Evaluating 4G Network Performance in North-Central Nigeria: A Drive Test-Based Assessment of Key Performance Indicators

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ABSTRACT

This study evaluates the performance of 4G/LTE networks in North-Central Nigeria using a comprehensive drive test methodology. Key performance indicators (KPIs), including network speed, packet loss, latency, uptime, coverage, and signal power, were assessed across major Mobile Network Operators (MNOs)—MTN, Airtel, GLO, and 9Mobile. The drive tests, conducted in Abuja, Lafia, and Jos, utilized advanced tools like G-Net Solutions Pro and propagation models such as Okumura-Hata and Walfisch-Ikegami. Results revealed MTN's dominance in network speed (9.543 Mbps mean), latency (25.921 ms mean), uptime (97.714% mean), and coverage (87.514% mean), while Airtel followed closely. GLO and 9Mobile showed competitive but slightly lower performance. The study highlights the importance of generalized metrics for holistic network evaluation, providing actionable insights for stakeholders to enhance connectivity and user satisfaction. Despite its contributions, the study acknowledges limitations, such as real-time monitoring gaps and a focus solely on 4G/LTE networks. Future research should address these limitations and explore the interplay between different network technologies to further bridge the digital divide in Nigeria.

Keywords: 4G/LTE Networks, Drive Test, Key Performance Indicators (KPIs), Mobile Network Operators (MNOs), North-Central Nigeria, Network Optimization

INTRODUCTION

The evolution of mobile networks in Nigeria reflects the country's digital transformation journey. The introduction of 2G networks in the early 2000s enabled basic voice calls and SMS, driving rapid subscriber growth as major operators like MTN, Airtel, and Glo entered the market (Adeyemi, 2015). By the late 2000s, 3G networks brought mobile internet, paving the way for data-driven services like mobile banking and e-commerce (Oyedemi, 2018). The rollout of 4G networks in the mid-2010s marked a significant leap, offering faster speeds, lower latency, and enhanced capacity for multimedia applications (Nwankwo & Eze, 2020). Today, 4G is the backbone of Nigeria's digital economy, supporting innovations in education, healthcare, agriculture, and governance. However, 4G deployment remains uneven, with significant disparities between urban and rural areas (GSMA, 2021).

4G networks are pivotal for socio-economic development, enabling access to digital services and fostering innovation. In Nigeria, 4G has transformed education through e-learning platforms (Adewale *et al.*, 2019), healthcare via telemedicine (Ogunlade *et al.*, 2020), and agriculture through mobile apps providing weather and market information (Ojo & Adeyemo, 2021). It has also empowered SMEs by facilitating online commerce and digital payments, driving economic growth (Okonkwo *et al.*, 2022). Despite these benefits, 4G's full potential remains untapped in many regions, particularly in North-Central Nigeria, where infrastructure gaps and limited access hinder connectivity (NCC, 2022).

North-Central Nigeria, comprising states like Benue, Kogi, and the FCT, is a region of strategic importance with a population of over 25 million (National Population Commission, 2019). While urban centers enjoy good 4G coverage, rural areas often rely on outdated 2G and 3G networks due to rugged terrain, low population density, and limited investment (Ndukwe, 2021). Addressing these challenges is critical for achieving inclusive growth and bridging the digital divide.

The deployment of 4G networks in North-Central Nigeria is marred by significant challenges, including uneven coverage, inadequate infrastructure, and limited investment in rural areas (NCC, 2022). While urban centers like Abuja and Jos benefit from robust 4G connectivity, rural regions rely on outdated 2G and 3G networks, exacerbating the digital divide (Ndukwe, 2021). Factors such as rugged terrain, low population density, and insufficient MNO investment further hinder 4G accessibility, excluding millions from socio-economic opportunities like e-learning, telemedicine, and digital finance (GSMA, 2021).

Despite its transformative potential, the performance of 4G networks in the region remains understudied, particularly in rural and peri-urban areas. Key performance indicators (KPIs)—such as speed, latency, and coverage—are not comprehensively evaluated, leaving policymakers and MNOs without empirical data to guide infrastructure improvements (Okonkwo et al., 2022). This study addresses these gaps by evaluating 4G network performance in North-Central Nigeria, aiming to inform strategies for enhancing connectivity, promoting digital inclusion, and unlocking the region's socio-economic potential.

This study aims to assess the performance of 4G/LTE networks in selected cities within North-Central Nigeria. The specific objectives include the following: determining the Key Performance Indicators (KPIs) of 4G/LTE networks, such as network speeds, packet loss, latency, uptime, coverage, and signal quality; and, conducting a descriptive analysis of these KPIs with respect to selected mobile network operators in the Nigerian north-central region; using data collected through drive tests.

Global Trends in 4G Performance

The global deployment of 4G networks has transformed mobile connectivity, enabling faster speeds, lower latency, and enhanced capacity for data-intensive applications. In advanced economies like South Korea and Japan, 4G networks achieve average download speeds of over 50 Mbps, supported by extensive infrastructure investment and efficient spectrum management (Kim et al., 2021). These countries also boast near-universal coverage, even in rural areas, due to strong government policies and public-private partnerships (Ericsson, 2020).

In developing regions, however, 4G/LTE performance varies significantly. For example, in India, urban areas experience average speeds of 15-20 Mbps, while rural regions face slower speeds and inconsistent coverage due to infrastructure gaps (GSMA, 2021). Similarly, in Sub-Saharan Africa, 4G adoption is growing, but challenges such as limited spectrum availability, high deployment costs, and energy constraints hinder optimal performance (Nwankwo & Eze, 2020).

Key performance indicators (KPIs) such as network speed, latency, and coverage remain critical metrics for evaluating 4G performance globally. Studies emphasize the importance of continuous network optimization, spectrum management, and investment in rural infrastructure to ensure equitable access and high-quality service (Oyedemi, 2018). These global trends and state-of-the-art practices provide valuable insights for addressing 4G performance challenges in Nigeria, particularly in underserved regions like North-Central Nigeria.

The Nigerian Situation

As of March 2020, Nigeria's telecommunications sector had reached 189.3 million subscribers, contributing 10.88% to the nation's GDP, with major operators such as 9Mobile, Airtel, Globacom, and MTN leading the market (Yusuf *et al.*, 2024; NCC, 2021). Despite this growth, a significant digital divide persists, particularly in rural areas, where approximately 40 million people still lack access to reliable telecom services (Okocha & Edafewotu, 2022). To address this, the Nigerian Communications Commission (NCC) has encouraged tower expansion initiatives by MTN Nigeria, Airtel, Globacom, and 9Mobile. However, estimates suggest that over 80,000 additional towers are required to achieve nationwide coverage (Yusuf *et al.*, 2024; Okoyeuzu et al., 2023).

MTN Nigeria pioneered the rollout of 4G LTE services in 2016, though concerns have been raised about fair competition and spectrum pricing, which tend to favor larger operators. Currently, the four major operators—MTN Nigeria, Airtel, Globacom, and 9Mobile—hold 2.1GHz spectrum slots, with MTN Nigeria recently acquiring additional spectrum to align with its Ambition 2025 strategy and support the government's broadband penetration goals. Despite the increasing adoption of 4G technology, significant challenges remain, particularly in North-Central Nigeria, where issues such as inconsistent network speeds, poor signal quality, and limited coverage continue to hinder connectivity (Yusuf, *et al.*, 2024; Abubakar, *et al.*, 2018; Adetunmbi & Daramola, 2015; Olawale *et al.*, 2018; Mohammed & Kebande, 2016; Akinwale & Adetunmbi, 2019).

Overview of 4G LTE Systems

4G LTE (Long-Term Evolution) represents a significant leap in mobile communication technology, offering faster data speeds, lower latency, and greater network capacity compared to previous generations (Figure 1) (Arthur D. Little, 2012). Designed as an all-IP packet-switched network, LTE supports peak data rates of up to 100 Mbps for high-mobility users and 1 Gbps for low-mobility users, enabling seamless multimedia applications and ultra-mobile broadband access (ITU, 2018). LTE replaces older technologies like CDMA with Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO)**,** which enhance spectral efficiency and signal reliability (Srinivasulu & Kumar, 2024).

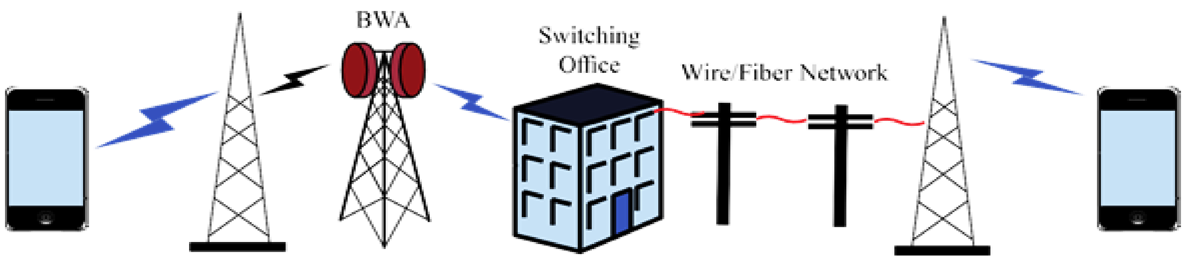

Figure 1: 4G Cellular Network

The LTE architecture is divided into two main components: the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC)**.** The E-UTRAN consists of eNodeBs (evolved NodeBs), which handle radio resource management, mobility control, and connectivity to the EPC (Gieske, 2024). The EPC, entirely packet-switched, includes key elements like the Mobility Management Entity (MME)**,** Serving Gateway (SGW)**,** and Packet Data Network Gateway (PGW)**,** which manage user authentication, data routing, and IP address allocation (Bisio *et al.*, 2015).

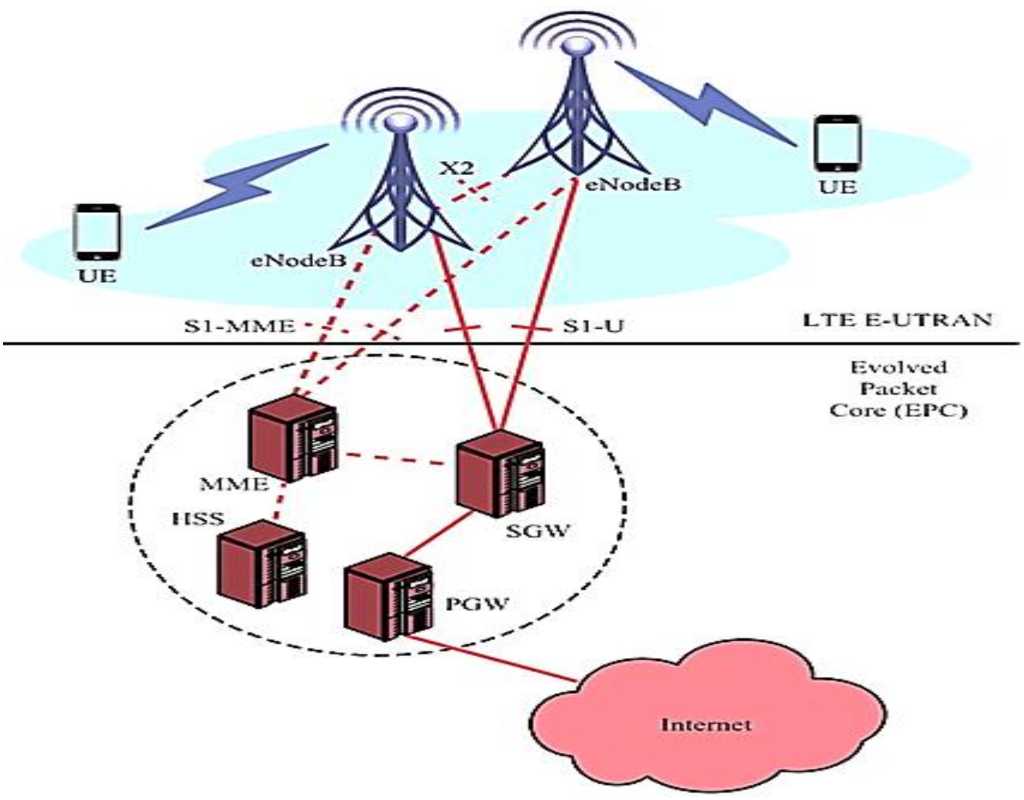

Figure 2: LTE Architecture

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The Evolved Packet Core (EPC) includes critical components such as the Serving Gateway (SGW), Mobility Management Entity (MME), Packet Data Network Gateway (PDN GW), Home Subscriber Server (HSS), and Policy and Charging Rules Function (PCRF) (GSM Association, 2019). The User Equipment (UE), which represents end-user devices, establishes a wireless connection to the network via the air interface, linking to the eNodeB (Vilakazi *et al.*, 2023). To optimize the wireless medium, Multiple Input Multiple Output (MIMO) technology is employed, allowing the simultaneous transmission and reception of multiple data streams through the use of multiple antennas (Yusuf *et al.*, 2024; Imam-Fulani et al., 2023). LTE introduces advanced features such as Carrier Aggregation (CA), which combines multiple frequency bands to increase bandwidth, and Quality of Service (QoS) management through EPS bearers (as shown in Figure 3), ensuring differentiated treatment for various traffic types like voice, video, and data. Additionally, LTE supports seamless handovers across heterogeneous networks, including 2G, 3G, and small cells, ensuring uninterrupted connectivity.

Globally, LTE has become the universal standard for 4G, driving innovations in mobile broadband, IoT, and smart cities. However, challenges such as spectrum scarcity, energy constraints, and uneven infrastructure deployment persist, particularly in developing regions. By addressing these challenges, LTE has paved the way for future advancements in mobile communication such as 5G and even 6G.

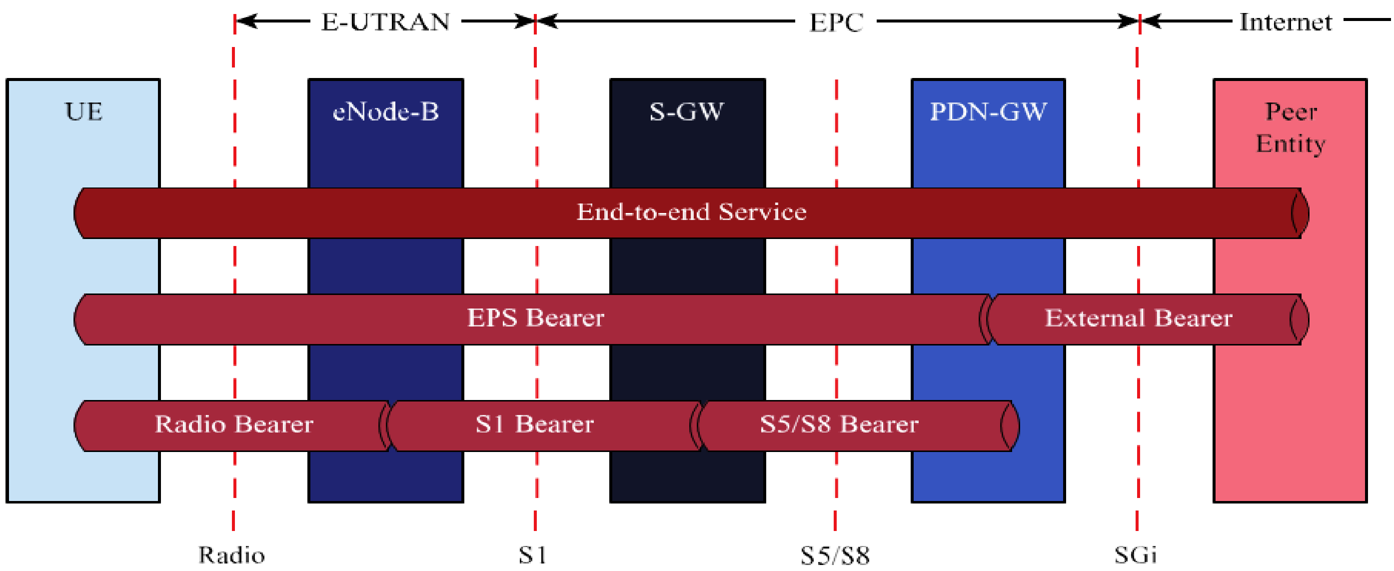

Figure 3: LTE QoS Bearers

RELATED WORKS

Yusuf et al. (2024) evaluated 4G/LTE networks in North-Central Nigeria via drive tests, highlighting MTN's superior performance over Airtel, GLO, and 9Mobile, but noted real-time monitoring limitations. El-Saleh et al. (2023) assessed 3G/4G performance in Cyberjaya, Malaysia, focusing on outdoor and in-building metrics. Yadav et al. (2022) used OPNET to analyze LTE-4G multimedia performance, finding static nodes outperformed mobile nodes in delay. Kuboye (2021) compared LTE scheduling algorithms in Akure, Nigeria, identifying QoS-Aware Proportional Fair as optimal. Oje and Edeki (2021) evaluated 4G performance at the University of Ilorin, noting variability across locations. Raphael et al. (2020) assessed MNOs in Shiroro, Nigeria, with MNO C excelling in service quality and MNO B in latency and throughput. Imoize and Adegbite (2018) analyzed LTE performance in Lagos using Huawei tools, aligning results with NCC standards. Despite these studies, a gap remains in evaluating 4G LTE networks in North-Central Nigeria, underscoring the need for performance assessments as providers address legacy network limitations (Yusuf *et al.*, 2024; Abubakar & Wakili, 2019).

THE STUDIED AREA

The study focused on North-Central Nigeria, encompassing Abuja, Lafia, and Jos (as shown in Figure 4). This region, rich in mineral resources and cultural diversity, spans 105,863 km² with a tropical savanna climate (average temperature: 26°C; annual rainfall: 1,100 mm). Key features include undulating terrain and major water bodies like the Niger and Benue rivers, making it a unique area for network performance evaluation.

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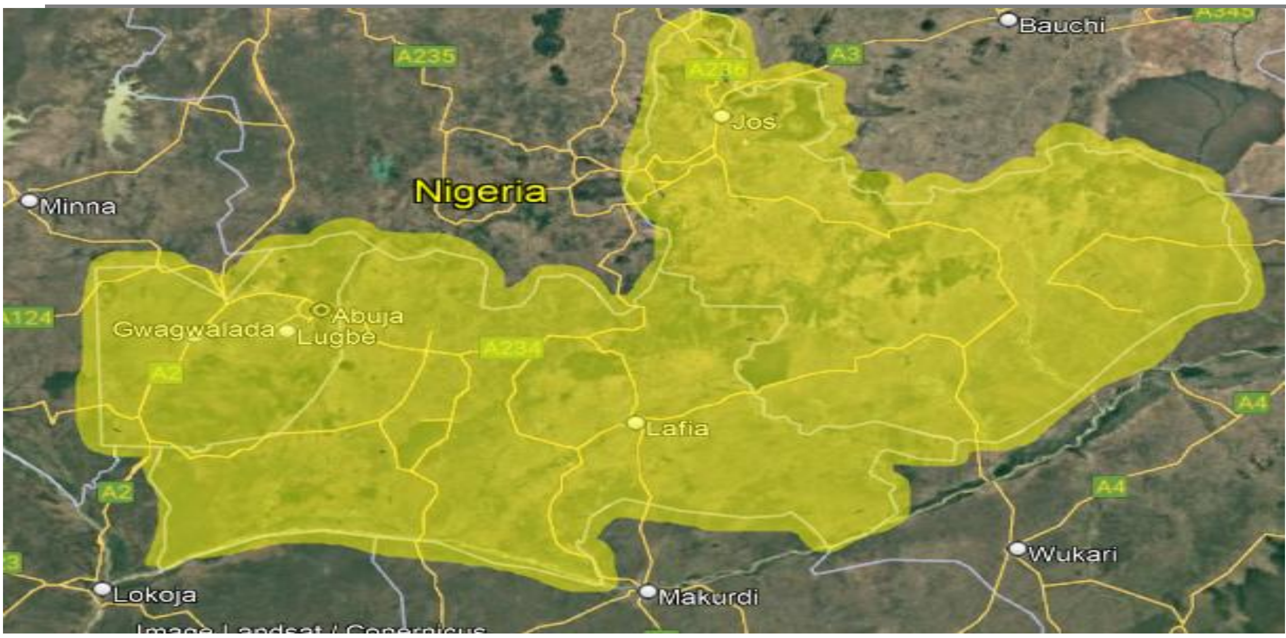

Figure 4: Map of the Studied Area

Network Drive Test (DT)

A Drive Test (DT) is a vital method for collecting data on LTE cellular networks, offering insights to optimize wireless operations. By evaluating parameters such as signal strength, quality, interference, call performance, handover data, and GPS coordinates, DTs assess Quality of Service (QoS) (Shakir *et al.*, 2023). Drive tests are categorized into three types: Single Site Verification (SSV), Multiple Site Verification (MSV), and Operator Benchmarking Drive Test, each serving specific network evaluation purposes.

Targeted MNOs

The study evaluated four leading Mobile Network Operators (MNOs)—Airtel, Glo (Globacom), 9Mobile, and MTN—recognized for their LTE/4G services in Nigeria. These MNOs operate on the 2.1GHz spectrum (Table 1), as regulated by the NCC. Their selection reflects their market dominance and influence, ensuring a comprehensive comparison of network performance in North-Central Nigeria.

Airtel Nigeria, a subsidiary of Bharti Airtel, provides 2G, 3G, and 4G LTE services across North-Central Nigeria, focusing on widespread coverage (Yusuf *et al.*, 2024; Airtel Africa, 2022). GLO, the second-largest MNO, emphasizes network expansion and service enhancement to deliver reliable connectivity (Okonji, 2023). 9Mobile, formerly Etisalat Nigeria, prioritizes network optimization and modernization to improve voice and data services (Yusuf *et al.*, 2024; Oxford Business Group, 2022). MTN Nigeria, the largest MNO, invests heavily in infrastructure and technology upgrades, ensuring robust 2G, 3G, and 4G LTE coverage in the region (Yusuf *et al.*, 2024; Oxford Business Group, 2022).

Table 1: 2.1 GHz Frequency Assignments for MNOs in the North Central Region

Operator		MTN	Globacom	9Mobile	Airtel
Block	Block 1	Block A	Block B	Block C	Block D
Rx Freq.	TDD	1910-1920	1920-1930	1930-1940	1940-1950
Tx Freq.	TDD	2110-2120	2120-2130	2130-2140	2140-2150
Guard Band	1880-1890	1890-1910	1950-1960	1980-1990	2170-2180

All four MNOs employ the Partial Usage of Sub-Channels (PUSc) 1x3x3 reuse scheme (Figure 5), which uses three sector antennas and a single radio frequency (RF) channel per base station. This scheme allocates distinct

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tone sets to each sector, reducing inter-cell interference, minimizing outage areas, and simplifying RF planning (Yusuf *et al.*, 2024; Tchao *et al.*, 2018).

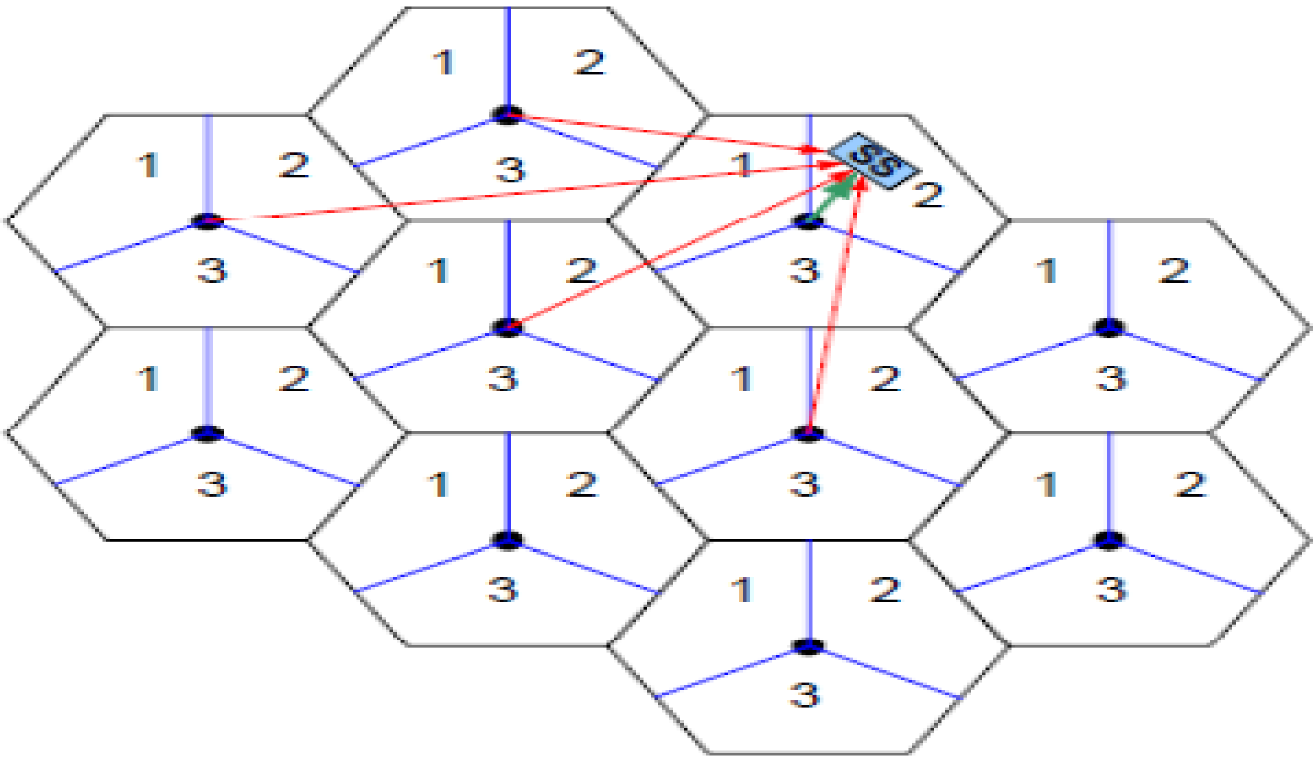

Figure 5: Partial Usage of Sub-Channels (PUSc) 1x3x3 Frequency Reuse Scheme (Yusuf *et al.*, 2024)

Key Performance Indicators (KPIs) in LTE Network Evaluation

Key Performance Indicators (KPIs) are critical for assessing LTE network performance, providing insights into network quality and user satisfaction. For this study, KPIs such as network speed, packet loss, latency, uptime, coverage, and signal strength were selected based on their alignment with NCC QoS standards and relevance to the 2.1GHz frequency spectrum (Yusuf *et al.*, 2024; Shakir *et al.*, 2023). These KPIs enable a holistic evaluation of LTE/4G networks, helping ordinary users understand network quality in North-Central Nigeria.

The Selected KPIs

1) *Network Speed:* Network speed, measured in bits per second (bps), represents the rate of data transmission over a network. In drive tests, speed measurements account for all data types, including voice calls, text messages, internet browsing, video/audio streaming, online gaming, and other digital activities. Mathematically, network speed is expressed as the ratio of total data transmitted to the time taken for transmission.

$$\text{Network Speed} = \frac{\text{Data Transmission}}{\text{Time Taken}} \qquad (1)$$

2) *Packet Loss:* Packet loss is the percentage of transmitted packets that fail to reach their destination, expressed as:

$$\text{Packet Loss (\%)} = \left(\frac{\text{Lost Packets}}{\text{Total Packets Sent}}\right) \times 10 \quad (2)$$

3) *Latency:* Latency is the time delay (in milliseconds) between data packet transmission and reception, expressed as:

$$\text{Latency(ms)} = \text{Reception Time} - \text{Transmission Time} \qquad (3)$$

4) *Uptime:* Uptime is the percentage of time an MNO's network is operational, expressed as:

$$\text{Uptime}\ (\%) = \left(\frac{\text{Operational Time}}{\text{Total Time}}\right) \times 100 \qquad (4)$$

5) *Network Coverage:* This study used the Okumura-Hata and Walfisch-Ikegami Models within G-Net Solutions Pack to estimate MNO coverage areas, accounting for handovers. These models consider signal strength, frequency, terrain, and structures, enabling accurate coverage assessments.

6) *Signal Power:* Signal power, measured in decibels (dB), represents the strength of transmitted or received signals. The combined use of Okumura-Hata and Walfisch-Ikegami Models, along with environmental factors, allowed precise computation of mean signal power for each MNO during the drive tests.

The Okumura-Hata Model used for the drive test was calibrated as follows:

$$\text{PL} = \text{PL}_{\text{free space}} + \text{A}_{\text{exc}} + \text{H}_{\text{cb}} + \text{H}_{\text{cm}} \qquad (5)$$

Where:

$\text{PL}_{\text{free space}}$ represents the Free Space Path Loss.

A_{exc} denotes Excess Path Loss for a Base Station height of 200 meters and Mobile Station (MS)/User Equipment (UE) of 3 meters.

H_{cb} and H_{cm} are both correction factors.

The Free Space Path Loss is further expressed as:

$\text{PL} = \text{A} + \text{B}\log(\text{d}) + \text{C}$

Where:

A, B and C are factors dependent on both frequency and antenna height, and:

$\text{A} = 69.55 + 26.16\log(\text{F}_\text{C}) - 13.82\log(\text{h}_\text{b}) - \text{a}(\text{h}_\text{m})$

$\text{B} = 44.9 - 6.55\log(\text{h}_\text{b})\log d$

In this context:

F_C = Frequency in MHz

d = distance in km

h_b = Base Station Height

h_m = MS/UE Height

The function $a(\text{h}_\text{m})$ and factor C vary according to the environment:

For small and medium-sized cities;

$\text{a}(\text{h}_\text{m}) = (1.1\log(\text{F}_\text{c}) - 0.7)\text{h}_\text{m} - (1.56\log(\text{F}_\text{c}) - 0.8)$

$\text{C} = 0$

In metropolitan areas;

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$$a(h_m) = \begin{cases} 8.29(\log(1.54h_m)^2) - 1.1 & \text{for frequencies} \leq 200\text{MHz} \\ 3.2(\log(11.75h_m)^2) - 4.97 & \text{for frequencies} \geq 400\text{MHz} \end{cases}$$

$$C = 0$$

For suburban environment:

$$C = -2[log(F_c/28)]^2 - 5.4$$

In rural areas:

$$C = -4.78[log(F_c)]^2 + 18.33\, log(F_c) - 40.98$$

Note: the function $a(h_m)$ for rural and suburban areas was calibrated similarly to that for small and medium-sized cities.

The Cost 231 Walfisch-Ikegami model also used; was calibrated into its three main components for the purpose of the measurement campaign:

Loss in the free space (L_0)

Loss by diffraction and scattering from rooftop to street (L_{Bs}).

Loss due the multi-screen diffraction (L_{UE}).

The total attenuation or path loss (PL) for the non-line-of-sight conditions is given by:

$$PL_{NLOS} = \begin{cases} L_0 + L_{rts} & L_{rts} + L_{ms} > 0 \\ L_0 & L_{rts} + L_{ms} \leq 0 \end{cases} \quad (6)$$

The average transmission losses are given by:

$$L_0 = 32.4 + 20 \log d + 20 \log f \quad (7)$$

$$L_{rts} = -16.9 - 10 \log W + 10 \log f + 20 \log \Delta h_m + L_{ori} \quad (8)$$

$$L_{ms} = L_{bsh} + k_a + k_d \log d + k_f \log f + 9 \log B \quad (9)$$

Where L_{bsh} is the shadowing gain that occurs when the base station antenna is higher than the rooftops; and is given by:

$$L_{bsh} = \begin{cases} -18 \log(1 + \Delta h) & \text{for } h_{base} > h_{roof} \\ 0 & \text{for } h_{base} > h_{roof} \end{cases} \quad (10)$$

The factor k_a is given by:

$$k_a = \begin{cases} 54 & h_{roof} > h_{base} \\ 54 + 0.8\Delta h_b & d \geq 0.5 \text{ and } h_{roof} \leq h_{base} \\ 54 + 0.8\Delta h_b \dfrac{d}{0.5} & d < 0.5 \text{ and } h_{roof} \leq h_{base} \end{cases} \quad (11)$$

The k_a formula results in 54dB loss when the base station antenna is above the rooftops; and more than 54dB if it is below rooftops.

The factor k_f is given as:

$$k_f = -4 + \begin{cases} 0.7\left(\frac{f}{925} - 1\right) & \text{medium} - \text{sized and suburban areas} \\ 1.5\left(\frac{f}{925} - 1\right) & \text{metropolitan areas} \end{cases} \quad (12)$$

The distance factor k_d is given by:

$$k_d = \begin{cases} 18 - 15(\Delta h_b / h_r) & h \leq h_b \\ 18 & h \leq h_b \end{cases} \quad (13)$$

The orientation factor L_{ori} is given by:

$$L_{ori} = \begin{cases} -10 + 0.35\phi & \text{for } 0° \leq \phi \leq 35° \\ 2.5 + 0.075(\phi - 35°) & \text{for } 35° \leq \phi < 55° \\ 4.0 - 0.11(\phi - 55°) & \text{for } 55° \leq \phi < 90° \end{cases} \quad (14)$$

Where:

$d =$ the height of the transmitter antenna;

$\Delta h_m = h_r - h_m$ is the difference between the height of the rooftops h_r and the height of the mobile station h_m;

$\Delta h_b = h_b - h_r$ is the height of the base station antenna above rooftops;

B = the distance between buildings; and;

W = the average width of the streets.

For line-of-sight (LOS) conditions the total attenuation or path loss (PL_{LOS}) is given by:

$$PL_{LOS} = 42.6 + 26 \log d + 20 \log f$$

Of course, the predicted path loss in this case varied accordingly with the above parameters (i.e. street orientation, street width, building separation, base station height, and roof height) calibrated in the drive test set-up.

METHODOLOGY

Drive Test Execution

The 4G/LTE network drive test was conducted across three North-Central locations—Abuja, Lafia, and Jos. The process involved meticulous route planning, vehicle setup, and device configuration. Infinix 693, A Touch 105, and Infinix Note-4 Android phones, securely mounted in vehicles, were connected to HP ProBook Folio laptops running G-Net Solutions Pro software. This setup enabled precise data collection using advanced propagation models like Okumura-Hata, COST 231 Hata, Walfisch-Ikegami, and Free Space Path Loss. Key parameters such as network speed, packet loss, latency, uptime, coverage, and signal power were monitored. Drive tests were conducted at optimal speeds of 10 km/h, with GPS coordinates and timestamps recorded for each measurement.

Route Planning

Test routes were carefully planned to cover a 1.5 km radius around identified cell towers in each location. GPS coordinates for measurement sites were noted, and tests were conducted simultaneously at consistent speeds, starting from predetermined locations and following planned routes. Adequate time was allocated at each site for accurate data capture.

GPS Coordinates

The drive tests captured GPS coordinates marking the boundaries of test locations in Abuja, Lafia, and Jos:

Abuja: 9°04'23.52" N, 7°28'03.22" E; 9°05'31.83" N, 7°27'54.59" E; 9°05'25.01" N, 7°29'57.84" E;

9°04'10.75" N, 7°29'36.57" E

Lafia: 8°29'36.66" N, 8°30'37.52" E; 8°30'24.46" N, 8°30'34.20" E; 8°29'21.68" N, 8°31'39.85" E; 8°29'35.46" N, 8°31'34.36" E

Jos: 9°54'07.02" N, 8°52'50.67" E; 9°54'03.80" N, 8°53'25.09" E; 9°53'28.33" N, 8°52'20.19" E; 9°53'25.23" N, 8°53'20.68" E

Time Stamps

Drive tests were conducted over three days (January 10–13, 2025) between 12:00 PM and 3:00 PM. Each day’s test was divided into 3,600 time-steps (1 second each), scaled to 1:150 units. At each time-step, measurements prioritized the serving cell, followed by neighboring cells based on signal density.

Configuration Parameters

The configuration parameters for the drive test set-up are presented in Table 2.

Table 2: Configuration Parameters for the Drive Test

Parameter	Description
Carrier Frequency	1910-2145 MHz
System Bandwidth	10.5 MHz
OFDM Symbol Time	103 ms (Average)
Transmit Power	44.5 dBm (Average)
Receiver Sensitivity	-109 dBm (Average)
Mobile Receiver Height	Up to 3.2 m (Average)
Base Station Antenna Height	34.5 m (Average)
Transmitter Antenna Gain	18.5 dBi (Average)
Area	Urban/Metropolitan/Suburban/Rural
LTE Duplex Mode	TDD
MIMO Scheme	2x2, 4x4, 8x8 MIMO
Downlink Multiple Access	OFDMA
Azimuth (degree)	0/120/240

Database Setup

The required database scripts were downloaded from http://www.gyokovsolutions.com/downloads/scripts/scripts.rar. A local server with PHP and MySQL support was set up on the master station computer at the Lafia test location. A new database was created, and the "create_table.txt" script was executed to generate a 'measurements' table. The "test_insert.php" script validated record insertion, while the "insert.php" script facilitated the insertion of measurement records. Server details were configured accordingly to ensure seamless operation.

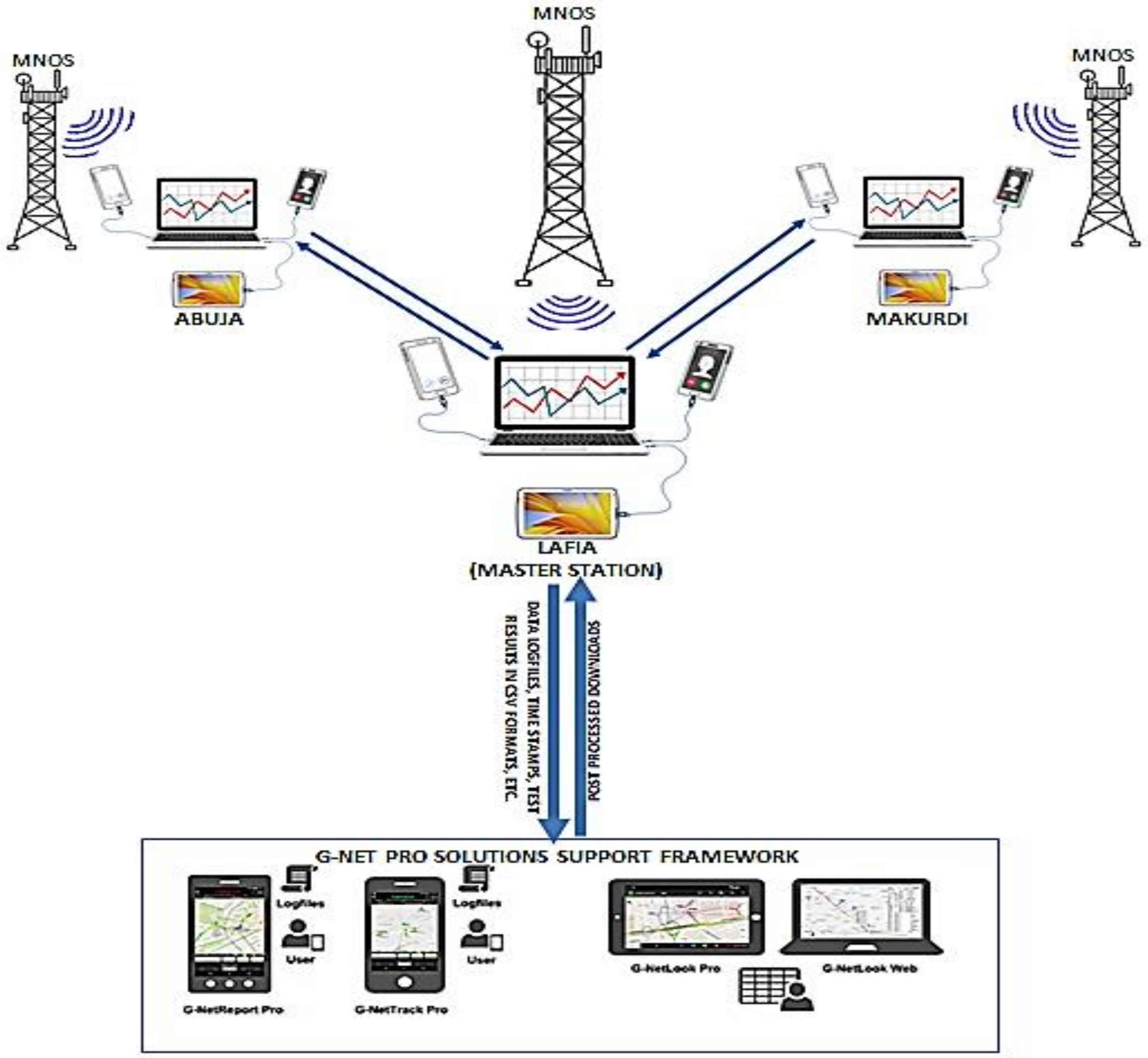

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Figure 6: Drive Test Set-up for the measurement of KPIs across Multiple MNOs

Reporting Server Configuration

G-Net Report Pro's reporting server was configured to connect to the database server. In the software settings, the "Report URL" under "SETTINGS - ONLINE REPORTING" was set to the URL of the "insert.php" file. Data from each location underwent preparation for post-processing, including cleaning to remove outliers and inconsistencies. The cleaned data was exported in a format compatible with the selected analysis tools. The 4G/LTE network drive test, conducted using G-Net Solutions Pro software across Lafia and two other locations, successfully collected valuable data simultaneously.

Data Collection and Processing

During drive tests, G-Net Solutions Pro software collected network performance metrics, including signal strength, call quality, data speed, coverage, GPS coordinates, and timestamps. Post-test, a database and reporting server were set up for streamlined data analysis. Database setup involved creating tables, testing record insertion, and configuring server parameters. The G-Net Report Pro reporting server was linked to the database, enabling efficient data processing. Data cleaning procedures removed outliers, ensuring data integrity. The cleaned data was exported in a suitable format for analysis, providing a robust dataset for evaluating network performance across Abuja, Lafia, and Jos.

Descriptive statistics were used to summarize the dataset, offering a clear understanding of trends and facilitating meaningful conclusions about LTE/4G network performance. This approach is versatile and well-suited for analyzing the selected KPIs, each with unique metrics and determination methods. Figure 6 illustrates the drive test setup across the three test locations.

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RESULTS AND DISCUSSION

Signal density visualizations (Figures 7–9) depict the distribution and strength of signals from each MNO across the test locations. Signal density reflects the number of signal sources or transmitters in a specific area, with higher density indicating stronger coverage or more access points. These visualizations provide valuable insights into the performance and coverage of LTE/4G networks in North-Central Nigeria.

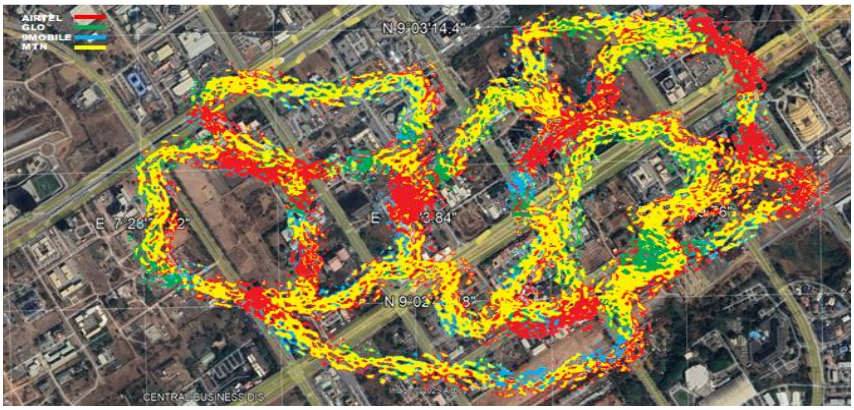

Figure 7: Visualization for Signal Density of the MNOs in Abuja

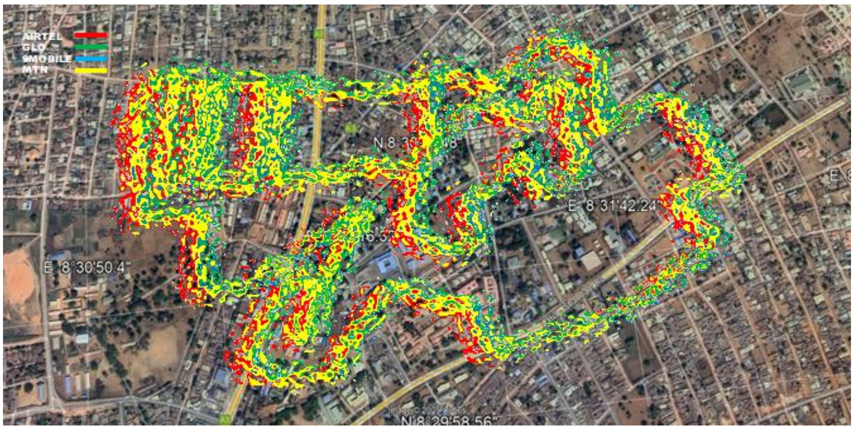

Figure 8: Visualization for Signal Density of the MNOs in Lafia

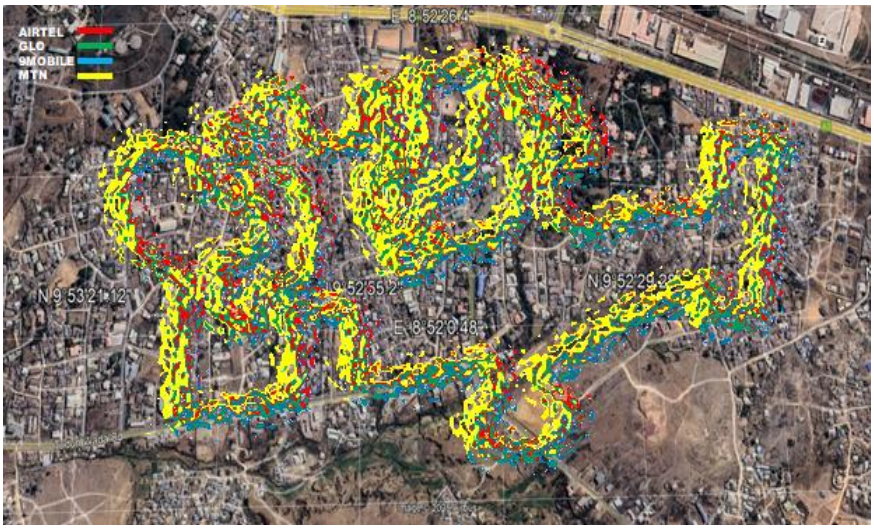

Figure 9: Visualization for Signal Density of the MNOs in Jos

Network Speed Analysis (Table 3 & Figure 10)

MTN emerged as the top performer with the highest mean speed (9.543 Mbps) and maximum speed (19.000

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Mbps), showcasing the most reliable estimates. Airtel followed closely with a mean speed of 9.320 Mbps, while GLO and 9Mobile trailed slightly behind (Figure 10).

Packet Loss Analysis (Table 4 & Figure 11)

MTN recorded the highest mean packet loss (2.007%), followed by GLO (1.939%), Airtel (1.743%), and 9Mobile (0.121%). 9Mobile had the lowest minimum packet loss (0.065%), while GLO had the highest (1.228%). MTN also showed the highest maximum packet loss (2.500%). Variance and standard deviation were low across all providers, indicating consistent performance. MTN's higher packet loss may be attributed to its larger data throughput footprint (Figure 11).

Latency Analysis (Table 5 & Figure 12)

MTN led with the lowest mean latency (25.921 ms) and minimum latency (17.500 ms), followed by Airtel (41.381 ms), 9Mobile (35.340 ms), and GLO (44.070 ms). Lower latency, as seen with MTN (Figure 12), enhances user experiences in gaming and video streaming, while higher latency, as with GLO, may cause delays and slower data transfer.

Uptime Analysis (Table 6 & Figure 13)

MTN dominated with the highest mean uptime (97.714%), followed by Airtel (79.569%). GLO and 9Mobile had lower uptimes. Airtel had the highest minimum uptime (78.082%), while MTN achieved the highest maximum uptime (99.000%). MTN and Airtel demonstrated stronger reliability, with MTN showing slightly more variability (Figure 13).

Network Coverage Analysis (Table 7 & Figure 14)

MTN outperformed with the highest mean coverage (87.514%), followed by Airtel (75.284%), 9Mobile (64.479%), and GLO (60.731%). Airtel had the highest minimum coverage (67.552%), while MTN achieved the highest maximum coverage (95.000%). MTN also had the highest confidence level, indicating more reliable coverage estimates (Figure 14).

Signal Power Analysis (Table 8 & Figure 15)

Airtel led with the highest mean signal power (-61.867 dBm), followed by GLO (-65.599 dBm) and MTN (-68.214 dBm). Airtel also had the highest minimum signal power (-66.414 dBm), while GLO recorded the highest maximum signal power (-55.075 dBm) (Figure 15). These metrics highlight variations in signal strength, crucial for ensuring reliable connectivity and user satisfaction.

Table 3: Network Speed Statistics

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean (Mbps)	9.320	6.765	6.638	9.543
Minimum (Mbps)	1.962	1.424	1.397	2.000
Maximum (Mbps)	18.641	13.530	13.275	19.000
Sum (Mbps)	652.432	473.547	464.642	668.000
Variance (Mbps)	24.852	13.092	12.605	25.817
Standard Deviation (Mbps)	4.985	3.618	3.550	5.081
Mode (Mbps)	3.924	7.833	4.891	11.000
Confidence Level	1.189	0.863	0.847	1.212

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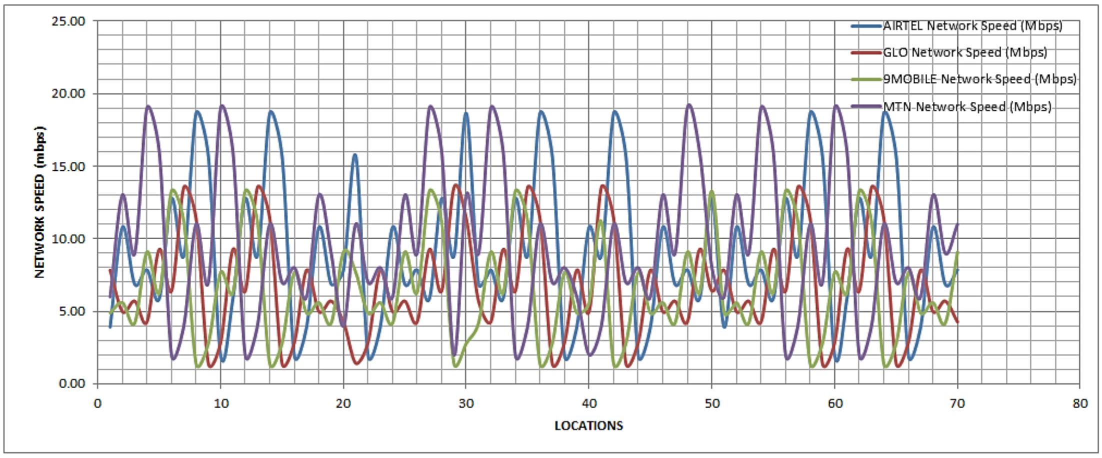

Figure 8: Network Speed across MNOs

Table 4: Packet Loss Statistics

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean (%)	1.743	1.939	0.121	2.007
Minimum (%)	0.295	1.228	0.065	1.300
Maximum (%)	2.456	2.559	0.163	2.500
Sum (%)	122.002	135.741	8.439	140.500
Variance (%)	0.333	0.145	0.001	0.096
Standard Deviation (%)	0.577	0.381	0.029	0.309
Mode (%)	1.965	2.047	0.130	2.000
Confidence Level	0.138	0.091	0.007	0.07

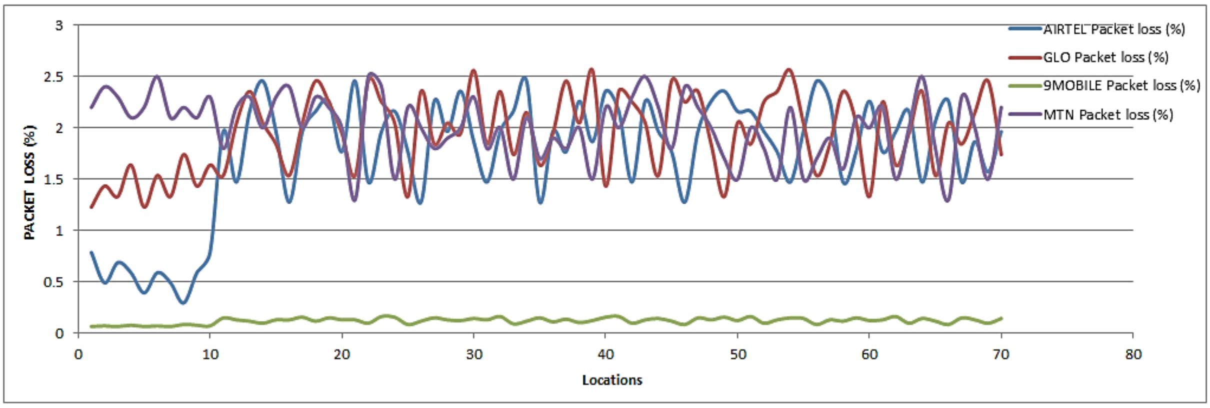

Figure 9: Packet Loss across MNOs

Table 5: Latency Statistics

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean (ms)	41.381	44.070	35.340	25.921
Minimum (ms)	18.357	31.224	25.571	17.500
Maximum (ms)	55.070	57.987	43.835	45.000
Sum (ms)	2896.668	3084.882	2473.781	1814.500

Variance	86.554	33.158	25.515	15.244
Standard Deviation	9.303	5.758	5.051	3.904
Mode (ms)	45.891	44.605	36.530	25.000
Confidence Level	2.218	1.373	1.204	0.931

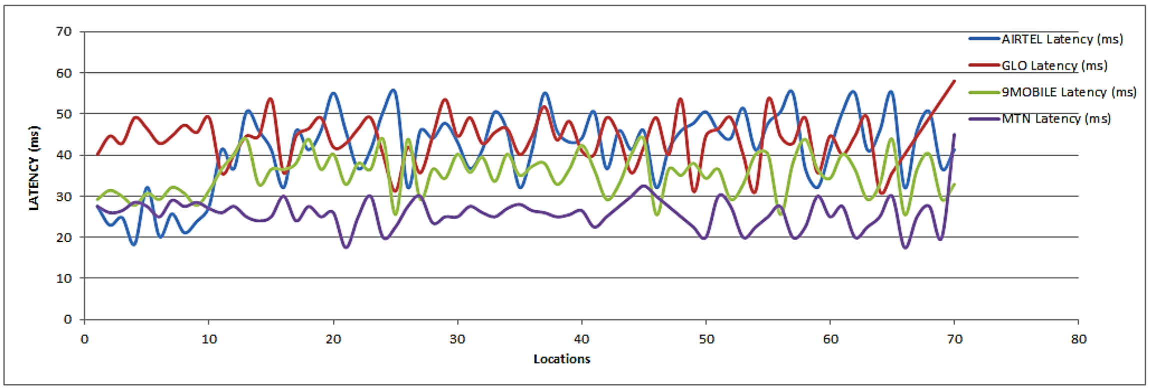

Figure 9: Latency across MNOs

Table 6: Uptime Statistics

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean Uptime (%)	79.569	73.587	38.706	97.714
Minimum Uptime (%)	78.082	71.700	37.631	96.000
Maximum Uptime (%)	80.522	74.719	39.215	99.000
Sum of Uptime (%)	5569.841	5151.060	2709.427	6840.000
Variance	0.843	0.722	0.219	1.077
Standard Deviation	0.918	0.850	0.468	1.038
Mode (%)	80.522	73.209	39.215	97.000
Confidence Level	0.219	0.203	0.112	0.247

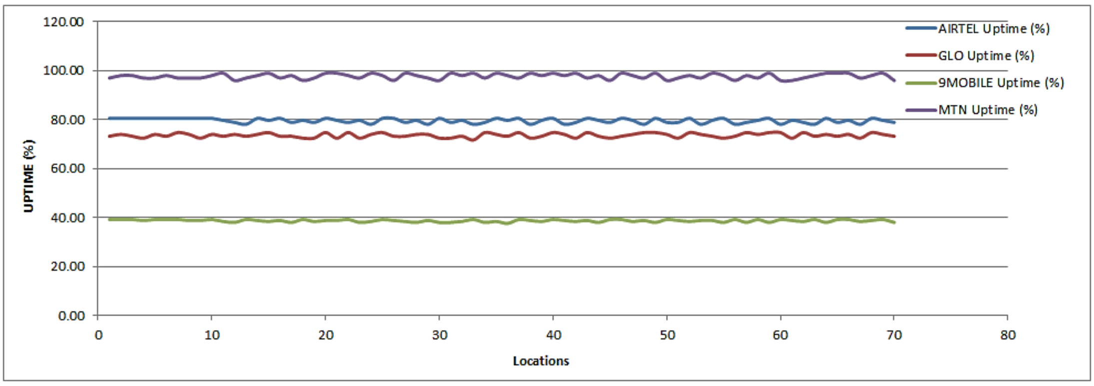

Figure 11: Uptime across MNOs

Table 7: Network Coverage Statistics

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean Network Coverage (%)	75.284	60.731	64.479	87.514

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Minimum Network Coverage (%)	67.552	54.863	58.173	80.000
Maximum Network Coverage (%)	82.751	65.149	69.080	95.000
Sum of Network Coverage (%)	5269.907	4251.163	4513.501	6126.000
Variance	20.040	9.442	13.422	13.268
Standard Deviation	4.477	3.073	3.664	3.643
Mode (%)	71.774	58.291	61.809	85.000
Confidence Level	1.067	0.733	0.874	0.869

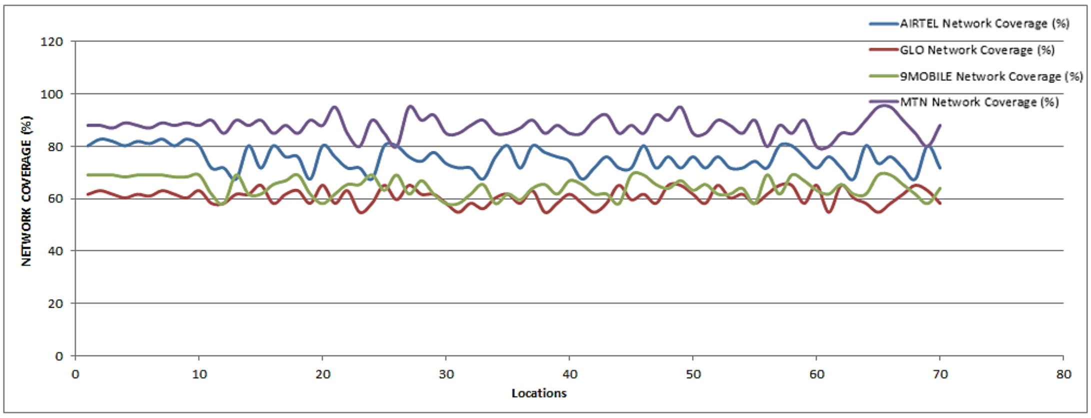

Figure 12: Network Coverage across all MNOS

Statistics	AIRTEL	GLO	9MOBILE	MTN
Mean Signal Power (dBm)	-61.867	-65.599	-78.057	-68.214
Minimum Signal Power (dBm)	-66.414	-69.807	-83.000	-73.200
Maximum Signal Power (dBm)	-55.075	-59.591	-72.000	-61.595
Sum of Signal Power (dBm)	-4330.669	-4591.945	-5464.000	-4774.983
Variance of Signal Power (dBm)	9.455	7.077	8.837	11.191
Standard Deviation (dBm)	3.075	2.660	2.973	3.345
Mode of Signal Power (dBm)	-60.744	-63.848	-75.000	-71.415
Confidence Level (95.0%)	0.733	0.634	0.709	0.798

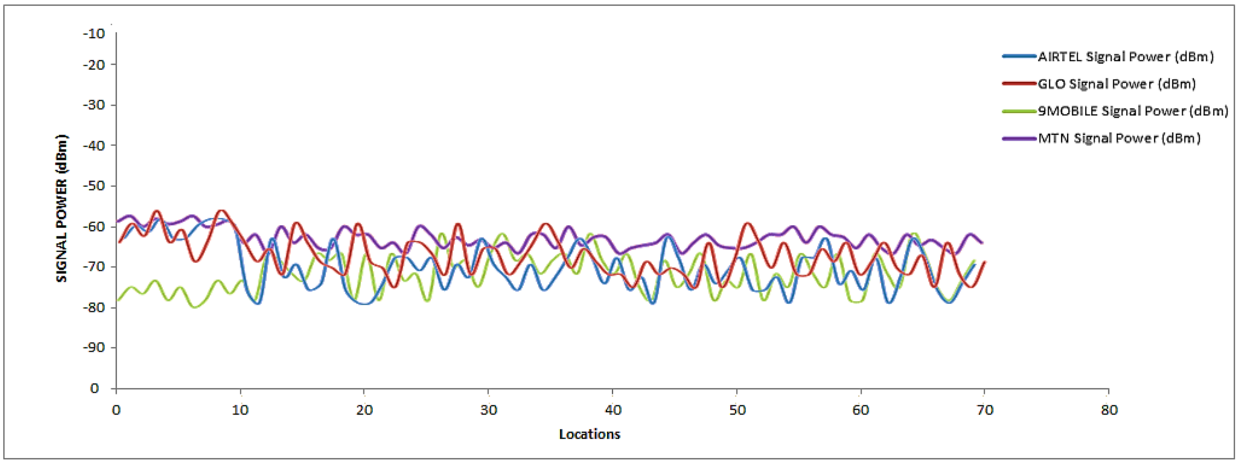

Figure 13: Signal Power across MNOs

CONCLUSION

This study employed a comprehensive drive test methodology to evaluate 4G/LTE network performance in North-Central Nigeria. By meticulously planning routes and utilizing advanced data collection tools, reliable metrics across key performance indicators (KPIs) were obtained.

MTN emerged as the top performer, excelling in network speed, latency, uptime, coverage, and signal power. Airtel demonstrated competitive performance, while GLO and 9Mobile lagged slightly in certain metrics. The use of generalized metrics provided a holistic view of network performance, enabling easier comparisons and informed decision-making. The prioritization of generalized metrics over specific ones was deliberate. Generalized metrics provide a comprehensive overview of network performance, reflecting real-world user experiences and facilitating inclusive evaluations. This approach enhances the study's applicability, enabling informed decision-making and policy development in the telecommunications sector.

Despite its insights, the study has limitations, including the inability to capture real-time variations and its focus solely on 4G/LTE networks. These findings offer valuable insights for stakeholders to enhance network quality and user satisfaction in the region. Future research could address these limitations and explore the interplay between different network technologies.

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