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Comparative Analysis and Optimization of Okumura-Hata and COST 231 Propagation Models with Field Measurements in Sokoto Metropolis, Nigeria

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ABSTRACT
Accurate path loss prediction is critical for efficient GSM network planning. This study evaluates the performance of Okumura-Hata, and COST 231 models against field-measurements for Airtel and 9mobile in Sokoto Metropolis, Nigeria. Field data were collected using a Gionee S9 smartphone with installed Network Cell Info Lite, GPS tools, and a cell tower locator app, across urban-suburban routes, and models were optimized with terrain specific clutter factors. Results show the modified COST 231 model (with a clutter factor of 1.8 dB/Km) achieved the lowest prediction errors, reducing RMSE to 4.0 dB for Airtel and 3.6 dB for 9mobile, outperforming the standard models by 35-42%. The study concludes that model localization is essential for optimal GSM deployment in Sokoto's urban-suburban environment.

Keywords: Path loss, Okumura-Hata, COST 231, Clutter factor,Sokoto, Airtel, 9mobile

I. INTRODUCTION

Radio propagation models are vital for cost-effective GSM network planning, but their accuracy depends on environmental adaptability. Sokoto Metropolis, with its mix of urban and suburban terrains, presents unique challenges due to irregular building distributions and foliage. While global models like Okumura-Hata and COST 231 are widely used, their unmodified forms often mispredict path loss in specific locales.

Prior studies highlight the need for localized model tuning. Michael et al. (2017) reported that Hata model worked best in AkwaIbom, Nigeria, except in hilly areas where Egli model is preferred. Deme et al. (2013) validated COST 231 for Maiduguri (RMSE = 5.33 dB). Sharma (2010) found ECC-33 optimal for urban India, while Okumura-Hata suited rural zones. In a study by Ogbulezie (2013), COST 231 showed superior accuracy at 1800 MHz in Port Harcourt. However, few studies address Sokoto's hybrid urban-suburban terrain, necessitating this work.

In this work, standard Okumura-Hata and COST 231 models were compared with field measurements, modified versions of these models tailored to Sokoto's environment were developed, and the most accurate model for GSM network planning in the region was recommended.

II. METHODOLOGY

2.1 Materials/Tools used

Gionee S9 smartphone with:
Network Cell Info Lite (RSS measurements),
GPS Tools (distance to cell tower) and
Cell Tower Locator

2.2 Data collection

Measurements were taken at 100m intervals along four (4) routes (AbdullahiFodio road, Aliyu Jodi road, Sultan Bello road, DioriHammani road to KofarMarke). Five readings per point averaged to reduce noise. All the measurement was carried out with the Gionee S9 cellular phone with the aid of previously mentioned installed applications.

Figure 1: Google map showing Sultan Bello road of Sokoto metropolis

2.3 Path Loss Calculation

Measured path loss derived from:

$$PL = EIRP - P_R + G_R \quad (1)$$

where EIRP = Effective Isotropic Radiated Power, P_R = received power (dBm), G_R = receiver gain.

2.4 Model Formulations

2.4.1 Standard Models

1. Okumura-Hata:

$$L_{50}(dB) = L_f + A_{mu}(f, d) - G(h_b) - G(h_m) - G_{AREA} \quad (2)$$

where

$L_{50}(dB)$ is the median value (i.e. 50^{th} percentile) of path (propagation) loss, L_f is the free space loss, A_{mu} is the median attenuation relative to free space, $G(h_b)$ is the base station antenna height gain factor, $G(h_m)$ is the mobile antenna height gain factor, and G_{AREA} is the gain or correction factor due to the type of environment.

$G(h_b)$ and $G(h_m)$ are calculated using these simple formulae:

$$G(h_b) = 20\log_{10} 1000_m > h_b > 30_m \quad (3)$$

$$G(h_m) = 10\log_{10}\left(\frac{h_m}{3}\right) h_m \leq 3 \quad (4)$$

$$G(h_m) = 20\log_{10}\left(\frac{h_m}{3}\right) 10_m \leq h_m \leq 3_m \quad (5)$$

2. COST 231:

$$L = 46.3 + 33.9\log f - 13.82\log h_B - a(h_R) + (44.9 - 6.55\log h_B)\log d + C \quad (6)$$

where,

C=0 for medium cities and suburban areas

C=3 for metropolitan areas

L = Median path loss in Decibels (dB)

f = Frequency of Transmission in Megahertz (MHz)

h_B = Base Station Antenna effective height in Meters (m)

d = Link distance in Kilometers (km)

h_R = Mobile Station Antenna effective height in Meters (m)

a (h_R) = Mobile station Antenna height correction factor as described in the Hata Model for Urban Areas.

2.4.2 Modified Models

1. Modified Hata model:

Added urban correction factor C_{urban} to account for Sokoto's building density:

$$L_{Mod} = L_{Hata} + C_{urban} \quad (7)$$

where $C_{urban} = 2.5$ dB

2. Modified COST 231 model:

Incorporated clutter loss factor C_f, which is an empirical correction term that accounts for additional path loss caused by terrain obstructions (buildings, foliage, etc). Excess pathloss is calculated as the difference between measured and predicted values:

$$\Delta PL = PL_{Meas} - PL_{Pred} \quad (8)$$

Regression analysis is carried out for ΔPL against distance d, from which C_f was evaluated to be 1.8 dB/km as the slope of the linear model.

$$\Delta PL = C_f . d + \epsilon \quad (9)$$

where ϵ is the random error (mean = 0 dB) and C_f (slope) is the terrain specific clutter factor.

The modified COST 231 model becomes:

$$PL_{Mod} = PL_{COST\ 231} + C_f\log_{10}(d) \quad (10)$$

III. RESULTS AND DISCUSSION

3.1 Results

Figures 1 and 2 illustrate the measured and predicted pathlosses for Airtel and 9-mobile networks in Sokoto metropolis, utilizing Okumura-Hata and COST 231 models.Figures 3 and 4 present the modified path loss models alongside the measured data.

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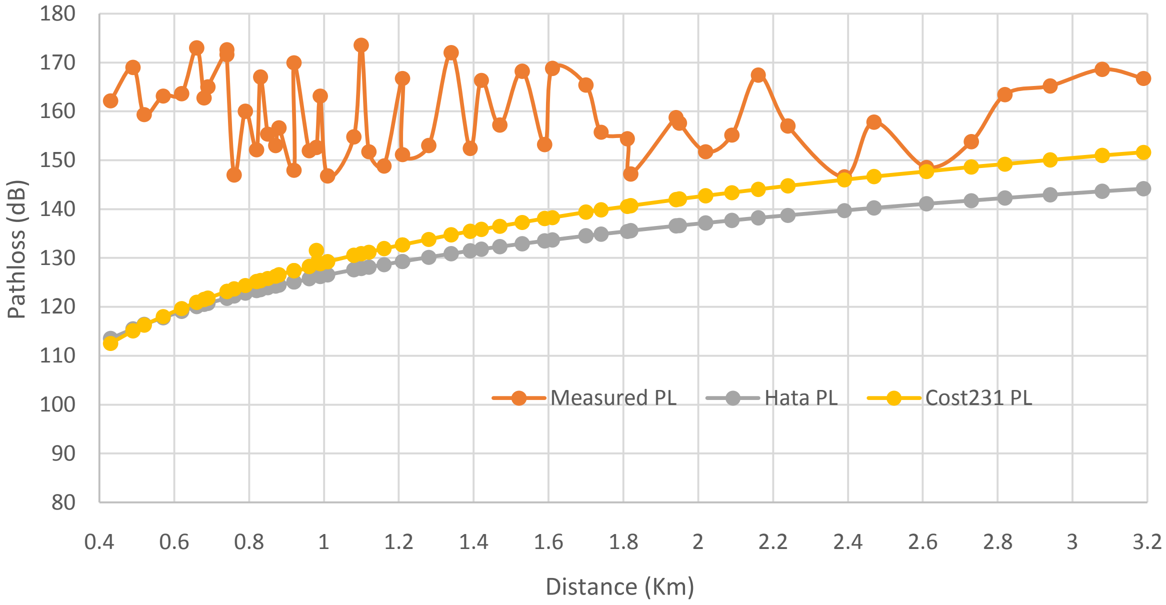

Figure 2: Measured and Predicted Path Losses along Sultan Bello road for Airtel.

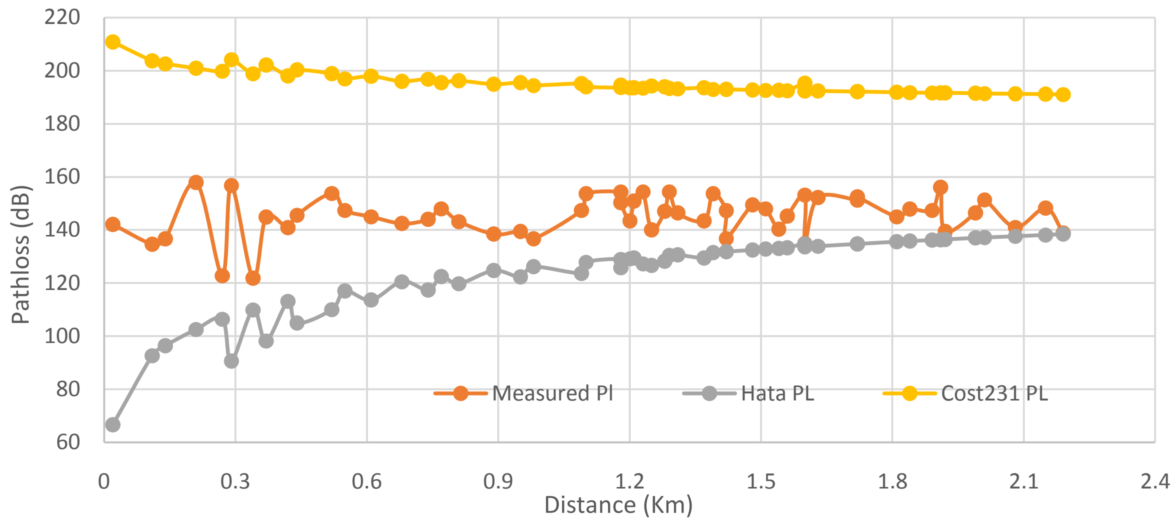

Figure 3: Measured and Predicted Path Losses along sultan Bello road for 9-Mobile.

The acceptable range between measured and predicted pathloss is typically between 1 and 20 dB (Rakesh and Srivatsa2012), highlighting the need to modify predictive models for suitability in the studied environment.

Subsequently, both Okumura-Hata and COST 231 models were modified to suit the Sokoto environment, with the modified equations presented as Equations 11 and 12, respectively. Equation 11 modifies the standard Okumura-Hata model by addingurban correction factor (C_{urban} = 2.5 dB)and frequency adjustment terms, while Equation 12 modifies the standard COST 231 model by incorporating a clutter factor, C_f= 1.8 dB/Km.

$$PL_{mod}\,(dB) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - G(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + 2.5 + 0.5\log_{10}(\frac{f}{100}) \quad (11)$$

where the last term is the frequency adjustment term,with values of 0 dB for Airteland 0.15 dB for 9-Mobile. The urban correction factor remains the same for both Airtel and 9-Mobile networks.

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$$L_{mod} = 46.3 + 33.9\log f - 13.82\log h_B - a(h_R) + (44.9 - 6.55\log h_B)\log d + 1.8\log_{10}(d) \quad (12)$$

Figures 4 and 5 show the modified predicted path losses for the Okumura-Hata and COST 231 models plotted alongside the measured data for Airtel and 9-mobile networks, respectively.

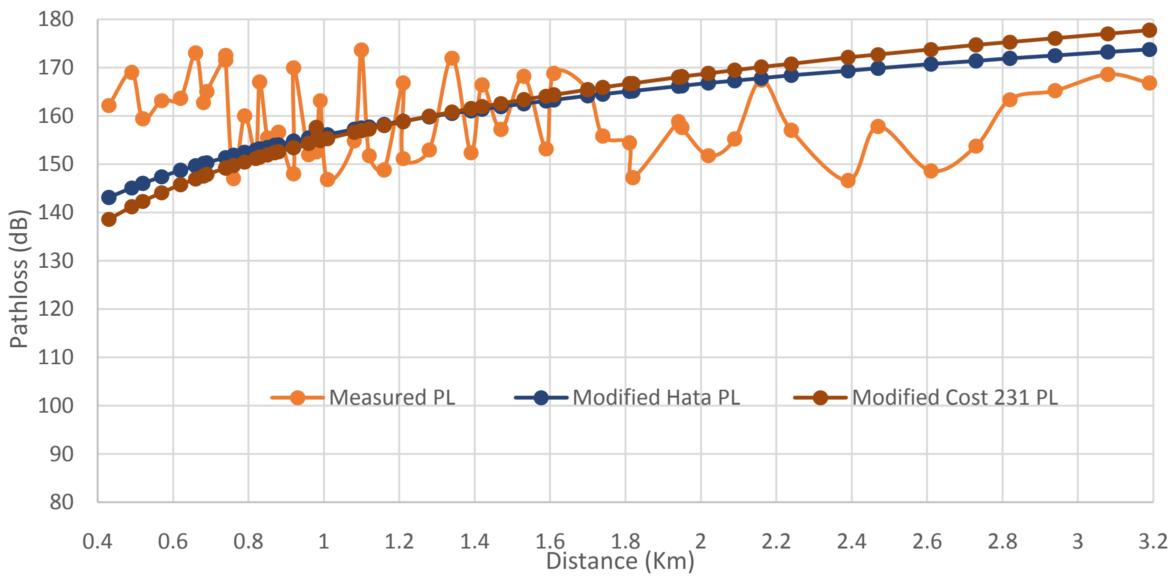

Figure 4: Measured and Modified Predicted Path Losses along Sultan Bello road for Airtel

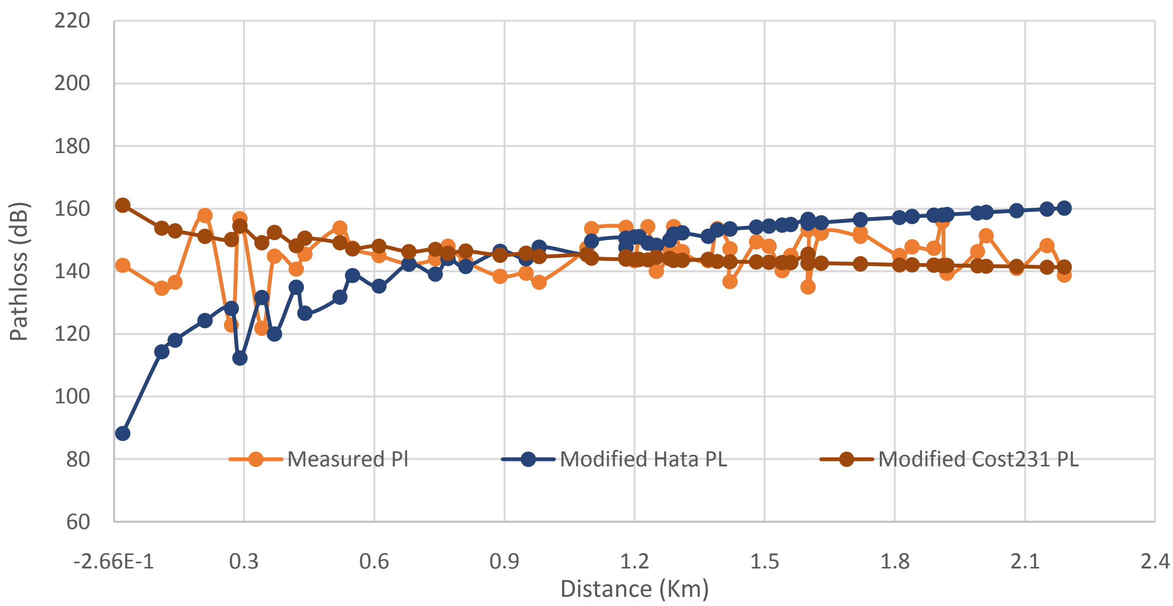

Figure 5: Measured and Modified Predicted Path Losses along Sultan Bello road for 9-Mobile

The performance comparison results of the predictive models employed in this study are presented in Table 1, where Root Mean Squared Error (RMSE) and Mean Biased Error (MBE) statistical used to evaluate their performance.

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Table 1: Model Performance Comparison

Model	Network	RMSE (dB)	MBE (dB)
Standard Okumura-Hata	Airtel	7.9	+2.5
Modified Hata	Airtel	5.3	+0.8
Standard COST 231	Airtel	6.1	-1.2
Modified COST 231	Airtel	4.0	-0.3
Standard Okumura-Hata	9mobile	8.5	+3.1
Modified Hata	9mobile	5.8	+1.2
Standard COST 231	9mobile	5.5	-0.9
Modified COST 231	9mobile	3.6	+0.2

3.2 Discussion

Figure 2 shows that both the COST 231 and Okumura-Hata models underestimate the path loss for Airtel network along the chosen route in Sokoto metropolis. However, COST 231 outperforms Okumura-Hata as the distance increases. The difference between measured and predicted path losses averages more than 30 dB, highlighting the need to modify the predictive models. The measured is observed to fluctuate between 150dB and 170dB. On the other hand, the COST 231 model overestimates the path loss for 9mobile while the Okumura-Hata model underestimates it as shown in Figure 3. The measured path loss is observed to fluctuate between 120dB and 160dB. Okumura-Hata outperforms COST 231 for 9mobile network. Therefore, modifying these models to suit the Sokoto environment is necessary.COST 231 outperformed Okumura-Hata in both standard and modified forms.

The modification significantly reduced the error, as evident in Figures 4 and 5, where the predicted and measured pathloss curves for both networks closely align and intertwine.Statistical tests on the models' performance shown in Table 1; show that Hata's RMSEimproved from 7.9 dB to 5.3 dB, while COST 231's RMSE dropped from 6.1 dB to 4.0 dB for 9mobile.Similar improvements were observed for Airtel network such thatHata's RMSE improved from 8.5 dB to 5.8 dB, while COST 231's RMSE dropped from 5.5 dB to 3.6dB.It was found thaturban zones required higher corrections due to multipath effects.

IV. CONCLUSION

This study evaluated the performance of Okumura-Hata and COST 231 propagation models, both in their standard and modified forms, for Airtel and 9mobile in Sokoto metropolis, Nigeria. The COST 231 model demonstrated superior accuracy over Okumura-Hata for both networks. Modified COST 231 achieved the lowest RMSE (4.0 dB for Airtel and 3.6 dB for 9mobile)proving its adaptability to Sokoto environment. Optimal clutter factor for Sokoto was found to be 1.8 dB/Km, which minimize prediction errors by 35-49%. Network planners should prioritize localized model tuning over standard models and should also use clutter factors for urban-submixed regions.

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