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An Empirical Propagation Model for Path Loss Prediction at 2100MHz in a Dense Urban Environment

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Abstract

Objectives: Radio propagation models are used to predict signal strength in order to characterize the radio frequency channel. This will help in providing sufficient data required for the design of appropriate receivers that can recover the transmitted signal distorted due to fading and multipath effect. **Methods/Statistical analysis**: Data collection was carried out through drive test using TEst Mobile System, TEMS W995 phone interfaced with TEMS investigation tool version 13.1, Gstar GPS location finder and MapInfo professional and analyzed using Root Mean Squared Error (RMSE) statistical tool and tenth degree polynomial for fitting measured data with empirical models. **Findings**: Considering the contending empirical propagation models, the Ericsson model showed a better fit for the measured path loss data with root mean squared errors of 5.86dB, 5.86dB and 5.85dB at 1.0m, 1.5m and 2.0m mobile antenna heights respectively in comparison with Okumura model which is currently in use. It also outperformed other investigated models which are; Hata, COST 231, and SUI models at 2100MHz. These findings will help in revamping radio frequency planning and system design of the investigated and similar terrains thereby optimizing overall system performance while minimizing dropped calls, handover/quality issues and other network inherent failings. **Application/Improvements:** Results showed a minimum error estimate within the acceptable range of 6dB for signal prediction. This model can be used for signal prediction and channel characterization of any wireless mobile environment with similar channel characteristics. The other propagation models that over predicted the radio channel could be further investigated in future work and possibly tuned to accommodate dense urban areas.

Keywords: Ericsson Model, Okumura Model, Propagation Model, Path Loss, Signal Prediction

1. Introduction

The complexity of wireless network environment necessitates the study of the characterizing properties of the wireless channel as the inherent dynamic engagements within the channel alter signal transmission processes. Once signal is transmitted from the source, the terrain formation, objects and human interactions'/orientation act on the signal thereby resulting in signal scattering, reflection, shadowing and diffraction with consequent impact of signal fading and multipath propagation[1,2]. The dynamic nature of the wireless channel determines

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the eventual output of the propagated signal so that techniques for the development of efficient signal recovery and processing equipment's become a paramount interest to the radio frequency design Engineer. Path loss analysis is an essential consideration in designing wireless communication transceivers[3,4].

The growing need for excellent performing wireless infrastructure, high data rate transmission has also resulted in the investigation of propagation mechanisms of higher-order frequencies[5], with enormous prospects in increasing data rate with respect to higher bandwidth. To combat wireless channel deficiencies such as poor signal quality, blocked calls, dropped calls and interference problems, path loss prediction estimation provides an approximation used for the development of models that predicts the signal strength of any given terrain[6].

The focus of this study is on a suitable propagation model for path loss estimation at 2100MHz in an urban environment. The data of the received signal strength and other parameters were taken using TEMS tools at 2100MHz in the Alagbado area of Lagos, Nigeria.

Considering the enormous prospects in mobile networks operating at 2100MHz, technology integration also poses practical challenges in terms of network planning, implementation, pilot-pollution analysis and cell parameter evaluation with respect to the given terrain. To alleviate this challenge, propagation models can be tuned or developed with respect to the investigated environment. Essentially, these models are suitable for wireless communication planning, pilot pollution analysis, frequency allocation and cell parameters estimation as reported[7].

They are designed to predict the variation in received signal strength given the transmitter-receiver separation distance[8,9]. Since these models are site specific, it becomes difficult to generalize such models as a single model fit all purpose. In an attempt to overcome this challenge, certain parameters in the empirical model can be optimized to suit the investigated environment[10].

The vision for mobile radio communication infrastructure rollout by the Nigerian government in 2001 was to extend the country's Tele-density that was about 450,000 landlines for over 120 million people, make communication affordable, readily available and accessible to the average residents[11]. Undoubtedly, this technology has revolutionized mobile radio communication in Nigeria, but the subscribers' satisfaction in some part of the country like Lagos is highly unimpressive. The services provided by the telecommunication operators; MTN, Globacom, Airtel and Etisalat, need improvement for subscribers satisfaction. The error messages sent to mobile subscribers are generally incongruent with the real problem[12,13]. Poor quality issues, blocked calls, frequent call drops, poor interconnectivity to and from diverse network operators, noisy reception and congestion are disturbing issues that need urgent attention. Thus, this study is geared towards examining the consistency or variability of models with measured path loss, in order to determine the propagation model which best predicts the path loss of measured data with the least Root Mean Squared Error (RMSE) in the environment of study. This model will be used as a basis for predicting the path loss of measured data with improved signal prediction.

This study is focused on determining the mathematical model that can characterize the channel in the dense urban area of Lagos, Nigeria. This will serve as a basis for predicting the path loss of measured data in the environment studied with greater accuracy. The characterization of the channel encompasses coverage prediction, pilot pollution estimation and frequency management which are vital for network planning. This will help in optimizing the overall performance of the wireless mobile network in proffering seamless services in Lagos, Nigeria.

According to[14,15], as wireless mobile networks become all-pervasive, the need to investigate the wireless channel becomes a necessity as signals propagate through a variable non-ideal radio environment. Besides, the deployment of efficient and cost effective infrastructure rollout depends largely on the understanding of the intended propagation channel. Hence, the characterization of the dynamic channel via the use of statistical techniques has been well validated in the research community[7, 10]. Practically, it is relatively difficult to find a method of signal estimation that achieves a generic estimate with respect to time-signal variation. This is because the performance of the wireless channel depends on the dynamically varying properties of the wireless channel, its terrain characterization and land use per time. As a result, getting a well-defined model which appropriately covers all propagation phenomena in a given environment will require an accurate computation of the median path loss and a statistical modeling of other attenuations likely to occur as indicated by[14].

In the existing literature, most authors are proposing their own models for radio wave propagation in the environment of interest. A large number of these models;

Free space propagation model[9,10,16], Okumura model[17], Okumura-Hata model[18], COST-231 Hata model[19,20], Ericsson model[21,22], SUI model[7,23] have been well validated, while others are yet to receive common acceptance in the international community. A critical review of these literature revealed that some authors compared field test results with already validated models as in the case of this study.

In Cambridge[7], an extensive set of propagation measurements was carried out at 3.5GHz and measured data was compared with three popular path loss models. The results revealed that the ECC 33 model provided the best result in urban environments while the SUI model and the COST-321 model over predicted the path loss in the investigated environment. A similar analysis was presented with measurements taken at 900MHz in the Narnaul city of India[23]. However, the results do not agree with those carried out in Cambridge[7], as the SUI and COST 231 models performed better in the Indian environment. Obviously, this can be attributed to the differences in the geographical characteristics of the environments.

In the South-South region of Nigeria[16], a path loss variation at 876MHz was studied. The authors stated that path loss increased by 35.5dB/decade and 25.7dB/decade in urban and suburban areas respectively and they recommended the modified Hata models for use in the region. However, their inability to classify a coverage area in Port-Harcourt as a rural area is questionable. This is because highly developed regions of the world like Cambridge[7], India[23] and Japan[17], have been categorized based on population density.

In the Niger Delta region of Nigeria[11], measurement validation of modified Hata model was presented for path loss evaluation in rural environments at 1.8GHz. The authors developed the JOEF models which predicted the received signal with reasonable accuracy, a mean prediction error <10.4dB and a standard deviation error <18dB for the networks considered in the study. The Updated ITU model[24] and the Weisberg Vegetation model[25,14] could better characterize the rural areas of NIFOR and Oghara since both lie in the rain forest zone of Nigeria.

In a related study[26], the power received at 1800MHz in a mountainous terrain was investigated using an existing Egli model. Although, the model developed to predict power received in the area is quite efficient, better results could be achieved if the diffraction loss due to the presence of mountains in the propagation paths is analyzed using the Deygout and Causebrook methods[19]. Places like Mpape, Katamkpe, Guzape and Mabushi in Abuja and Okpella in Edo state may be better environments for such studies. Related studies have also been carried by[27–31].

2. Propagation Models

Propagation models are mathematical representations used to plan, design and optimize wireless networks. These models are useful for coverage prediction, spectrum allocation and pilot pollution studies. They are also used in network planning, particularly for conducting preliminary studies during initial rollout[1]. These models can be categorized as empirical, deterministic or stochastic models[6].

Empirical models result from measurement and observations and find wide application in the prediction of path loss while the deterministic model takes its reference from the governing laws of electromagnetic wave propagation in determining the received signal strength of a particular coverage area. Stochastic models predict the investigated environment in terms of a set of random variables. The mean path loss is predicted in terms of transmitter – receiver separation distance, antenna height and other variables with minimal information about the investigated environment. The propagation models commonly in use are;

2.1 Free Space Path Loss (PLFSPL)

Free space path loss model provides a mathematical model for signal strength variation given a particular transmitter-receiver separation and is given[32];

$$PL_{FSPL}[dB] = 32.45 + 20.\,log d + 10.\,log f \tag{1}$$

Given that f is the frequency in MHz and d is the separation distance in Km

2.2 Okumura-Hata Model

For urban environment, this model is given by[17,18];

$$PL_{OKUMURA-HATA}(dB) = 69.55 + 26.16.\,log f - 13.82.\,log \boldsymbol{h}_t - a(\boldsymbol{h}_r) + [44.9 - 6.55.\,log \boldsymbol{h}_r].\,log d \tag{2}$$

Given that;

f = frequency measured in MHz, $150<f<1500$.

$\boldsymbol{h}_t$ = height of the transmitter measured in meters for $30<\boldsymbol{h}_t<200$

d = transmitter-receiver separation distance in Km for *1<d<20*

$a(h_r)$ = correction factor for the height of the receiver.

For small/ medium sized city,

$$a(h_r) = (1.11\log(f) - 0.7)h_r - (1.56\log(f) - 0.8) \quad (3)$$

For $1 \leq h_r \leq 10m$

Given that;

h_r is the height of the receiver measured in meters

For a large/metropolitan city,

$$a(h_r) = \begin{cases} 8.29.(\log[(1.54h_r))^2 - 1.1 & f \leq 200MHz] \\ 3.2.(\log[(11.75h_r))^2] - 4.97 & f \geq 400MHz \end{cases} \quad (4)$$

2.3 COST 231 Model

The COST 231 model is the modification of Okumura-Hata model and is given by[19];

$$PL_{COST231}(dB) = 46.3 + 33.9\log(f) - 13.82\log(h_t) - a(h_r) + [44.9 - 6.55\log(h_t)]\log(d) + C \quad (5)$$

Given that;

f , ranges from 1500MHz to 2000MHz

h_t , ranges from 30m to 200m

h_r , ranges from 1m to 10m

d ranges from1Km to 20Km

C is the correction factor for medium city/ suburban areas with a typical value of 0dB

C is the correction factor for metropolitan areas with a typical value of 3dB.

2.4 Stanford University Interim (SUI) Model

This model is an extension of Hata model and investigates operations below 11GHz frequencies and it is given as;

$$PL_{SUI}(dB) = A + 10\gamma\log_{10}\left(\frac{d}{d_o}\right) + \chi_f + \chi_h + s \qquad for\ d > do \quad (6)$$

The parameter A is given as;

$$A = 20log.((4\pi d_1 0)/\lambda \ A = 20log.((4\pi d_1 0)/\lambda \quad (7)$$

$$\gamma = a - bh_b + \left(\frac{c}{h_b}\right)\gamma = a - bh_b + \left(\frac{c}{h_b}\right) \quad (8)$$

Given that;

d is the antennas separation distance measured in meters

d_o = 100m

λ = wavelength measured in meters

χ_f = correction factor for frequency greater than 2GHz measured in MHz

χ_h = correction factor for the height of the receiver measured in meters

s = correction factor for shadowing measured in dB

γ = path loss exponent

h_b = height of the transmitter measured in meters ranging from 10m – 80m

The values for the model parameters for different terrain types are described in[1]

The path loss exponent for urban area is γ = 2, while that for Non-Line-of-Sight (NLOS) is $3 < \gamma < 5$. For indoor propagation the path loss exponent take on values $\gamma > 5$.

The correction factor for frequency χ_f is given as;

$$\chi_f = 6log.\left(\frac{f}{2000}\right) \quad (9)$$

The correction for receiver antenna height χ_h is given as;

$$\chi_h = -10.8\ log.\left(\frac{h_r}{2000}\right) \qquad \textbf{for A and B terrain type} \quad (10)$$

$$\chi_h = -20.0\ log.\left(\frac{h_r}{20000}\right) \qquad \textbf{for C terrain type} \quad (11)$$

Given that;

f = frequency measured in MHz

h_r height of the receiver measured in meters

2.5 Ericsson Model

The Ericsson model also takes its cue from the Okumura-Hata model given by[21];

$$PL_{ERICSSON}(dB) = a_0 + a_1 log.(d) + a_2 log.(h_t) + a_3 log.(h_t).log.(d) - 3.2\,[[log.](11.75h_r)]^2 + g(f \quad (12)$$

Given that;

$$g(f) = 44.49\,log.(f) - 4.78[log.(f)]^2$$

f = frequency measured in MHz

h_t = height of the transmitter measured in meters

h_r = height of the receiver measured in meters

The parameters required for estimation using Ericsson model are documented in[1].

3. Investigated Environment

The investigated terrain falls within the northern part of Lagos, Nigeria. This area is characterized by its tropical wet and dry climate. The region is densely populated with structures ranging from a storey building to three storey building. For the purpose of this study, measurements typical of an urban settlement were taken from three Node_B's operating at 2100MHz in the Alagbado area of Lagos. This region is on latitude 6° 41' 11" North of the Equator and on Longitude 3° 18' 8" East of the Greenwich Meridian. It falls between Sango Ota along Abeokuta road in Ogun State and Ikeja in Lagos which are the two major industrialized towns in the region. Prior to urbanization which has made the region largely residential, it used to be reserved for agricultural purposes. Citation of Figures 1, 2 and 3 depict the pictorial view of the coverage area of the three sectors of one of the Node_Bs under investigation. The characterizing parameters for the three Node_Bs are as shown in Table 1 depicting the coordinates of the Node_Bs and the azimuth of each sectorized antenna.

Figure 1. Sector 1: coverage area of node_B_1 at 298° azimuth.

Figure 2. Sector 2: coverage area of node_B_1 at 118° azimuth.

Figure 3. Sector 3: coverage area of node_B_1 at 205° azimuth.

3.1 Measurement Setup

The measurement equipment comprises of TEst Mobile System (TEMS) W995 phones connected via the USB hub port to a digital computing system with TEMS investigation tool version 13.1 installed. Gstar GPS location finder and TEMS version 13.1 dongle were also connected to the USB port. The W995 phone sends the measured data to the computing device which stores data as recorded log files. The recorded log files were then interpreted and analyzed using the MapInfo professional tool (version 10.5). Field

Table 1. Parameters of the node B

Node B ID	*Coordinates*	*Azimuth*		
		Sector 1	*Sector 2*	*Sector 3*
Node_B_1	*6° 40' 32"N, 3° 17' 57"E*	*298°*	*118°*	*205°*
Node_B_2	*6° 40' 12"N, 3° 17' 31"E*	*60°*	*130°*	*270°*
Node_B_3	*6° 39' 58"N, 3° 18' 1"E*	*60°*	*150°*	*230°*

measurements were collected to the tune of over 100,000 samples at various mobile heights of 1.0m, 1.5m and 2.0m along LOS and NLOS. The transmitter – receiver distance was between 40m to 0.9km with the Node Bs distributed at about 32m height above sea level. Figure 4 shows the experimental setup for the drive test and Figure 5 shows the path loss map for the three Node_Bs.

Figure 4. Experimental setup.

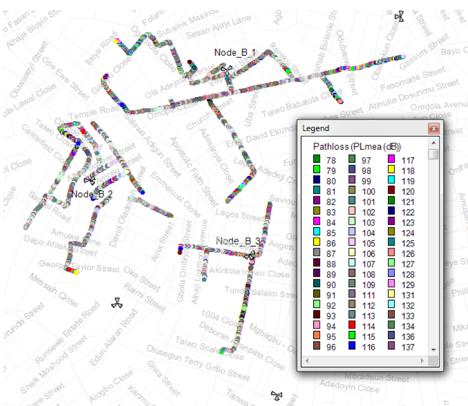

Figure 5. Path loss distribution for node_B_1, node_B_2 and node_B_3.

4. Results and Discussion

Path loss of measured data at 2100MHz for 1.0m, 1.5m and 2.0m mobile antenna heights are as shown in Figure 6. Measured path loss is also compared with free space model, Okumura-Hata model, COST231 model, SUI model and the Ericsson model for 1.0m, 1.5m and 2.0m mobile antenna heights as shown in Figures 7, Figure 8 and Figure 9, respectively.

In order to examine the consistency or variability of measured data with existing propagation models, higher order polynomials have been fitted to the measured data at 1.0m, 1.5m and 2.0m mobile antenna heights and the resulting equations are shown in Equation 13.

Measured data at 2100MHz in dense urban Lagos, have been compared against existing propagation models, the Ericsson model offered a satisfactory performance with an approximate average value of 5.86dB RMSE at various mobile antenna heights as shown in Table 2. Since the Okumura – Hata, SUI and COST 231 models over predict the path loss in the investigated area as shown in Table 2, the Ericsson model has been selected as the best model for path loss prediction in the investigated area which can be tuned with respect to the prediction errors.

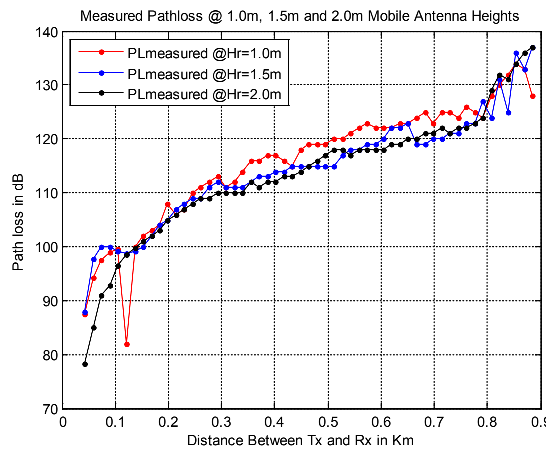

Figure 6. Measured path loss at mobile height of 1.0m, 1.5m and 2.0m for the operating frequency of 2100MHz.

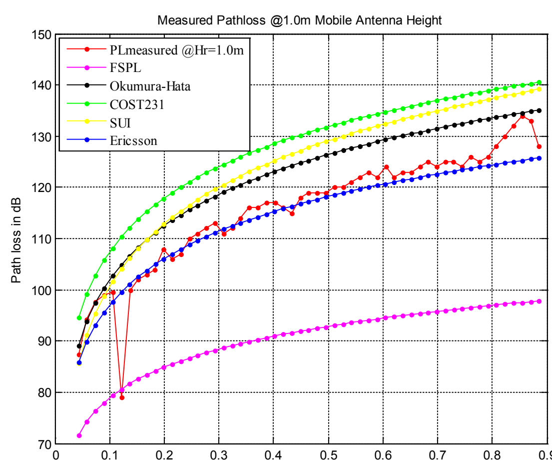

Figure 7. Comparison of measured path loss and predicted path loss at mobile height of 1.0m.

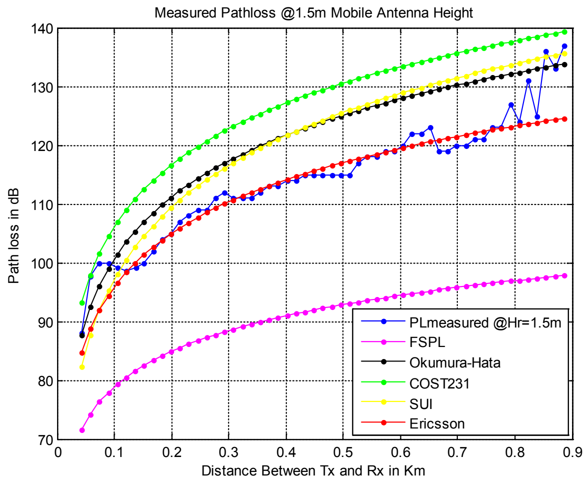

Figure 8. Comparison of measured path loss and predicted path loss at mobile height of 1.5m.

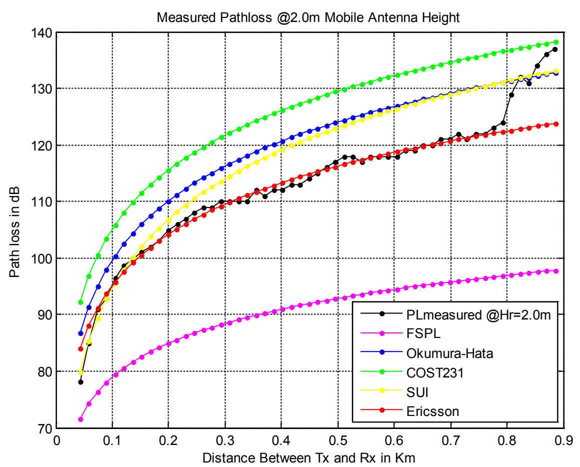

Figure 9. Comparison of measured path loss and predicted path loss at mobile height of 2.0m.

$$PL_M(dB) = P_1 z^{10} + P_2 z^{9} + P_3 z^{8} + P_4 z^{7} + P_5 z^{6} + P_6 z^{5} + P_7 z^{4} + P_8 z^{3} + P_9 z^{2} + P_{10} z^{1} + P_{11} \quad (13)$$

where z is centered and scaled: $z = \frac{(d-\mu)}{\sigma}$; μ = 0.46419; σ = 0.24992;

For mobile antenna lP_3ght of 1.0m, coefficients: P_1 = -4.145; P_2 = 0.72958; = 25.889; P_4 = -5.7551; P_5 = -53.471; P_6 = 14.57; P_7 = 40.736; P_8 = -11.179; P_9 = -11.718; P_{10} = 10.342; P_{11} = 118.86.

For mobile antenna height of 1.5m, coefficients: P_1 = -1.3101; P_2 = 1.9085; P_3 = 6.2322; P_4 = -11.485; P_5 = -5.8136; P_6 = 23.653; P_7 = -6.0176; P_8 = -16.887; P_9 = 5.662; P_{10} = 10.205; P_{11} = 114.84

For mobile antenna height of 2.0m, coefficients: P_1 = -1.017; P_2 = 0.48133; P_3 = 5.6364; P_4 = -3.3479; P_5 = -10.167; P_6 = 9.9504; P_7 = 6.6927; P_8 = -9.6266; P_9 = -2.6695; P_{10} = 9.9197; P_{11} = 115.02

5. Conclusion

The findings from this study showed that Ericsson model provided best performance, predicting the path loss of the investigated environment with RMSEs of 5.86dB, 5.86dB and 5.85dB at 1.0m, 1.5m and 2.0m as shown in Table 2 respectively. These results are within the acceptable range of up to 6.00dB for good signal prediction. The Okumura – Hata model, SUI model and the COST231 – Hata model generally predict the path loss in the tested area with RMSEs relatively higher than the acceptable value. This is perhaps to be expected owing to the dynamic nature of the investigated environment for which these models are most appropriate. The impact of different frequency bands can be analyzed with respect to the proposed model. Future studies could be directed towards optimizing the parameters of the Okumura – Hata model and the SUI model to better accommodate dense urban areas and investigating suitable parameters for the COST 231 Hata model in a built up environment.

Table 2. Comparison of RMSE

Mobile Antenna Height (m)	*Root Mean Squared Errors (RMSEs)*				
	Ericsson (dB)	*Okumura- Hata dB)*	*SUI (dB)*	*COST231 (dB)*	*FSPL (dB)*
1.0m	*5.86*	*11.66*	*15.12*	*20.20*	*43.05*
1.5m	*5.86*	*12.11*	*12.46*	*20.46*	*40.61*
2.0m	*5.85*	*11.22*	*9.36*	*19.92*	*39.56*

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