Analysis of Outdoor Path Loss Measurements for Triple Frequency Spectrum in Lagos State

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ABSTRACT

This paper presents pathloss measurement and modelling for Lagos State dense-urban (DU), urban (UR), sub-urban (SU), and non-urban (NU) G.S.M environments. It was carried out with data collection through drive testing using TEMS software in the chosen environments Lagos-Island (DU), Surulere (UR), Lekki-Oniru (SU), and Agbede-Ikorodu (NU), over a distance of 0.5-10 km from Base Station (BS) to Mobile Station (MS) with measurement taken at 0.5 km intervals for a period of 52 weeks.

Relative outdoor parameters like Rxlev, RSSI, and pathloss were measured in all areas of investigation under triple frequency spectrum (2G 900MHz, 2G 1800MHz, and 3G 2100MHz) of operation and twelve (12) different sites location were covered and analyzed. Cost231-Hata model was used as reference model for pathloss calculation of field data, this was further adjusted to develop optimized models for path loss prediction in the environments of study, which shows results within 6dB acceptable range, hence recommended for modelling in these environs and other similar GSM environments. Our new model is found to be suitable for outdoor prediction of signal loss in cellular wireless design and is useful for telecommunication providers to improve their service for better capacity and mobile user satisfaction.

(Keywords: global system for mobile communication, GSM, modelling, propagation environment, KPI, Rxlev, RSSI, pathloss)

INTRODUCTION

One of the most challenging features of any propagation environment is the path (propagation) loss – it is defined as the difference (in dB) between the effective transmitted power and the received power. However, it may or may not include the effect of the antenna gains.

Common literature reveals that path loss is also influenced by terrain contours propagation medium, distance between a base station and a mobile station, the height and location of transmitting and receiving antennas and the environment. The computation of pathloss is called pathloss prediction. However, pathloss prediction models are classified into two main categories namely outdoor propagation models and indoor propagation models.

The size of coverage areas for outdoor propagation shows that it is subdivided into megacircular, macrocellular, and microcellular. For indoor propagation it is picocellular and femtocellular studies from literature also reveals that pathloss prediction models are broadly divided into theoretical empirical and site-specific models. The major effort of this paper is to compare measured pathloss. Pathloss is usually influenced by contours along terrains, propagation medium and the distance between a base station and a mobile station.

Pathloss prediction models are generically divided into three broad categories namely; theoretical, empirical and site specific models. The comparative analysis to obtain the most accurate and reliable pathloss prediction model that could be adopted for a metropolitan pathloss computation in Nigeria is recommended.

In this paper, a .proposed model based on Hata relation is considered. The environment under study are microcells ND have different terrain irregularities. The application of Hata Model in microcellular systems have been discussed in the literature. It showed that Hata urban and Hata Suburban models are well suited for predictions in metropolitan environments.

Hata's Model

The literature has shown that this model has been introduced to urban areas and with some correction factors, it has adapted to suburban and non-urban (rural) areas.

For urban area the median pathloss equation is given by:

$$L_{(Urban)}(dB) = 69.55 + 26.16\log(fc) = 13.82\log(hr) - a(hr) + (44.9 - \log(ht))\log d \tag{1}$$

For suburban areas it is expressed as:

$$L_{(Urban)}(dB) = L_{(Urban)} - 2\left[\log\left(\frac{fc}{28}\right)\right]^2 - 5.4 \tag{2}$$

Finally for open non-urban areas it is modified as:

$$L_{(onu)}(dB) = L_{(Urban)} - 4.78\,[\log(fc)]^2 + 18.33\log(fc) - 40.94 \tag{3}$$

The correction factor, (a(hr)), in Equation (1) differs as a function of the size of the coverage area. It was observed that for small and medium environments it is:

$$a(hr) = (1.1\log(fc) - 0.7)hr - (1.56\log fc - 0.8)dB \tag{4}$$

For large environments, it is:

$$a(hr) = 81.29(\log 1.84hr)^2 - 1.1dB\ for\ fc < 300mHz \tag{5}$$

and

$$a(hr) = 3.2(\log 1.75hr)^2 - 4.97dB\ for\ fc > 300mHz. \tag{6}$$

In the equations in the ensuing discussions, d is the transmitter–receiver antenna separation distance and it is valid for 1 km – 10 km, f_c represents the operating frequency from 150MHz to 1800MHz. The transmit antenna height hr, ranges from 30m to 200m and the receive antenna height, hr ranges from 1m to 10m are considered.

Since the essential goal of any global system for mobile communication (GSM) service provider is to provide excellent services to her subscribers, which might be impeded by many effects like reflection, refraction, diffraction, scattering and absorption, which introduce pathloss to radio communication between the base transceiver station (BTS) of the provider and the mobile unit (MU) with the subscriber, it becomes imperative to constantly investigate and model this pathloss which is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas. Therefore this study presents pathloss measurement and modelling for Lagos State dense-urban, urban, sub-urban, and non-urban, GSM environments.

In this research work, Cost231 model was used to predict pathloss over the range of distance covered and further adjusted by finding the RMSE values between measured pathloss and Cost231 predicted pathloss to obtain optimized pathloss prediction model tagged (Lasu247).

Cost 231-Hata model was chosen as a reference model because of its peculiarity which makes it useful for predicting signal strength in all environments [5] [7], its frequency range that extends to 2000 MHz [2], and its incorporated signal strength prediction of up to 20 km from transmitter to receiver with transmitter antenna height ranging from 30 m to 200 m and receiver antenna height ranging from 1 m to 10 m [5] [6].

Past researchers [1] [3] have also suggested the Cost 231-Hata model to show the best performance in Lagos environments, hence its adoption as a reference model.

While the Cost 231 showed satisfactory RMSE values of 3.23dB, 1.7dB, 3.88dB, and 7.11dB for 2G-900MHz; 3.33dB, 3.38dB, 6.15dB, and 6.49dB for 2G-1800MHz; and 5.08dB, 2.99dB, 5.70dB, and 9.24dB for 3G-2100MHz, in non-urban, sub-urban, urban and dense-urban environments, respectively.

This model when modified (Lasu247) was found to predict pathloss better with RMSE values of 2.70dB, 1.60dB, 3.12dB, and 5.62dB for 2G-

900MHz; 2.66dB, 2.70dB, 4.83dB, and 5.08 dB for 2G-1800MHz; and 4.04dB, 2.43dB, 4.48dB, and 6.25dB for 3G-2100MHz, in non-urban, sub-urban, urban and dense-urban environments respectively, which are acceptable for prediction purposes.

PROBLEM STATEMENT

Efforts have been exerted on measurements and analysis of a particular terrain (e.g. Sub-Urban) [1], or pathloss modelling of three different environs using just one frequency of modulation (1800MHz) [3]. We therefore tried to take these studies further by considering four different GSM environments, modelled for these environments putting the 2G and 3G frequencies (i.e., 900 MHz, 1800 MHz, and 2100 MHz) into research consideration.

INVESTIGATED AREAS

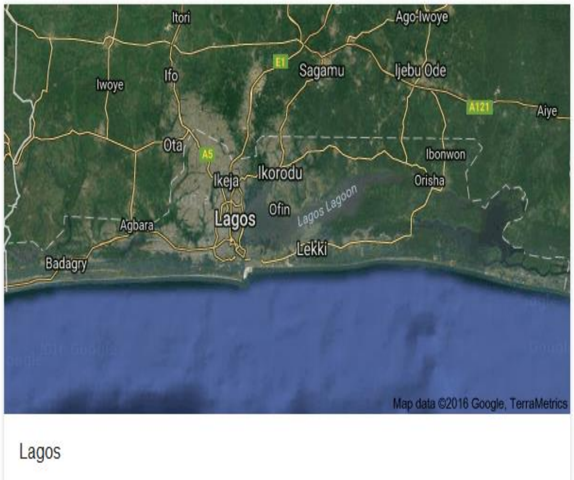

Figure 1: Map of Lagos State from Google.

Table 1: Environments of Study with GPS Values

SN	Environment	Location	GPS
1	Non- Urban	Agbede-Ikorodu	N6^0 39.9250’ E3^0 29.0363’
2	Sub- Urban	Lekki-Oniru	N6^0 26.6661’ E3^0 28.7463’
3	Urban	Surulere	N6^0 33.3844’ E3^0 20.9407’
4	Dense- Urban	Lagos-Island	N6^0 27.4832’ E3^0 23.5453’

Figure 2: TEMS Investigation Interface for Non-Urban(Agbede-Ikorodu) Environs.

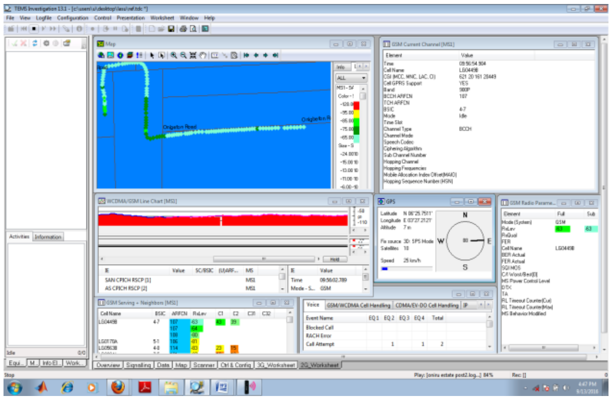

Figure 3: TEMS Investigation Interface for Sub-Urban(Lekki-Oniru) Environs.

Figure 4: TEMS Investigation Interface for Urban(Surulere) Environs.

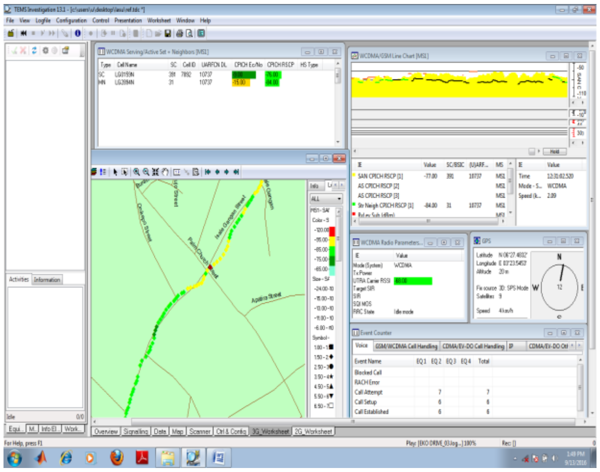

Figure 5: TEMS Investigation Interface for Dense-Urban(Lagos-Island) Environs.

Measured Parameters in 2G Environments

Quality of GSM/EDGE 2G 900/1800 MHz coverage is described basically by two indicators (KPIs); according to ECC Report 118 (2008) [8] these are:

Receive Level: RxLev – this is the received signal strength on serving cell, measured respectively on all slots RxLevFull and on a subset of slots RxLevSub. RxLevel is received power level at MS (maximum RxLevel measured by MS is (±) – 40 dBm [4].

Receive Quality: RxQual – this is the received signal quality on serving cell, measured respectively on all slots (RxQualFull) and on a subset of the slots (RxQualSub) [4]. Received signal quality level, are measured based on BER (bit error rate). The value is between 0-7, the lower the better.

Measured Parameters in 3G Environments

Quality of UMTS 3G 2100 MHz coverage is described basically by three indicators, according to the ECC Report 103 (2007) [8] these are:

Received Signal Code Power (RSCP): RSCP is the received power on one code measured on the pilot bits of the P-CPICH (Primary Common Pilot Channel).

Received Signal Strength Indicator: RSSI is the wideband received power within the relevant channel bandwidth; it is the measure of received signal strength in 3G domain.

Ec/No Service Quality: Ec/N0 is the ratio of received pilot energy, *Ec*, to the total received energy or the total power spectral density, *I0* .The received energy per chip, *Ec*, divided by the power density in the band. The Ec*/N0* is identical to RSCP/RSSI [8]. Measured in decibel; dB [1].

METHODOLOGY

Algorithm of Project Research Work

STEP 1: Drive Tests using TEMS 13 were carried out in four G.S.M environments in Lagos, data were analyzed with Mapinfo 11and extracted into Excel format.

STEP 2: RxLev (2G) and RSSI (3G) from 12 Base stations in total were recorded, Measurements range between BTS and MS is 0.5 to 10 km apart.

STEP 3: Measurements were taken at intervals of 0.5 km twice in a day in all environments and mean values calculated over a period of 52 weeks.

STEP 4: Agbede-Ikorodu, Lekki-Oniru, Surulere, and Lagos Island were chosen as non-urban, sub-urban, urban, and dense-urban environment, respectively.

STEP 5: Pathlosses measured were compiled using Equation (1).

STEP 6: Calculated (empirical) pathlosses were compiled using COST 231 Equation (3).

STEP 7: RMSE of Calculated (COST 231) pathloss and measured pathloss were found, using statistical formula Equation (4).

STEP 8: The RMSE of calculated (COST 231) was used to modify the original COST 231 Equation (3) to obtain new model referred to as Optimized model.

STEP 9: The optimized model was used to calculate new PREDICTED pathloss values.

STEP 10: RMSE of new predicted pathloss values (Optimized model) and measured pathloss were found, and compared with RMSE at STEP 7.

STEP 11: RMSE of STEP 10 was found to be of lesser values and also lower than 6dB standard, showing a better prediction and hence recommended for modelling

Experimental Setup of Drive Test

Figure 6: Drive Test TEMS Phones.

FLOWCHART OF DRIVE TEST

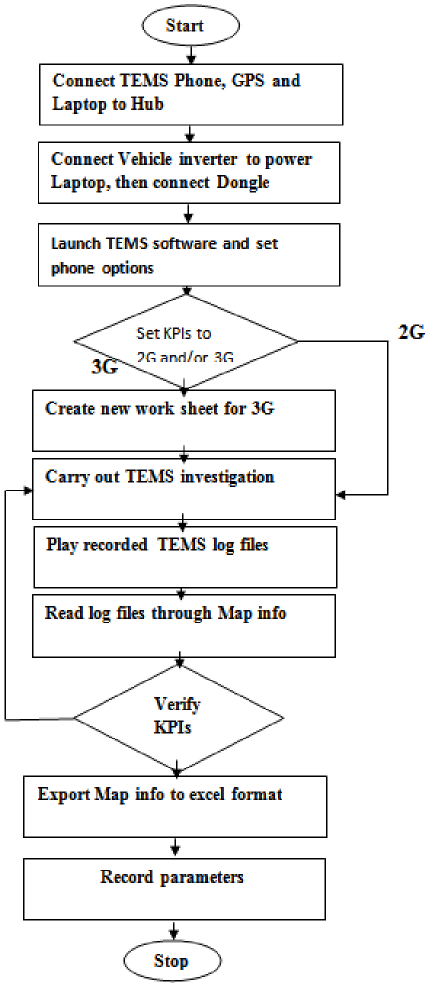

Figure 7: Flow Chart of Drive Test.

Data Analysis of Measured Pathloss

Table 2: GSM Environments and RF Parameters

Environment	BTS Power	BTS Antenna Height
Non-urban (Rural)	43dBm	45m
Urban	38 dBm	35m
Suburban	43 dBm	40m
Dense-Urban	36 dBm	30m

Where Connection loss = 4.3dBi, Feeder loss=0.3dBi, Duplexer loss=2.1dBi, Antenna Gain=2.1dBi, BTS antenna Gain=14dBi

The measured path loss PL_m (dB) for each measurement location at a distance d(km) can be found by equations given by Rappaport (2002) [9] and Seybold (2005) [10] as:

$$PL_m(dB)=EIRP_t(dBm)-P_r(dBm) \qquad \textbf{(7)}$$

Where $EIRP_t$ = effective isotropic radiated power in dBm and P_r = mean power received in dBm.

The effective isotropic radiated power $EIRP_t$(dBm) is given as:

$$EIRP_t=P_{BTS}+G_{BTS}+G_{MS}-L_{FC}-L_{AB}-L_{CF} \qquad \textbf{(8)}$$

Where P_{BTS} = BTS power (dBm),
G_{BTS} = BTS antenna gain (dBi), G_{MS}=MS antenna gain (dBi),
L_{FC} = feeder cable and connector loss (dB),
L_{AB} = antenna body loss (dB) and L_{CF} = combiner and filter loss (dB).

Substituting the values in Table II into equation (8), we calculated $EIRP_t$. The $EIRP_t$ values calculated above were further inserted into Equation (7) and the Tables for Pathloss measured (PL_m) were compiled.

Data Analysis of Calculated (Cost231) Pathloss

Calculations of Empirical Pathloss were achieved using Cost 231 pathloss model equation:

$$P_L(dB)=46.3+33.9\log_{10}f_c-13.82\log_{10}(h_t)-a(h_r)+[44.9-6.55\log10 h_t]\log_{10} d+C \qquad \textbf{(9)}$$

Where:
C= 0 dB, for suburban areas or open environments and 3dB for Urban environment [1] [3]

$a(h_r)$= mobile station antenna height correction factor is defined as:

$a(h_r)=(1.11\log_{10}f_c-0.7)h_r-(1.5\log10f_c-0.8)$, for suburban or rural areas [1] [3]

$a(h_r)=3.20[\log_{10}(11.75hr)] - 4.97$ for f > 400MHz for Urban environments [3].

Data Analysis of RMSE

RMSE (Root mean square error) statistic gives a quantitative measure of how close the predicted path loss values (COST 231) are to the measured path loss values. RMSE value closer to zero indicates a better fit. It is given as stated below:

$$RMSE=\sqrt{\sum_{i=1}^{k}\frac{\left[PL_m(d)-PL_r(d)\right]^2}{k}} \quad \textbf{(10)}$$

Where PLm (d) = measured pathloss (dB), PLr (d) = calculated path loss (dB) and k = 20 (number of measured data points).

Equation (10) above was applied to the numerical values of the measured path loss and the predicted path loss on the basis of each propagation model to obtain the RMSEs for different environments under study as shown in Table 3.

Table 3: Root Mean Square Error of Calculated Pathloss and Measured Pathloss.

Environment	2G – 900 MHz	2G–1800 MHz	3G–2100 MHz
NU	3.23	3.33	5.08
SU	1.74	3.38	2.99
UR	3.88	6.15	5.70
DU	7.11	6.49	9.24

The RMSE of calculated (COST 231) was used to modify the original COST 231 Equation (9) to obtain new model referred to as Optimized model, by simply subtracting the RMSE values from the constant (46.3) value in the formula below:

$P_L(dB)=46.3+33.9\log_{10}f_c-13.82\log_{10}(h_t)-a(h_r)+[44.9-6.55\log10h_t]\log_{10}d+C$

Table 4: Residual Values from COST 231 Formula.

Environments	2G – 900 MHz	2G–1800 MHz	3G–2100 MHz
NU	43.07	42.97	41.22
SU	44.56	42.92	43.31
UR	42.42	40.15	40.6
DU	39.19	39.81	37.06

The optimized model taking care of the environments where tests were carried out will now have the following COST 231 modified equations as PREDICTION MODELS: named ***LASU247 Pathloss Prediction Model*.**

FOR 2G-900 MHz

$P_{L(NU)}=43.07+33.9\log_{10}f_c-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10ht]\log_{10}d + C$ **(11a)**

$P_{L(SU)}=44.56+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(11b)**

$P_{L(UR)}=42.42+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(11c)**

$P_{L(DU)}=39.19+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(11d)**

FOR 2G-1800 MHz

$P_{L(NU)}=42.97+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(12a)**

$P_{L(SU)}=42.92+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(12b)**

$P_{L(UR)}=40.15+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(12c)**

$P_{L(DU)}=39.81+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(12d)**

FOR 3G-2100 MHz

$P_{L(NU)}=41.22+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10}d + C$ **(13a)**

$$P_{L(SU)}=43.31+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C \quad \textbf{(13b)}$$

$$P_{L(UR)}=40.60+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C \quad \textbf{(13c)}$$

$$P_{L(DU)}=37.06+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C \quad \textbf{(13d)}$$

Substituting the f_c as appropriate - 900, 1800 and 2100 and $a(h_r)$ as given above and h_t from Table II above, where h_r (Height of MS)=3m, then we have simplified forms of **LASU247 Pathloss Prediction Models** as shown in Equations (14-25) below, where d is distance between BTS and MS.(0.5-10 km).

FOR 2G-900 MHz

$$P_{L(NU)}=116.53+34.07\log_{10}d \quad \textbf{(14)}$$

$$P_{L(SU)}=118.73+34.41\log_{10}d \quad \textbf{(15)}$$

$$P_{L(UR)}=118.54+37.79\log_{10} d \quad \textbf{(16)}$$

$$P_{L(DU)}=116.24+38.22\log_{10} d \quad \textbf{(17)}$$

FOR 2G-1800 MHz

$$P_{L(NU)}=126.11+34.07\log_{10} d \quad \textbf{(18)}$$

$$P_{L(SU)}=126.77+34.41\log_{10} d \quad \textbf{(19)}$$

$$P_{L(UR)}=126.47+37.79\log_{10} d \quad \textbf{(20)}$$

$$P_{L(DU)}=127.06+38.22\log_{10} d \quad \textbf{(21)}$$

FOR 3G-2100 MHz

$$P_{L(NU)}=126.52+34.07\log_{10} d \quad \textbf{(22)}$$

$$P_{L(SU)}=129.31+34.41\log_{10} d \quad \textbf{(23)}$$

$$P_{L(UR)}=129.19+37.79\log_{10} d \quad \textbf{(24)}$$

$$P_{L(DU)}=126.58+38.22\log_{10} d \quad \textbf{(25)}$$

The optimized models, Equations (14-25) were used to calculate new PREDICTED pathloss values, and RMSE Equation (10) was used to analyze its values with measured pathloss to obtain Table 5.

Table 5: RMSE of Optimized Pathloss Model.

Environment	2G–900 MHz	2G–1800 MHz	3G–2100 MHz
NU	2.70	2.66	4.04
SU	1.60	2.70	2.43
UR	3.12	4.83	4.48
DU	5.62	5.08	6.25

RESULT ANALYSIS

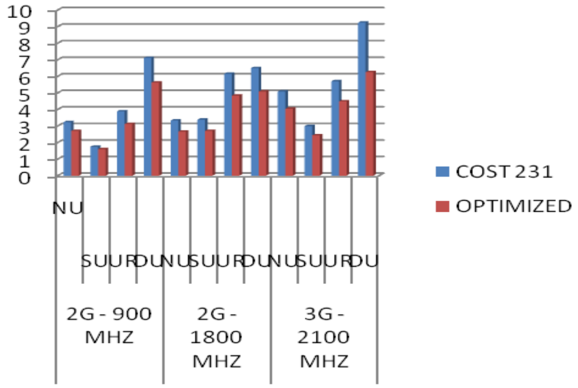

Figure 8: RMSE of Cost231 and Optimized Models.

RMSE of optimized model found to be of lesser values and also within 6dB standard [11], virtually in all showing a better prediction and hence recommended for modelling.

We further used MATLAB 2015 edition to plot the graphs of the measured, calculated and optimized pathloss values in all environments to test the correctness of our prediction models, hence we have:

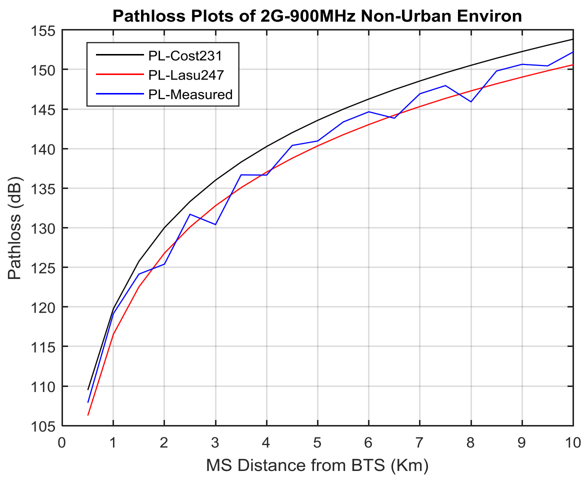

Figure 9: Plots of Measured, Cost231 and Optimized Pathloss in 2G-900MHz Non-Urban Environment.

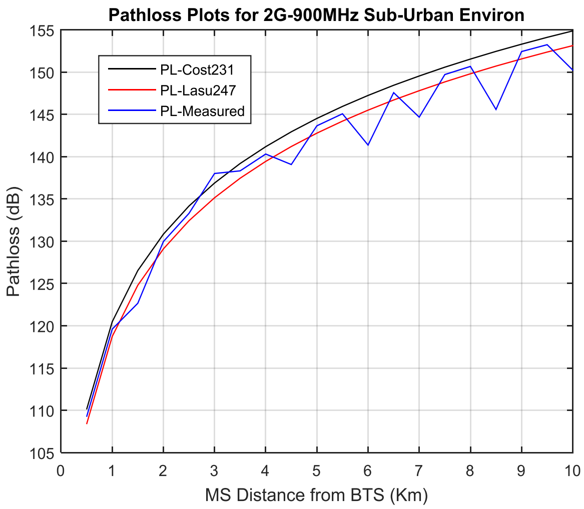

Figure10: Plots of Measured, Cost231 and Optimized Pathloss in 2G-900MHz Sub-Urban Environment.

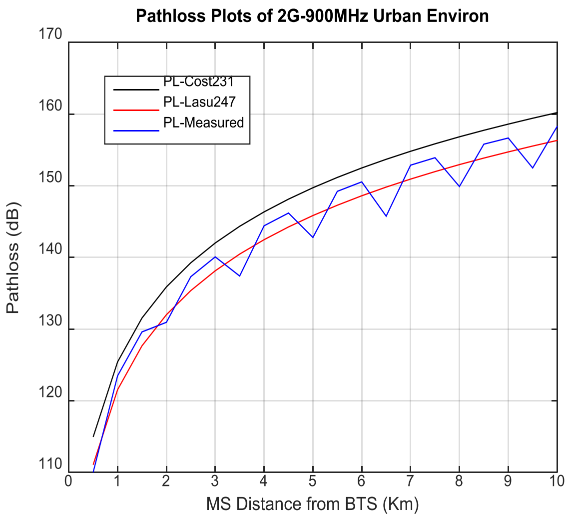

Figure 11: Plots of Measured, Cost231 and Optimized Pathloss in 2G-900MHz Urban Environment.

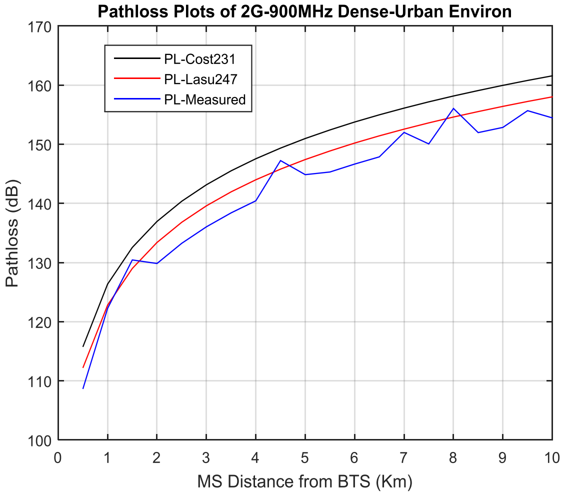

Figure12: Plots of Measured, Cost231 and Optimized Pathloss in 2G-900MHz Dense-Urban Environment.

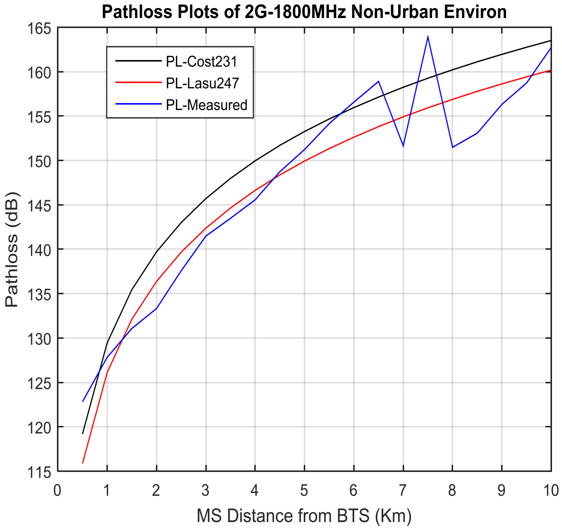

Figure 13: Plots of Measured, Cost231 and Optimized Pathloss in 2G-1800MHz Non-Urban Environment.

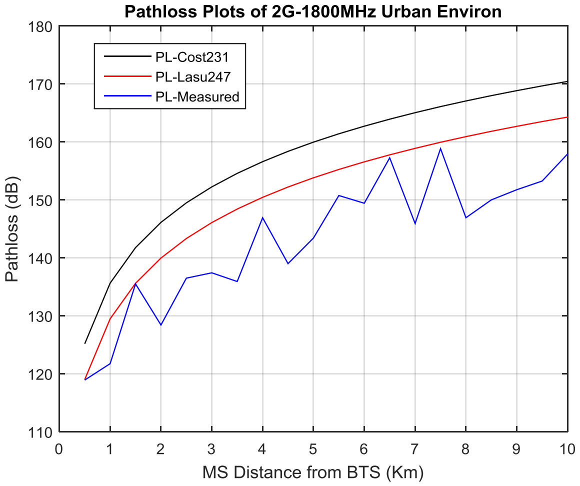

Figure15: Plots of Measured, Cost231 and Optimized Pathloss in 2G-1800MHz Urban Environment.

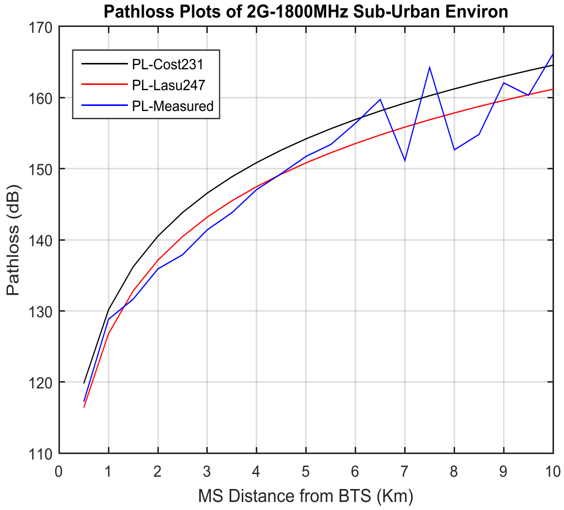

Figure 14: Plots of Measured, Cost231 and Optimized Pathloss in 2G-1800MHz Sub-Urban Environment.

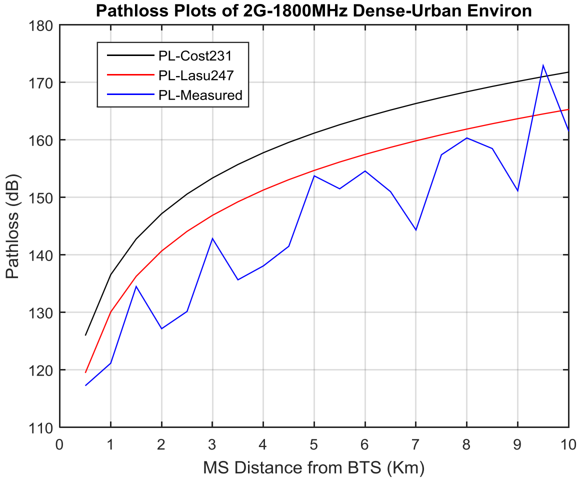

Figure 16: Plots of Measured, Cost231 and Optimized Pathloss in 2G-1800MHz Dense-Urban Environment.

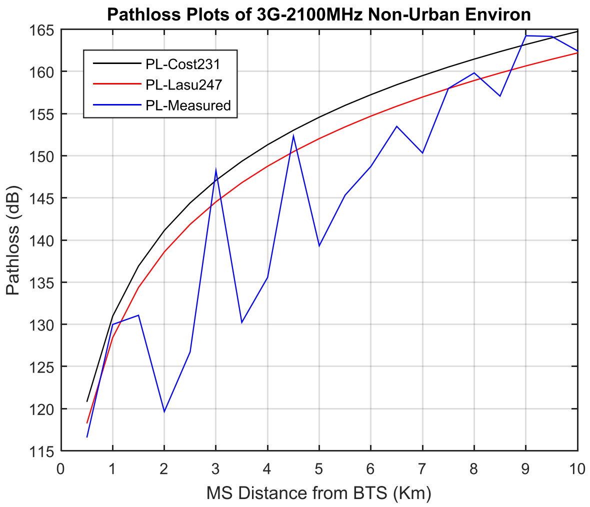

Figure 17: Plots of Measured, Cost231 and Optimized Pathloss in 3G-2100MHz Non-Urban Environment.

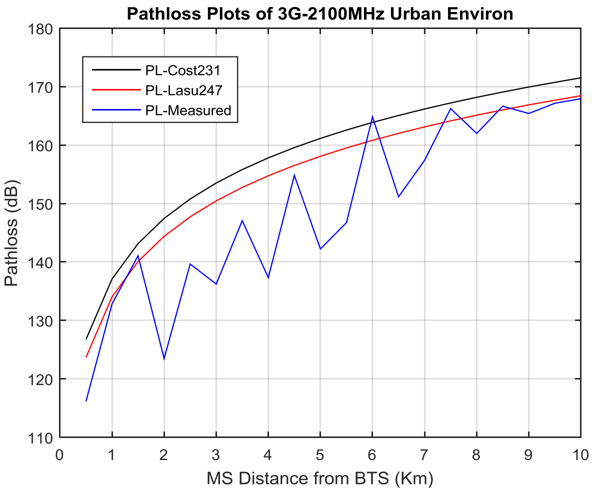

Figure 19: Plots of Measured, Cost231 and Optimized Pathloss in 3G-2100MHz Urban Environment.

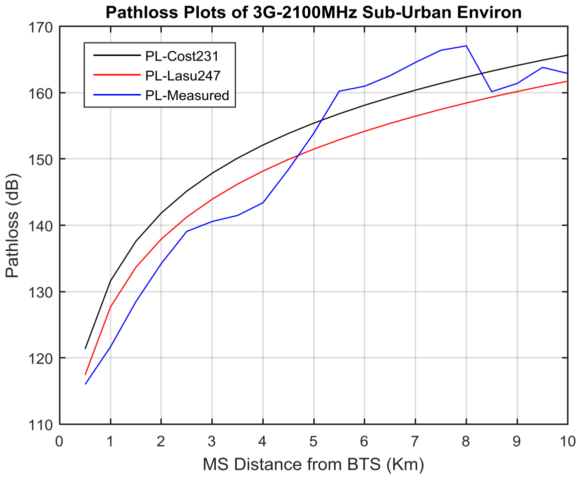

Figure 18: Plots of Measured, Cost231 and Optimized Pathloss in 3G-2100MHz Sub-Urban Environment.

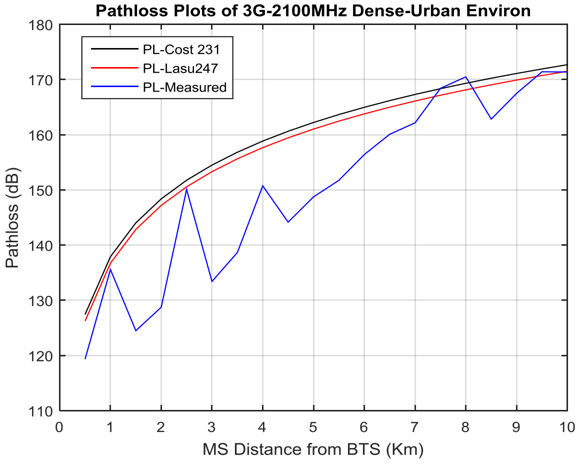

Figure 20: Plots of Measured, Cost231 and Optimized Pathloss in 3G-2100MHz Dense-Urban Environment.

CONCLUSION

The results of this study revealed that the Cost 231-Hata model showed a satisfactory performance in the chosen environments based on its RMSE values as shown in Table 3. Pathloss plots among Measured, Predicted (Cost231) and Optimized models as we have in Figures 9-20 revealed the closeness of our optimized model results to the measured pathloss, which shows accuracy of our results.

Likewise from Table 4 and Figure 8, it was observed that the RMSE values obtained from the optimized model is lower than the one from the predicting model (Cost 231), and at the same time meet the 6dB [11] standard, hence our prediction models, tagged **LASU247** can be used in these environments of study and in any other environments with similar characteristics.

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