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PATH LOSS MEASUREMENT AND MODELING FOR LAGOS STATE G.S.M ENVIRONMENTS

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ABSTRACT
This paper presents path loss measurement and modeling 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), Agbede-Ikorodu (NU), over a distance of 0.5-10Km from Base station (BS) to Mobile station (MS) with measurement taken at 0.5Km intervals for a period of 52 weeks. Relative parameters like Rxlev, RSSI, Path loss were measured in all areas of investigation under 2G and 3G frequencies of operation and twelve (12) different sites location were covered and analysed. COST 231-Hata model was used as reference model for path loss calculation of field data, this was further adjusted to develop optimized models (tagged OMODEEN models) for path loss prediction in all environments of study, which shows results within 6dB acceptable range, hence recommended for modeling in these environs and other similar G.S.M environments.

Keywords: GSM, Modeling, Environment, KPI and path loss.

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Contribution/ Originality

This study is one of very few studies which have investigated path loss in classified environment. Effort was geared towards four chosen environment in Lagos metropolitan terrain. A new model known as OMODEEN was developed and can be used for specific environs. MATLAB was used to develop graphical representation of the model.

1. INTRODUCTION

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 path loss 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 path loss 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 work presents path loss measurement and modeling for Lagos state dense-urban, urban, sub-urban and non-urban, G.S.M environments.

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In this research work, COST 231 model was used to predict path loss over the range of distance covered and further adjusted by finding the RMSE values between measured path loss and COST 231 predicted path loss to obtain optimized path loss prediction model tagged (OMODEEN).

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 [1, 2] its frequency range that extends to 2000 MHz [3] and its incorporated signal strength prediction of up to 20km from transmitter to receiver with transmitter antenna height ranging from 30m to 200m and receiver antenna height ranging from 1m to 10m [1, 4].

Past projects [5, 6] 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,7.11dB for 2G-900MHz, 3.33dB, 3.38dB, 6.15dB, 6.49dB for 2G-1800MHz, and 5.08dB, 2.99dB, 5.70dB, 9.24dB for 3G-2100MHz, in non-urban, sub-urban, urban and dense-urban environments respectively, this model when modified (OMODEEN) was found to predict path loss better with RMSE values of 2.70dB, 1.60dB, 3.12dB, 5.62dB for 2G-900MHz, 2.66dB, 2.70dB, 4.83dB, 5.08 dB for 2G-1800MHz, and 4.04dB, 2.43dB, 4.48dB, 6.25dB for 3G-2100MHz, in non-urban, sub-urban, urban and dense-urban environments respectively, which are acceptable for prediction purposes.

2. PROBLEM STATEMENT

Efforts have been exerted on measurement and analysis of a particular terrain e.g. Sub-Urban [5] or path loss modeling of three different environs using just one frequency of modulation (1800MHz) [6] we therefore tried to take these studies further by considering four different G.S.M environments, modeled for these environments putting the 2G and 3G frequencies, i.e. 900MHz, 1800MHz, and 2100MHz into research consideration.

3. INVESTIGATED AREAS

Fig-1. Map of Lagos State from Google Map

Table-I. GPS Values From Measured Data

SN	Environments of study with G.P.S Values		
	Environment	**Location**	**G.P.S**
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'

Fig-2. TEMS Investigation Interface for Non-Urban(Agbede-Ikorodu) Environ from logfiles

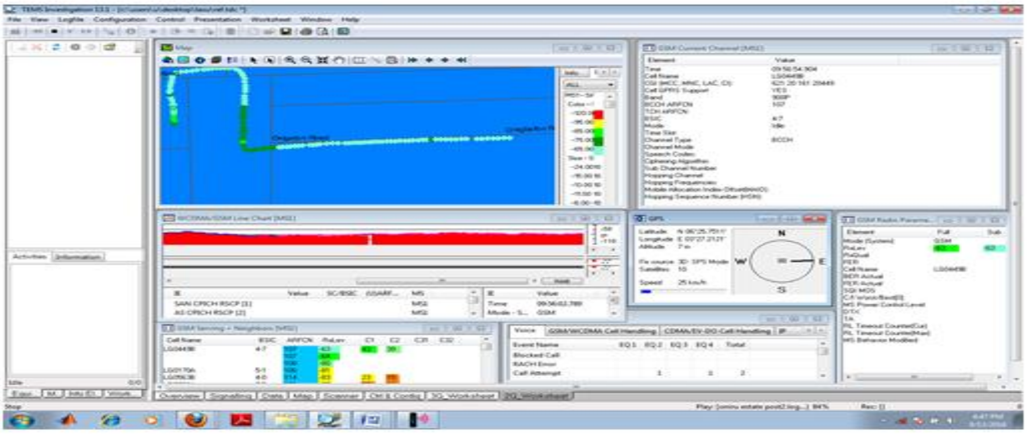

Fig-3. TEMS Investigation Interface for Sub-Urban(Lekki-Oniru) Environ from Mapinfo

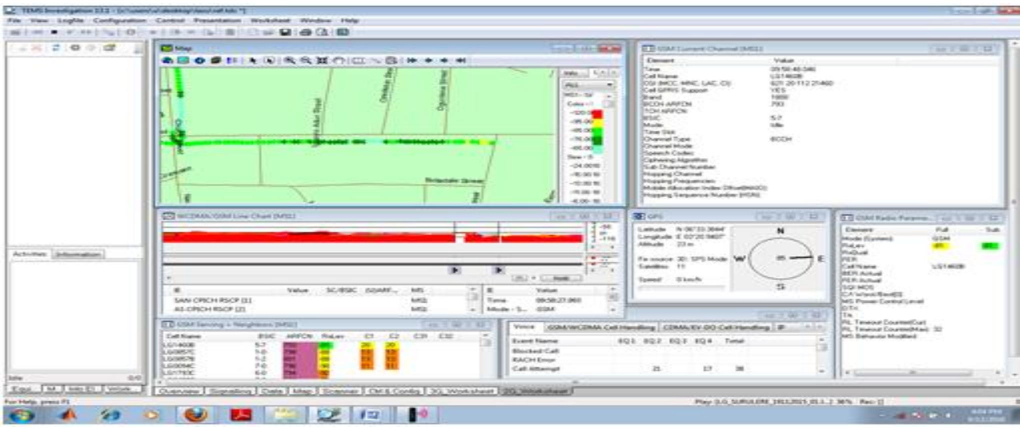

Fig-4. TEMS Investigation Interface for Urban(Surulere) Environ from Mapinfo

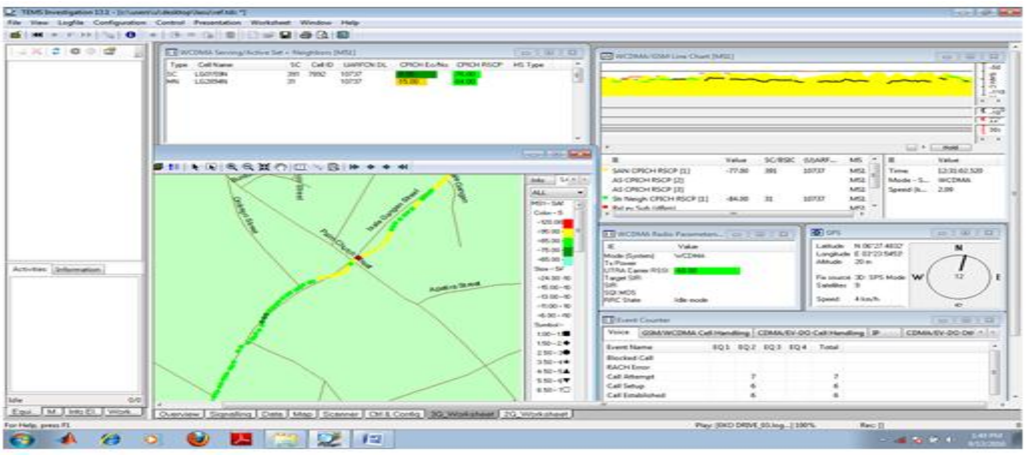

Fig-5. TEMS Investigation Interface for Dense-Urban(Lagos-Island) Environ from Mapinfo

A. 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) [7] 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 [8].

- **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) [8].

Received signal quality level, are measured based on BER (bit error rate). The value is between 0-7, the lower the better.

B. 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) [7] 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 [7]. Measured in decibel; dB [5].

C. Methodology

Algorithm of Research Study

STEP 1: Drive Tests using TEMS 13 were carried out in four G.S.M environments in Lagos, data were analysed 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 10Km 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 NonUrban, Sub- Urban, Urban and Dense-Urban environment respectively.

STEP 5: Path loss measured were compiled using equation (1)

STEP 6: Calculated (empirical) path loss were compiled using COST 231 equation (3)

STEP 7: RMSE of Calculated (COST 231) path loss and measured path loss 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 path loss values.

STEP 10: RMSE of new predicted path loss values (Optimized model) and measured path loss 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 modeling

D. Experimental Setup of Drive Test

Fig-6. Drive Test TEMS Phones of the Experimental setup

4. FLOWCHART OF DRIVE TEST

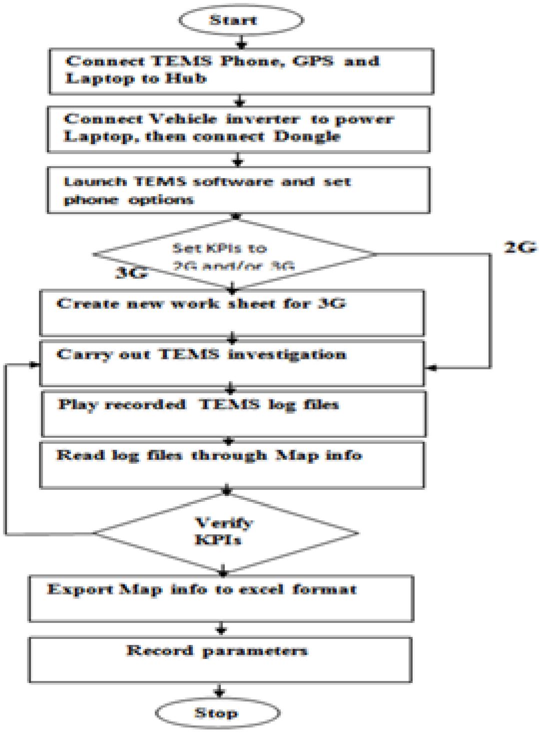

Fig-7. Flow chart of Drive Test for the Study

E. Data Analysis of Measured Pathloss

Table-2. G.S.M Environments and R.F 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 [9] and Seybold [10] as:

$PL_m(dB)=EIRP_t(dBm)-P_r(dBm)$……………….,...,,,,,,,.(1)

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:

$EIRP_t=P_{BTS}+G_{BTS}+G_{MS}-L_{FC}-L_{AB}-L_{CF}$……………..... (2)

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 (2), we calculated $EIRP_t$, the $EIRP_t$ values calculated above were further inserted into equation (1) and the tables for Path loss measured (PL_m) were compiled.

4.1. Data Analysis of Calculated (COST 231) Path loss

Calculations of Empirical Path loss were achieved using Cost 231 path loss model equation

$P_L(dB)=46.3+33.9\log_{10}f_c-13.82\log_{10}(h_t)-a(h_r)+[44.9-6.55\log10h_t]\log_{10} d+C$ ……………………………………………….(3)

Where:

C= 0 dB, for suburban areas or open environments and 3dB for Urban environment [5, 6]

(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 [5, 6]

$a(h_r)=3.20[\log_{10}(11.75hr)]$ - 4.97 for f > 400MHz for Urban environment [6]

4.2. 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

$$RMSE=\sqrt{\sum_{i=1}^{k}\frac{\left[PL_m(d)-PL_r(d)\right]^2}{k}}$$ ………… (4)

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

Equation (4) 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 III below.

Table-3. Root Mean Square Error of Calculated Path loss and Measured Path loss

	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 (3) 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

	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 ***OMODEEN Path loss Prediction Model.***

FOR 2G-900 MHz

$P_{L(NU)}=43.07+33.9\log_{10}f_c-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10ht]\log_{10}d + C$.........................(5a)

$P_{L(SU)}=44.56+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$.......................(5b)

$P_{L(UR)}=42.42+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$........................(5c)

$P_{L(DU)}=39.19+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$........................(5d)

FOR 2G-1800 MHz

$P_{L(NU)}=42.97+33.9\log_{10}fc-13.82\log_{10} (ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..................(6a)

$P_{L(SU)}=42.92+33.9\log_{10}fc-13.82\log_{10} (ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..................(6b)

$P_{L(UR)}=40.15+33.9\log_{10}fc-13.82\log_{10} (ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..................(6c)

$P_{L(DU)}=39.81+33.9\log_{10}fc-13.82\log_{10} (ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..................(6d)

FOR 3G-2100 MHz

$P_{L(NU)}=41.22+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$...(7a)

$P_{L(SU)}=43.31+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..(7b)

$P_{L(UR)}=40.60+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..(7c)

$P_{L(DU)}=37.06+33.9\log_{10}fc-13.82\log_{10}(ht)-a(hr)+[44.9-6.55\log10\ ht]\log_{10} d + C$..(7d)

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 **OMODEEN Path loss Prediction Models** as shown in equations (8-19) below, where d is distance between BTS and MS.(0.5-10Km).

FOR 2G-900 MHz

$P_{L(NU)}=116.53+34.07\log_{10}d$..(8)

$P_{L(SU)}=118.73+34.41\log_{10}d$...(9)

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

$P_{L(DU)}=116.24+38.22\log_{10} d$..(11)

FOR 2G-1800 MHz

$P_{L(NU)}$=126.11+34.07$\log_{10}$ d.......................................(12)

$P_{L(SU)}$=126.77+34.41$\log_{10}$ d.......................................(13)

$P_{L(UR)}$=126.47+37.79$\log_{10}$ d.......................................(14)

$P_{L(DU)}$=127.06+38.22$\log_{10}$ d.......................................(15)

FOR 3G-2100 MHz

$P_{L(NU)}$=126.52+34.07$\log_{10}$ d.......................................(16)

$P_{L(SU)}$=129.31+34.41$\log_{10}$ d.......................................(17)

$P_{L(UR)}$=129.19+37.79$\log_{10}$ d.......................................(18)

$P_{L(DU)}$=126.58+38.22$\log_{10}$ d.......................................(19)

The optimized models, equations (8-19) were used to calculate new PREDICTED path loss values, and RMSE equation (4) was used to analyse its values with measured path loss to obtain the following table:

Table-5. RMSE of Optimized Path loss Model from Measured Data

	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

F. Result Analysis

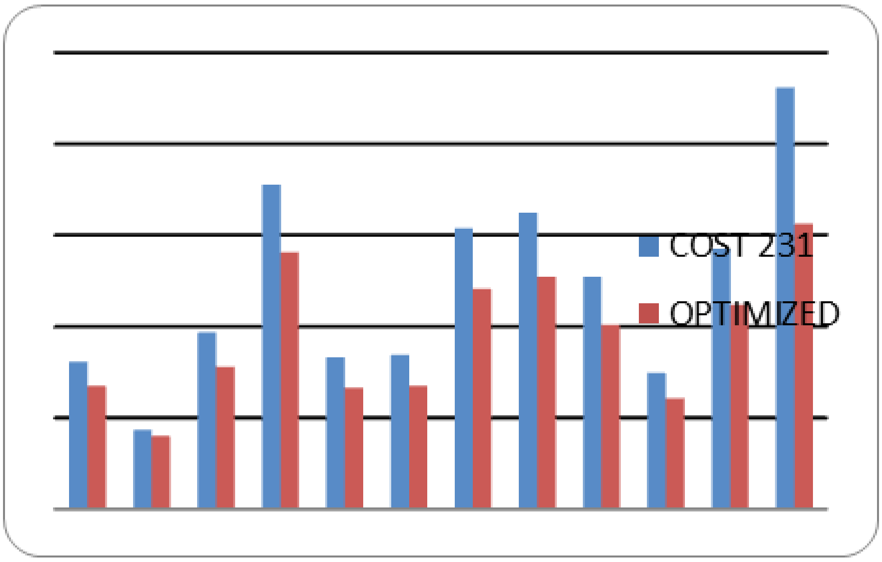

Fig-8. Bar chart of RMSE of Cost231 and Optimized Models from Excel

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 path loss values in all environments to test the correctness of our prediction models, hence we have:

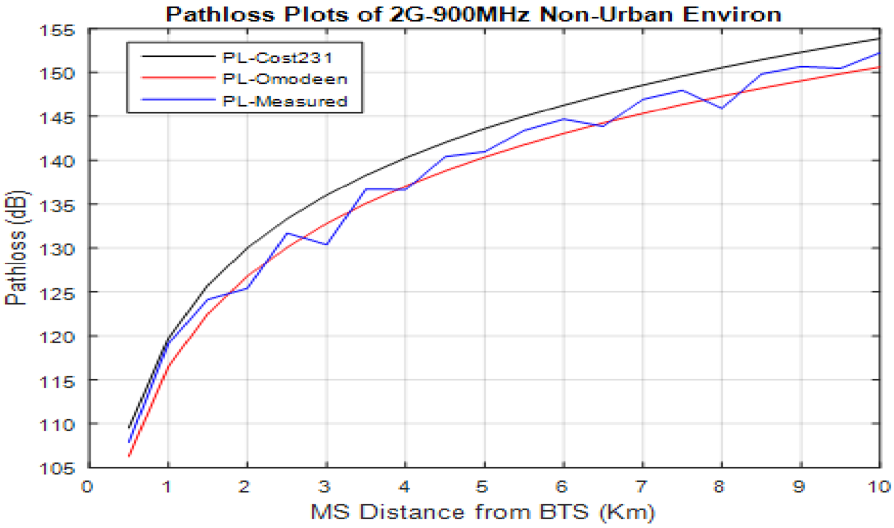

Fig-9. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-900MHz Non-Urban environment

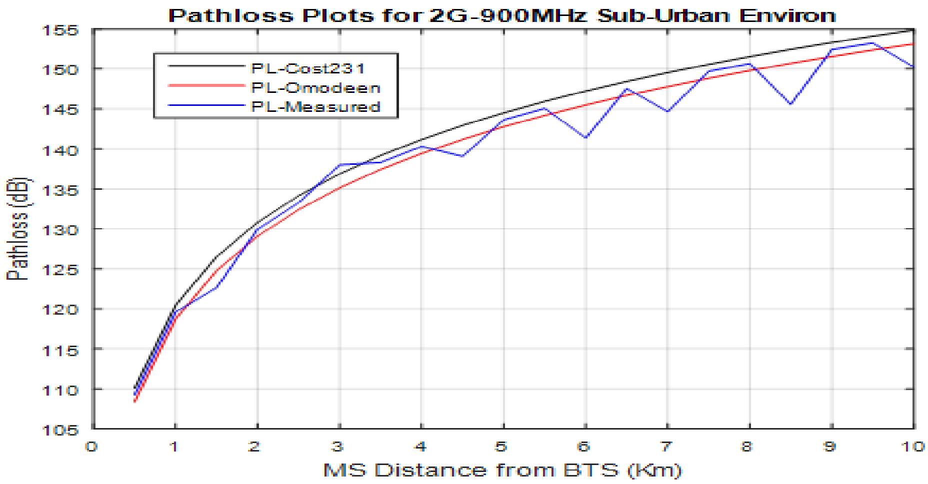

Fig-10. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-900MHz Sub-Urban environment

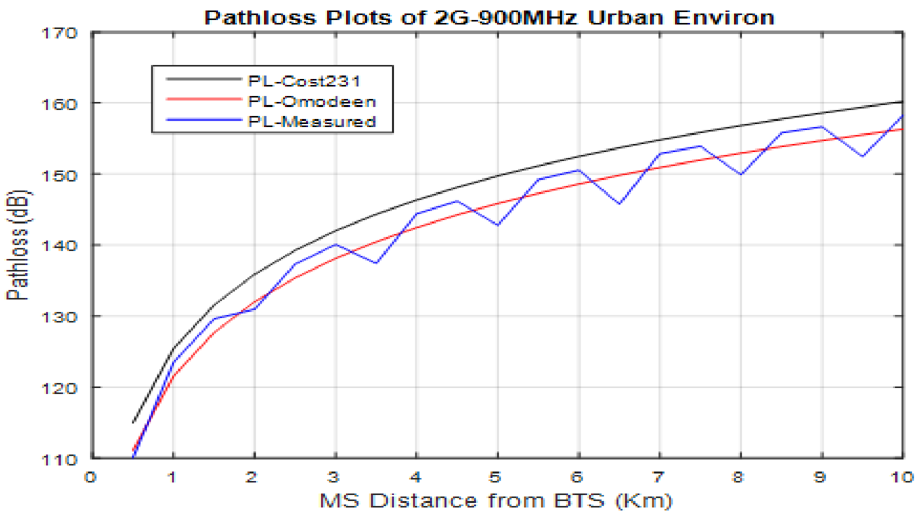

Fig-11. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-900MHz Urban environment

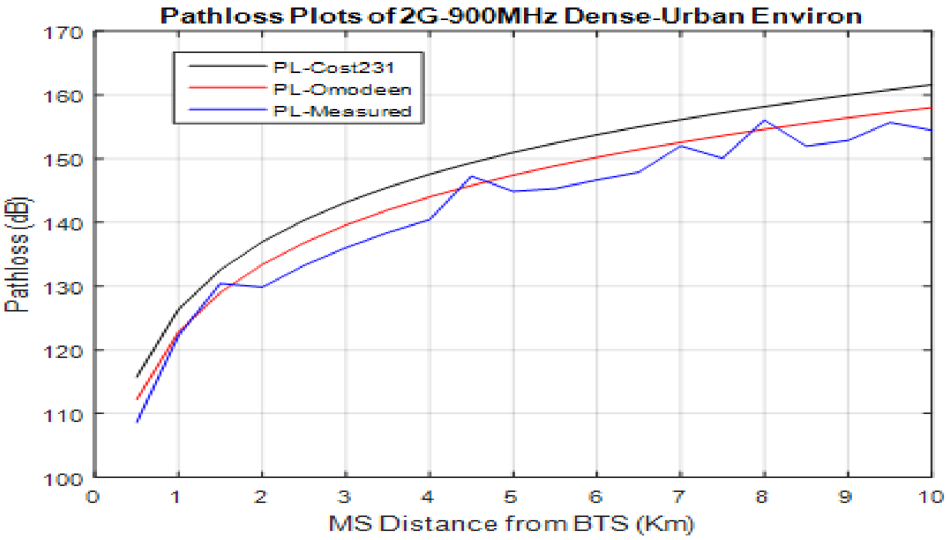

Fig-12. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-900MHz Dense-Urban environment

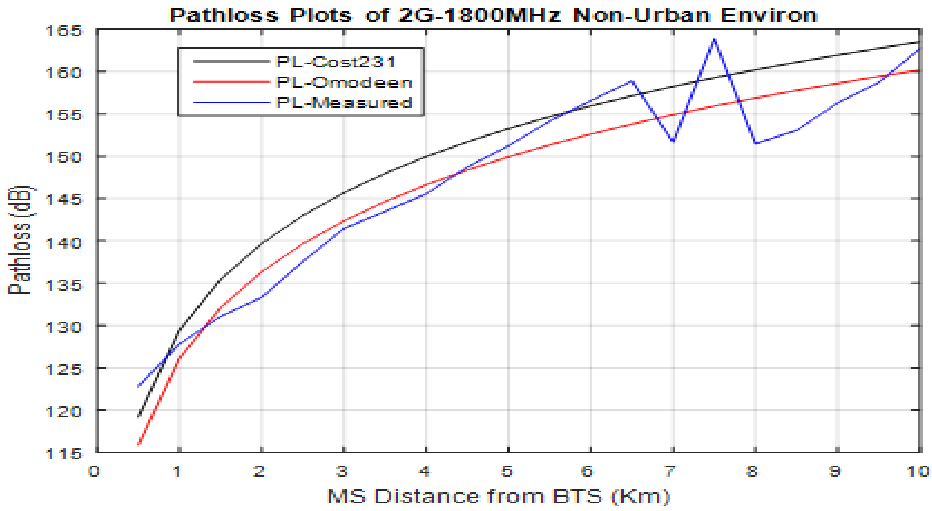

Fig-13. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-1800MHz Non-Urban environment

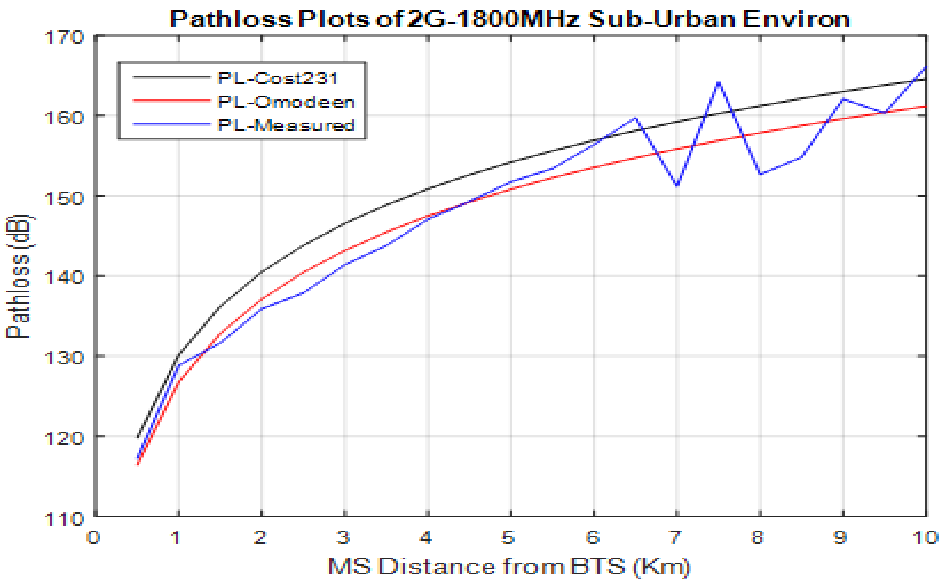

Fig-14. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-1800MHz Non-Urban environment

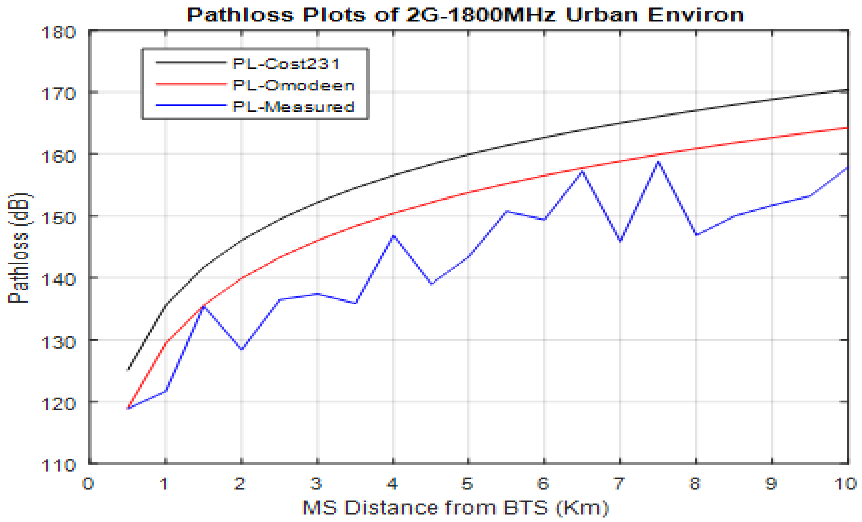

Fig-15. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-1800MHz Urban environment

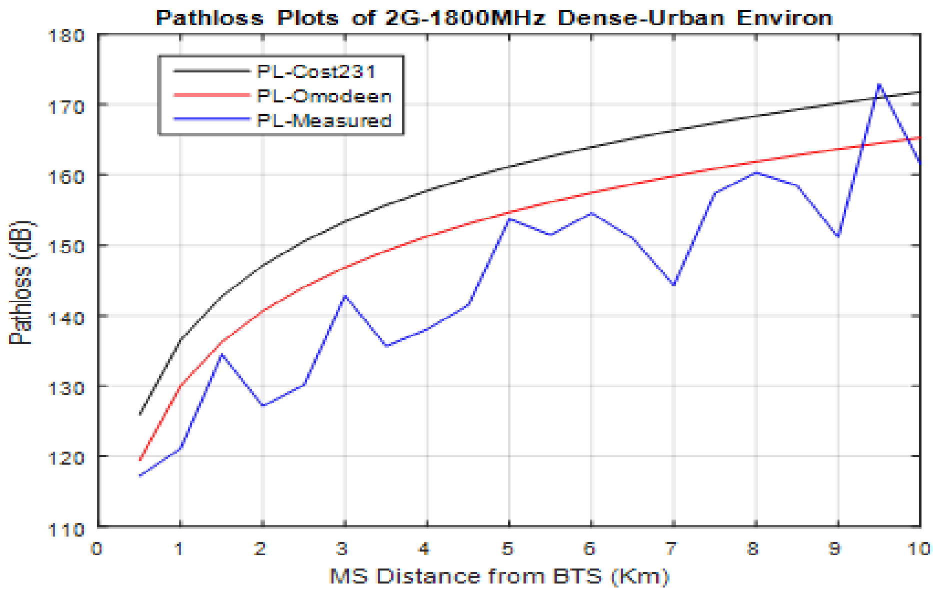

Fig-16. Matlab Plots of Measured, Cost231 and Optimized Path loss in 2G-1800MHz Dense-Urban environment

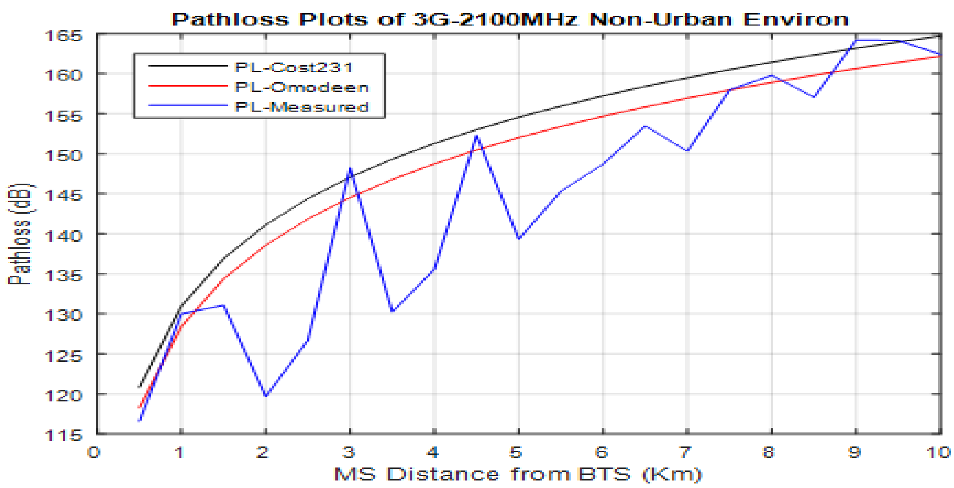

Fig-17. Matlab Plots of Measured, Cost231 and Optimized Path loss in 3G-2100MHz Non-Urban environment

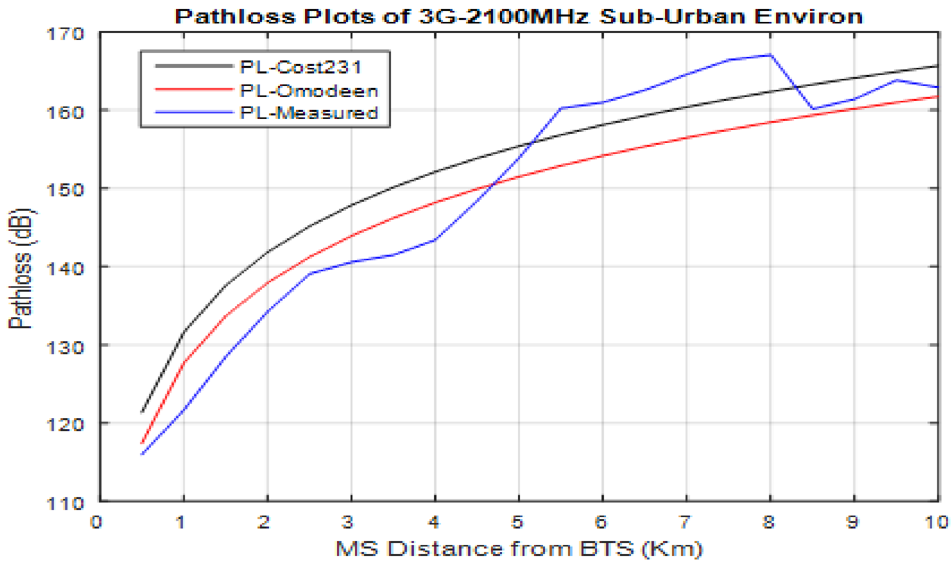

Fig-18. Matlab Plots of Measured, Cost231 and Optimized Path loss in 3G-2100MHz Sub-Urban environment

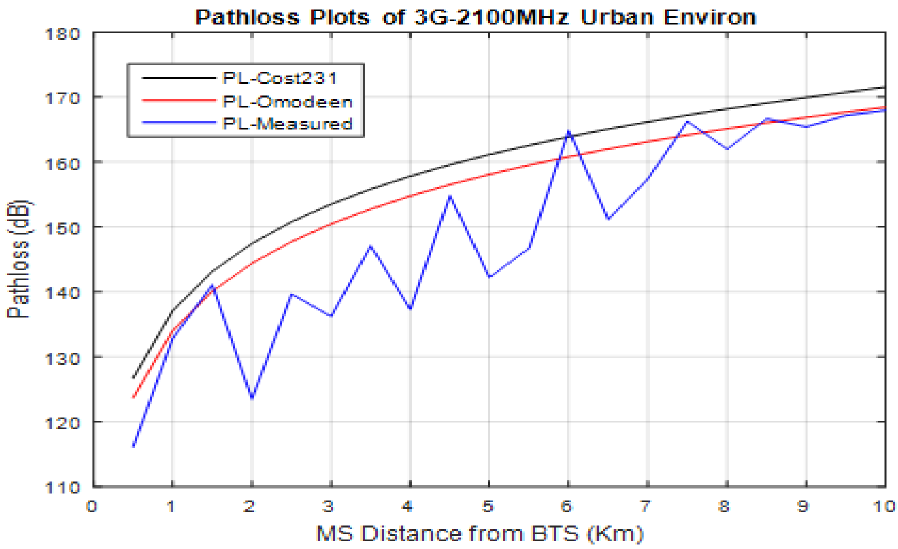

Fig-19. Matlab Plots of Measured, Cost231 and Optimized Path loss in 3G-2100MHz Urban environment

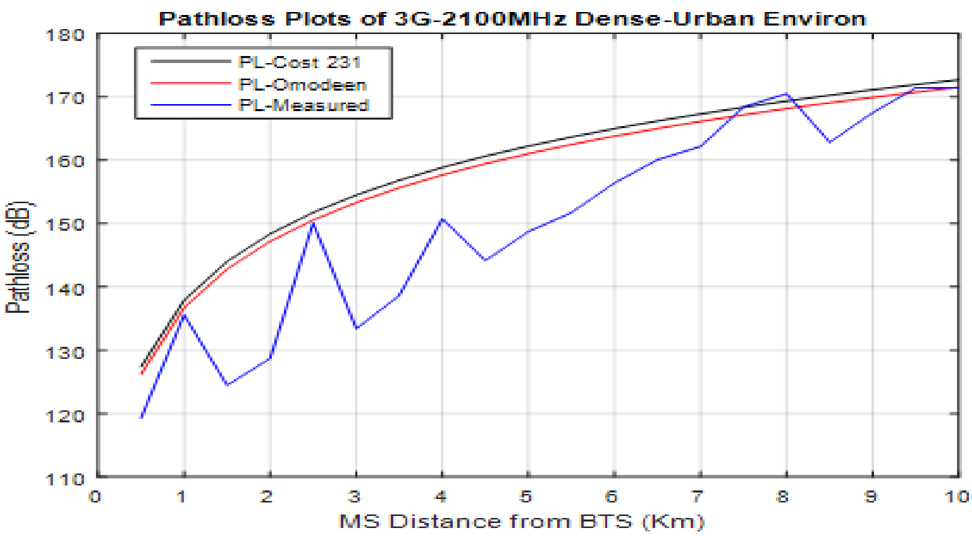

Fig-20. Matlab Plots of Measured, Cost231 and Optimized Path loss in 3G-2100MHz Dense-Urban environment

5. 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 III, Path loss 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 path loss, which shows accuracy of our results.

Likewise from Table IV 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 OMODEEN can be used in these environments of study and in any other environments with similar characteristics.

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