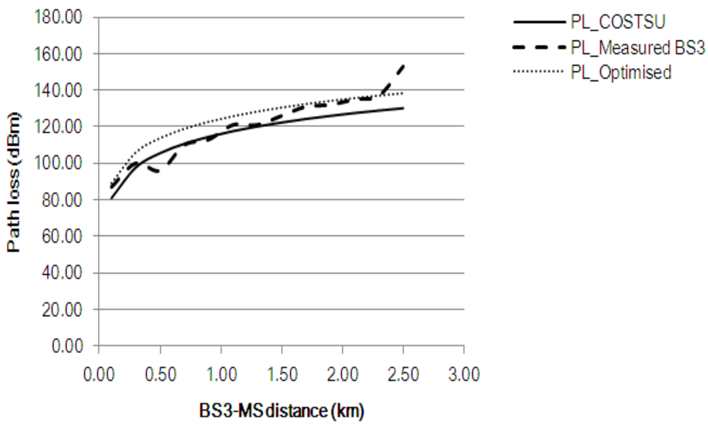

Figure 9. Optimized and predicted path loss for BS3

Table 2. Comparison of RMSE (ρ_e) for proposed model performance before and after optimization

Base Station	Before	After
BS1	5.85	4.08
BS2	6.75	2.43
BS3	8.27	8.07
Average	6.96	4.87

4. Conclusion

In this paper, the measured path losses in three cells are compared with theoretical path loss models: COST-231 Hata model, Ericsson model, Free Space model, SUI model, Walfish model, ECC-33 model, and Lee model. The measured path loss, when compared with theoretical values from the theoreticalmodels, showed the closest agreement with the path loss predicted by the COST-231 Hata model in terms of mean square error analysis. Based on this,an optimized COST-231 Hata model for theprediction of path loss experienced by GSM signals in the 900MHz band in suburban environment of Tarakan City, Indonesia is developed. The optimized model showed high accuracy and is able to predict path loss withsmaller average RSMEwas about 4.87 dBmas compared to the COST-231 Hata model was about 6.98 dBm.

References

[1] A Bhuvaneshwari, R Hemalatha, T Satyasavithri. *Statistical Tuning of the Best suited Prediction Model for Measurements made in Hyderabad City of Southern India.* Proceedings of the World Congress on Engineering and Computer Science. San Francisco. 2013; 2.

[2] Segun IP, Olasunkanmi FO. Empirical Path Loss Models for GSM Network Deployment in Makurdi, Nigeria. *International Refereed Journal of Engineering and Science (IRJES)*. 2014; 3: 85-94.

[3] NT Surajudeen Bakinde, N Faruk, AA Ayeni, MY Muhammad, MI Gumel. Comparison of Propagation Models for GSM 1800 and WCDMA Systems in Selected Urban Areas of Nigeria. *International Journal of Applied Information Systems (IJAIS).* 2012; 2(7): 6-13.

[4] Syahfrizal T. *Using of the Okumura-Hata Propagation Model for Pathloss Determination in Tarakan*. Proceedings of the 3rd International Conference on Radar, Antenna, Microwave, Electronics and Telecommunications (ICRAMET). 2014: 77-79.

[5] Julie CO, MU Onuu, JO Ushie, BE Usibe. Propagation Models for GSM 900 and 1800 MHz for Port Harcourt and Enugu, Nigeria. *Network and Communication Technologies*. 2013; 2(2).

[6] Abraham D, Danjuma D, Buba B, Mohammed M. Hata-Okumura Model Computer Analysis for Path Loss Determination at 900MHz for Maiduguri, Nigeria. *International Institute for Science, Technology, and Education (IISTE): Mathematical Theory and Modeling.* 2013; 3(3).

[7] Isabona Joseph, Konyeha CC. Urban Area Path loss Propagation Prediction and Optimization Using Hata Model at 800MHz. *IOSR Journal of Applied Physics (IOSR-JAP)*. 2013; 3: 8-18.

[8] Mohammed A, Tughrul A, John T, Ahmet TE. *Frequency Analysis of Path Loss Models on WIMAX*. 3rd Computer Science and Electronic Engineering Conference (CEEC). UK. 2011.

[9] Olasunkanmi FO, Segun IP, Robert OA, Oluwole AA. Comparative Analysis of Received Signal Strength Prediction Models for Radio Network Planning of GSM 900 MHz in Ilorin, Nigeria. *International Journal of Innovative Technology and Exploring Engineering (IJITEE).* 2014; 4(3): 45-50.
[10] Sachin SK, AN Jadhav. An Empirically Based Path Loss Models for LTE Advanced Network and Modeling for 4G Wireless Systems at 2.4 GHz, 2.6 GHz and 3.5 GHz. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*. 2013; 2(9): 252-257.
[11] Rekawt SH, TA Rahman, AY Abdulrahman. LTE Coverage Network Planning and Comparison with Different Propagation Models. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2014; 12(1): 153-162.