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Performance Evaluation of 4G Mobile Wireless Network in Nigeria

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ABSTRACT
The Fourth Generation (4G) of mobile wireless networks introduced significant improvements in terms of speed, reliability, and capacity compared to its predecessors. This study presents a comprehensive performance evaluation of 4G Long-Term Evolution (LTE) networks in urban environments using Free Space Path Loss Model and COST 231 Hata Model. Metrics such as pathloss, signal power and signal-to-noise ratio were determined through simulation. The results show that while 4G networks meet basic broadband requirements, performance varies significantly depending on factors like frequency, location and so on. The results also show that, out of the three selected mobile networks in Nigeria, Globacomm performs better than MTN and Airtel by 1.9% and 3.5% respectively with the application of Free space path loss model, and by 7.8% and 14.8% on application of COST 231 Hata model.
Keywords: Path loss, Signa-to-noise ratio,

I. INTRODUCTION

The significant escalation in the demand for mobile data has catalyzed the advancement of wireless communication systems. 4G LTE, which serves as the prevailing standard for the transmission of high-speed data for mobile devices and data terminals, has established itself as the international benchmark for mobile broadband services. In contrast to its predecessors, 4G offers superior data transmission rates, diminished latency, enhanced spectral efficiency, and robust facilitation for multimedia applications. In light of the surging demand for bandwidth in mobile communication, driven by a substantial increase in user numbers, mobile networks have progressed from 1G to 4G in order to adequately address this escalating requirement over the years. (James D. Gadzeet.al.2019). In Nigeria, MTN,Globacomm and Airtel have commercially deployed 4G LTE networks for higher throughputs and improved user experience.

Nevertheless, notwithstanding the increasing implementation of 4G/LTE networks in North Central Nigeria, users face ongoing difficulties in obtaining high-speed internet access, which engenders significant apprehensions. As a result, there exists a pressing necessity to examine the effectiveness of 4G/LTE technology within this geographical locale. Such an assessment must incorporate essential elements such as network coverage, latency, signal strength, and packet loss. (S.Y. Dauda et. al. 2024).

The expansion of mobile coverage throughout Nigeria was significantly facilitated by the issuance of digital mobile licenses (DMLs) to operators who initially implemented 2G technology to deliver voice services, thereby achieving coverage for over 89% of Nigeria's populace at present. The increasing demand for internet connectivity, coupled with the availability of spectrum, has catalyzed the advancement of 3G services, which now encompasses approximately 75% of the population. Deployments of 4G technology have primarily been confined to major urban centers over the past few years. The utilization of broadband in Nigeria has demonstrated a continuous upward trajectory, escalating from 40.9% in February 2022 to 44.5% in July 2022, a statistic regarded as optimistic for the attainment of the national broadband objective of 70% by the year 2025. (J. N. Dike and A G. Imoke, 2023).

This paper aims to evaluate the performance of 4G LTE networks in real-world scenarios. The primary goal is to understand how well 4G meets the expectations set by standard specifications and to identify factors influencing network performance. This evaluation is particularly critical for network operators, service providers, and researchers aiming to improve mobile broadband services.

II. REVIEW OF LITERATURE

In the study conducted by P. Pathania et al. (2014), a comprehensive evaluation of the performance of various path loss models was undertaken, leading to the identification of the most appropriate model for flat terrains in the northern region of India. The Hata Davidson model demonstrated superior performance in comparison to the extended version of the Hata model for extended distances; however, the cost-231 model exhibited the lowest mean square error relative to the other examined models.A. L. Imoize and T. E. Ogunfuwa (2018) conducted a study concentrating on the optimization of an advanced best-fit propagation model aimed at enhancing the accuracy of path loss predictions for a 4G LTE network situated within a Lagoon environment. The modified model consequently demonstrated a significant enhancement in the precision of signal forecasts. E.T. Tchao et al. (2018) similarly assessed the efficacy of specific prominent network parameters associated with a recently established LTE network operating in the 2600 MHz frequency band, situated within the unique terrain of Sub-Saharan Africa, under a variety of MIMO Antenna Configurations. The findings indicated that 4G LTE possesses the capability to meet the escalating broadband demands of the Ghanaian population when juxtaposed with the throughput requirements necessary to facilitate data-centric broadband applications.

James D. Gadze et al. (2019) conducted comprehensive measurements of LTE path loss at frequencies of 800MHz and 2600MHz within select urban and suburban locales in Ghana, subsequently juxtaposing these findings with six prevalent propagation models. The enhanced iterations of the Ericsson, SUI, and ECC-33 models, formulated during this investigation, exhibited a superior accuracy in predicting path loss specific to the Ghanaian contexts when contrasted with the standard propagation models. The data derived from the measurements unequivocally indicated that existing propagation models significantly deviate from optimal predictions. In the study by O.R. Abolade et al. (2021), the performance metrics of three mobile network operators (MNOs) were meticulously assessed and evaluated within the framework of mobile network services in Ibogun, Ogun State, Nigeria. The findings revealed that MTN emerged as the most proficient network in Ibogun, surpassing all competing providers in terms of Received Signal Strength Indicator (RSSI), upload and download speeds, call setup duration, SMS transmission time, and signal penetration across the region. Four distinct path loss propagation models—namely the Free Space Path Loss (FSPL) model, Okumura model, Okumura-Hata model, and COST 231-Hata model—were subjected to comparative analysis in the research conducted by I.O. Stella et al. (2022).

A comparative analysis of the evaluated propagation models revealed that the Okumura-Hata and COST 231-Hata models produced path loss predictions most closely aligned with the measured values. This outcome highlights the necessity for more refined path loss models tailored to 4G and 5G propagation environments. In a 2023 study by J. N. Dike and A. G. Imoke, the performance of 3G and 4G mobile networks in Port Harcourt and Calabar was compared using metrics such as data transfer rates and latency. The research yielded insights beneficial to network operators aiming to enhance service quality and meet performance objectives. Ultimately, the study contributed new perspectives to the telecommunications field and offered useful references for researchers and industry stakeholders.A. O. Akande et al. (2023) proposed a modified version of the Okumura-Hata model for 4G networks. Since the original model closely matched the measured path loss, it was refined using the path loss exponent and further optimized with the Gravitational Search Algorithm (GSA). Simulations were conducted in MATLAB R2018a, and performance was assessed using Root Mean Square Error (RMSE). Results indicated that the GSA-enhanced model significantly outperformed the conventional models.

In another 2023 study, A. A. El-Saleh conducted an in-depth evaluation of Mobile Broadband (MBB) performance in Cyberjaya City, Malaysia. The research offered practical recommendations for MBB providers to enhance network quality and customer satisfaction. The study also acknowledged several limitations, indicating directions for future research.S. N. Ogili and G. N. Onoh (2023) employed the Transverse Electromagnetic Wave Simulator (TEMS) to collect performance data—including call setup success rate (CSSR), call drop rate (CDR), paging success rate (PSR), grade of service (GoS), and handover success rate (HOSR)—from 30 base stations across Enugu metropolis over fifteen working days. The results showed strong network performance by MTN, attributed to its deployment in a suitable shadowed urban environment with a path loss exponent of 3.12.

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S. Y. Dauda et al. (2024) assessed 4G/LTE network performance in North-Central Nigeria using extensive drive tests in Abuja, Lafia, and Makurdi. The study recommended that Mobile Network Operators (MNOs) strengthen their infrastructure, especially in rural and suburban areas where service performance is weaker. D-NGN, the leading provider in terms of speed and coverage, was advised to address specific issues like latency and packet loss in Makurdi to maintain its competitive edge. Other MNOs were encouraged to expand and optimize their networks to improve competitiveness and customer satisfaction across the region.In a related 2024 study by Ikechi Risi et al., the performance of standard Okumura-Hata, COST 231-Hata, and Free-Space models was evaluated against measured path loss data at 2600 MHz in Port Harcourt, Nigeria. Among the three, the Free-Space model demonstrated superior accuracy in that particular environment.

III. METHODOLOGY

3.1Simulation Tools

Simulation was carried out using MATLAB software package. The simulation parameters are highlighted in Table 1:

Table 1: Simulation parameters

Parameters	Value
Frequency	700 MHz (Glo), 800 MHz (MTN), Airtel (900 MHz)
Transmitter power	45 dBm
BS Transmitter antenna height	30 m
UE antenna height	1.5 m
Transmitter gain	10 Db
Thermal Noise	-105.2 Db
Interference margin	3 dB
Additional loss margin	10 Db

3.2 Metrics Evaluated

The following key performance indicators (KPIs) were obtained:

- **Signal path loss**

Signal path loss (or **path loss**) is the **reduction in power** of a wireless signal as it travels from a transmitter to a receiver through a medium (such as air or space). It is a key concept in wireless communications, including **5G**, and it quantifies how much the signal weakens over distance and due to obstacles. In this research, two different path loss models are considered namely: Free space path loss, and COST 231 Hata Model. The free space path loss and COST 231 models are given in equations 1and 2 respectively.

$$\mathrm{FSPL(dB)} = 20\log(\mathrm{d}) + 20\log(\mathrm{f}) - 147.55 \qquad \text{equation 1}$$

where,
FSPL is the free space path loss
d is the distance in metres
f is the frequency of the signal transmitted in Hertz.
The COST 231-Hata model (A. Deme et.al., 2013)is an empirical radio propagation model used to predict path loss in urban environments, particularly for frequencies between 1500 MHz and 2000 MHz. It is an extension of the Hata model, widely used in planning 2G, 3G, and early 4G networks.

$$\mathrm{L(dB)} = 46.3 + 33.9\log(\mathrm{f}) - 13.82\log(\mathrm{h_b}) - \mathrm{a(h_m)} + [44.9 - 6.55\log(\mathrm{h_b})]\log(\mathrm{d}) + \mathrm{C} \qquad \text{equation 2}$$

Where
f is the frequency in MHz
h_b is the base station antenna height
$a(h_m)$ is the mobile antenna correction factor in dB
C is the constant factor (3 dB for urban; 0 dB for suburban and rural areas)
d is the distance between the transmitter and the receiver in km, and valid from 1 km to 20 km

- **Received Power**.

The received power is given as:

$$P_{received} = P_{total} - \mathrm{LOSS} \qquad \text{equation 3}$$

- **Signal -to -Noise Ratio (SNR)**

The SNR is an essential metric to determine the quality of signal received. The higher the SNR the better the signal quality. SNR is mathematically expressed as:

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$$\text{SNR (dB)} = \frac{\text{Signal Power}}{\text{Noise Power}} \qquad \text{equation 4}$$

IV. RESULTS AND DISCUSSION

The results of path loss models for the three selected mobile networks are shown in figures 1 and 2. It can be seen that the attenuation increases proportionally with distance, and the network (i.e Glo Network) with the low frequency is not as significantly attenuated as those with higher frequencies (i.e MTN and Airtel Networks).

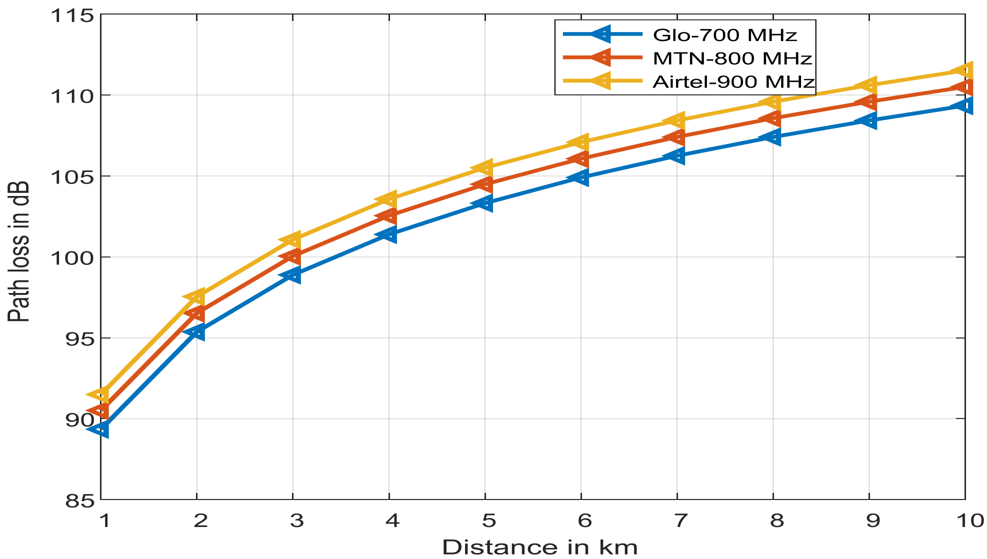

Figure 1: Path loss values for the three mobile networks using FSPL model

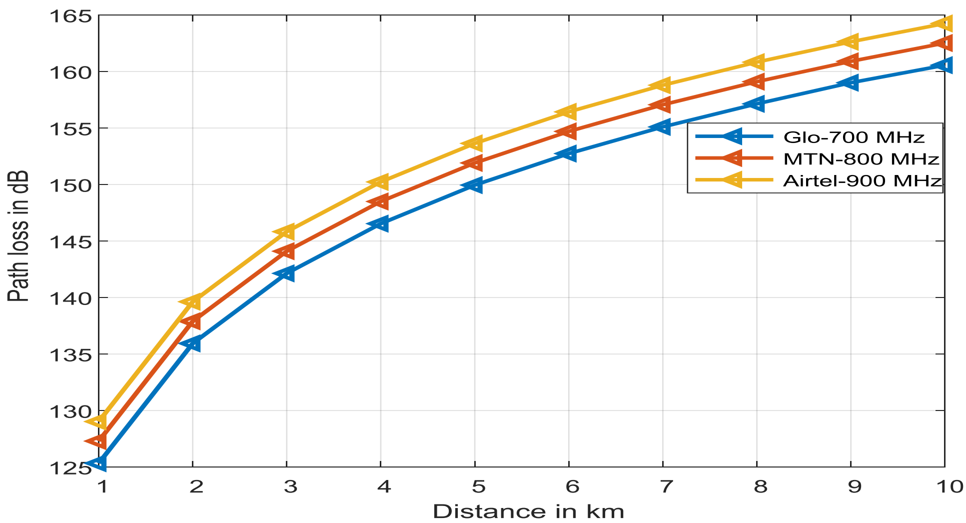

Figure 2: Path loss values for the three mobile networks using COST-231 Hata model

The results of the received power are shown in figures 3 and 4. It can be seen that the received power diminishes as the receiver is getting far away from the Base Station (BS) transmitter for all the three mobile networks, and this is more obvious in Airtel Network compared the other two networks (i.e MTN and Glo networks).

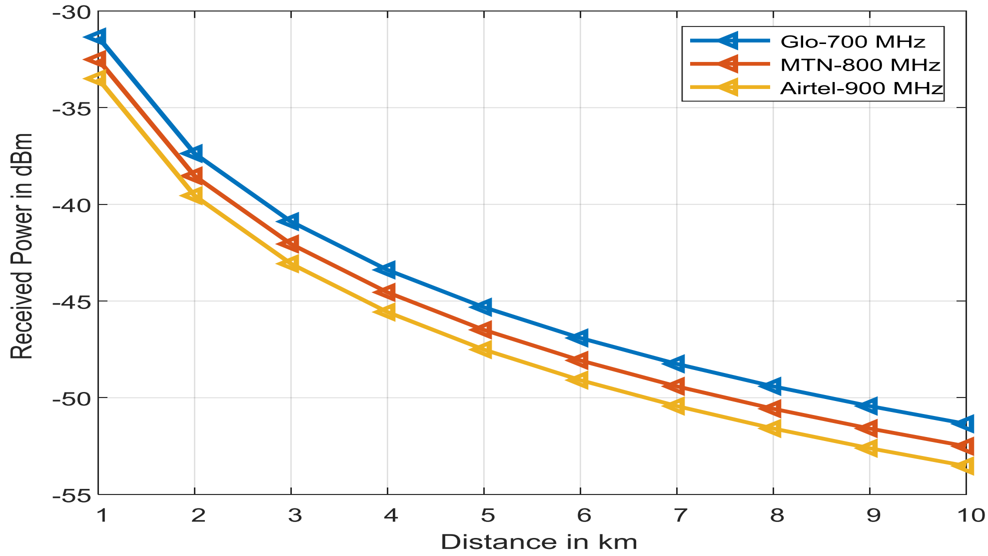

Figure 3: Received Power for the three mobile networks using FSPL model

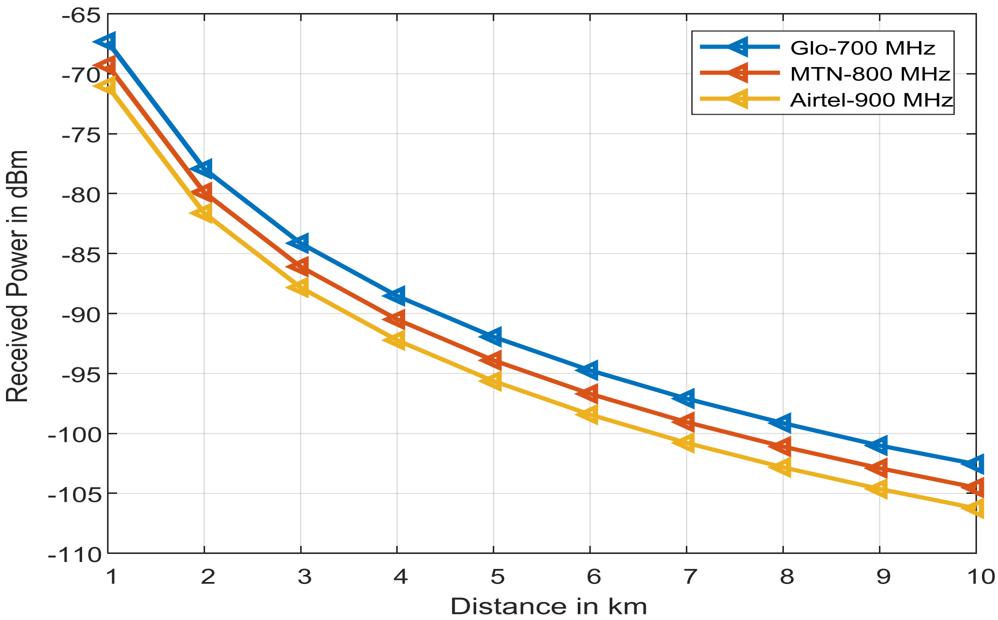

Figure 4: Received Power for the three mobile networks using COST-231 Hata model

In figures 5 and 6, the results of SNR were depicted. Airtel Network with higher frequency (i.e 900 MHz) has lower signal quality as the receiver moves far away from the BS transmitter. This makes Glo and MTN more suitable for long distance voice transmission (most especially Glo Network); although in terms of low latency, Airtel Network performs better.

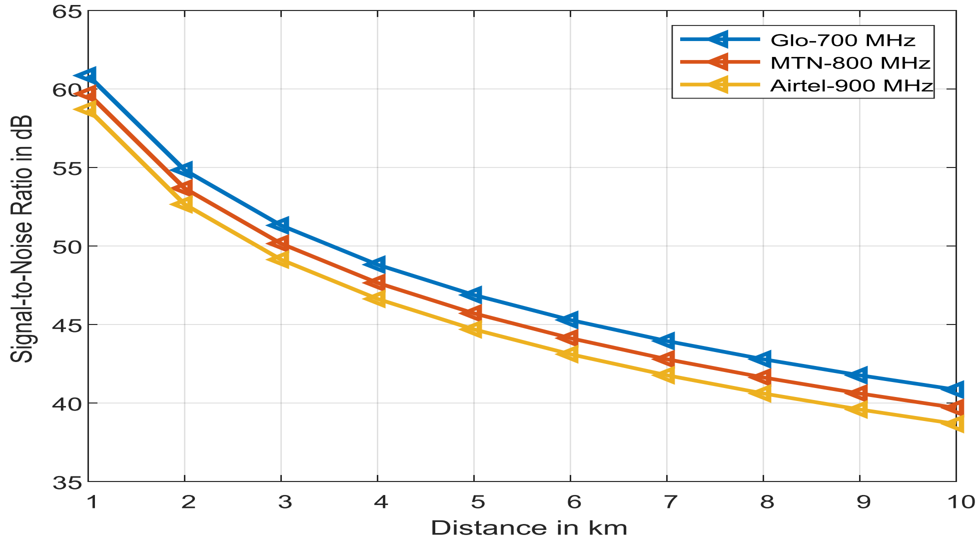

Figure 5: Signal-to-Noise Ratio for the three mobile networks using FSPL model

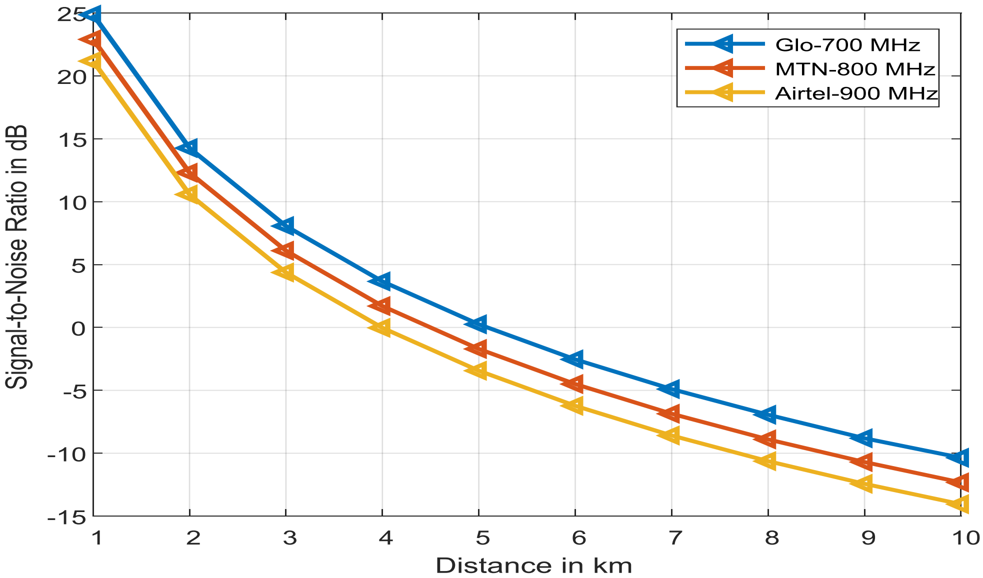

Figure 6: Signal-to-Noise Ratio for the three mobile networks using COST-231 Hata model

V. CONCLUSION

This study evaluated the performance of 4G LTE networks on application of two different path loss models: Free Space Path Loss Model and COST 231 Hata Model. While 4G meets the basic broadband standards, its performance is highly variable based on geographic and temporal factors. More so, the performance of the three selected networks varies depending on their frequency of operation. The suitability of each of the networks is dependent on the area of application. Based on the results obtained, the voice transmission over wider geographical coverage is possible with glo network, while for low latency, the airtel network is preferable.

The research can be further expanded through the application of more suitable path loss models, most especially the machine learning (ML) based path loss model.

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