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Analysis of 4G/LTE Network Performance in North-Central Nigeria: A Comprehensive Drive Test Approach

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Authors' contributions

This work was carried out in collaboration among all authors. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by authors SDY, SII and BJK. The first draft of the manuscript was written by author SII, reviewed and re-drafted by author SDY, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The proliferation of mobile devices and escalating demand for data services have resulted in a substantial increase in data traffic across Nigeria, especially in the North Central region due to heavy migration of individuals and organizations towards Abuja, the federal capital. However, despite the growing adoption of 4G/LTE networks in North Central Nigeria, users encounter

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persistent challenges in accessing high-speed internet and poor service network. This study investigates the performance of 4G/LTE networks in North-Central Nigeria using a comprehensive drive test methodology carried out in Abuja, Lafia and Makurdi. It covered a duration of 3hrs (12.00noon to 15.00pm) for 3days (3rd - 6th January, 2024). For each test day, drive tests covered a period of data measurements divided into 3,600 time-steps, with each time-step sized at 1sec; and scaled to 1:150 units. Key metrics including network speed, latency, uptime, coverage, and signal power were evaluated across major Mobile Network Operators. Result shows that D-NGN has the highest mean speed (9.543Mbps), packet loss (2.007%), uplink percentage (97.714%), and Network coverage (87.514%). It has the least latency (25.921) but high packet loss (2.007%). However, C-NGN shows lowest mean speed (6.638Mbps), uplink percentage (38.706%) and Signal power (-78.057dBm) but lowest mean packet loss (0.121%). A-NGN has the highest mean signal power (-61.867dBm) while B-NGN has highest latency (44.070ms) and lowest Network coverage (60.731%). This reveals that D-NGN has dominance in network performance, outperforming A-NGN, B-NGN, and C-NGN. It is recommended that MNOs in North-Central Nigeria should strategically enhance their network infrastructure to improve service delivery, particularly in suburban and rural areas where performance lags. D-NGN, the frontrunner in network speed and coverage, could further solidify its market leadership by addressing identified latency and packet loss issues especially in Makurdi. Moreover, MNOs with lower performance metrics could invest in expanding coverage and optimizing network configurations to meet user demands, thereby increasing competitiveness and customer satisfaction across the region.

Keywords: Mobile Network Operators (MNOs); generalized metrics; network performance evaluation; signal density; drive test; 4G/LTE networks.

1. INTRODUCTION

The progression of mobile networks persists, with ongoing developments in diverse domains, encompassing specialized networks like sensors, smart tags, and conventional telecom networks [1]. The introduction of 4G/LTE technology has markedly improved data rates, augmented capacity, and heightened the overall user experience. Notably, in Nigeria, there is a discernible surge in the embrace of 4G/LTE technology, as an increasing number of users are engaging with mobile internet services via smartphones and other mobile devices [2]. The North-Central region of Nigeria, inclusive of states such as, Benue, Nasarawa, and the Federal Capital Territory (FCT), has witnessed substantial strides in the adoption of mobile technology in recent years and the escalating demand for data services have resulted in a substantial increase in data traffic across Nigeria [3, 4, 5]. However, despite the growing adoption of 4G/LTE networks in North Central Nigeria, users encounter persistent challenges in accessing high-speed internet, giving rise to concerns. Consequently, there arises a compelling need to assess the efficacy of 4G/LTE technology in this region. This evaluation must encompass pivotal factors like network coverage, latency, signal strength, and packet loss.

As of March 2020, Nigeria's telecom industry boasted 189.3 million subscribers, contributing 10.88% to GDP, led by major players such as 9Mobile, Airtel, Globacom, and MTN [6]. However, rural areas face a digital divide, with around 40 million lacking telecom access [7]. Tower expansion, led by MTN Nigeria, Airtel, Globacom, and 9Mobile, is endorsed by the NCC, but over 80,000 towers are still needed [8]. MTN Nigeria initiated 4G LTE rollout in 2016, amid concerns over fair competition and spectrum pricing favoring larger operators. Currently, four major operators (MTN Nigeria, Airtel, Globacom, and 9Mobile) hold 2.1GHz spectrum slots, with MTN Nigeria recently acquiring additional spectrum in line with its ambition 2025 strategy and government broadband goals. Despite growing 4G adoption, challenges persist in North Central Nigeria, affecting network speeds, signal quality, and coverage [9, 10, 11, 12, 5].

In view of the above, the objective of this study is to evaluate the performance of 4G/LTE networks in some Nigerian North Central Cities. The study will determine the Key Performance Indicators (KPIs) of 4G/LTE networks in the study area, including network speeds, packet loss, latency, uptime, network coverage and signal quality. Then the descriptive analysis of the Key Performance Indicators (KPIs) will be determined through Drive Test data. The performance assessment of 4G/LTE technology in the study area is indispensable for gauging its adherence to expected standards and pinpointing areas necessitating enhancement. Equally critical is shedding light on determinants impacting user experience, including network quality, reliability, and availability. Furthermore, the identification of potential challenges and opportunities for mobile network operators in the region is imperative to catalyze service improvement and elevate user satisfaction [13]. In summation, evaluating the performance of 4G/LTE wireless technology and user satisfaction in Nigeria's North-Central region emerges as a vital endeavor, providing insights into the status of mobile technology adoption and usage within the region.

2. LITERATURE REVIEW

2.1 An Overview of the 4G LTE Networks

Long Term Evolution (LTE) commenced in 2004 as a project by the Third Generation Partnership Project (3GPP), aiming to revolutionize packet-switched data communication [14]. The LTE architecture (Fig. 1) consists of the Evolved Packet Core (EPC), Evolved NodeB (eNodeB), and User Equipment (UE). This architecture has gone through a significant transformation, resulting in the Evolved Universal Terrestrial Radio Access Network (EUTRAN) for the LTE access network. This evolution, known as the System Architecture Evolution (SAE), introduced the Evolved Packet Core (EPC) network. Both LTE and EPC collectively form the Evolved Packet System (EPS), operating on a fully packet-switched basis [15].

The EPC comprises essential 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) [17]. The UE, representing end-user devices, connects wirelessly to the network through the air interface to the eNodeB. Multiple Input Multiple Output (MIMO) enhances the wireless medium by enabling simultaneous transmission and reception of multiple data streams through multiple antennas [18].

2.2 Related Works

El-Saleh et al. [19] conducted drive tests in Cyberjaya, Malaysia, evaluating outdoor and in-building performance metrics for 3G and 4G technologies from various MNOs. Yadav et al. [20] assessed multimedia application performance in an LTE-4G network using OPNET. Kuboye [21] compared three LTE scheduling algorithms in Akure, Nigeria. Oje and Edeki [22] assessed 4G internet performance from multiple mobile network operators at the University of Ilorin, Nigeria. Using TEMS tools, they analyzed KPIs (RSRP, RSRQ and SINR) against NCC standards. Raphael et al. [23] assessed four MNOs in Shiroro, Nigeria, using TEMs and statistical analysis. Imoize and Adegbite [24] analyzed LTE performance in Lagos, employing Huawei drive test equipment. Key indicators, including RSSI, RSRQ, RSRP, SINR, and Throughput, were assessed with MapInfo and MATLAB, aligning with NCC standards.

Despite various approaches to evaluating network performance, there is a noticeable gap in research evaluating 4G LTE networks in North-Central Nigeria. As service providers roll out 4G networks to address legacy network limitations, there is a critical need to assess their performance and ascertain their ability to deliver on promised performance [25].

2.3 Network Drive Test (DT)

A Drive Test (DT) is a crucial method for gathering data on LTE cellular networks, providing valuable insights for optimizing wireless network operations. Through extensive data collection using DT, various parameters are evaluated to assess Quality of Service (QoS) offered by the network [26]. These parameters include voice and data services, signal strength and quality, interference levels, call performance metrics, handover information, neighboring cell data, and GPS coordinates. Drive tests are typically categorized into three types: Single Site Verification (SSV) or Single Cell Function Test (SCFT), Multiple Site Verification (MSV) or Cluster Drive Test, and Operator Benchmarking Drive Test (Market Level Drive Test).

2.4 Key Performance Indicators (KPIs) in LTE Network Evaluation

Key Performance Indicators (KPIs) are essential metrics for evaluating LTE network performance, providing valuable insights into factors influencing network quality and user satisfaction. In assessing the performance of LTE/4G Mobile Network Operators (MNOs), careful selection of KPIs is crucial to ensure comprehensive evaluation and effective monitoring of network performance [26]. For the evaluation of MNOs in North-Central Nigeria, a set of KPIs has been chosen to encompass various aspects of network performance, including network speed, packet loss, latency, uptime, coverage, and received signal strength. These KPIs have been selected based on their alignment with specific quality of service (QoS) metrics provided by the Nigerian Communications Commission (NCC) and their relevance in assessing network performance in the common frequency spectrum of 2.1GHz. By focusing on these key indicators, this study aims to provide a holistic assessment of LTE/4G network, ultimately contributing to the understanding of network quality by ordinary users in the region.

2.5 The Targeted MNOs

The study targeted four prominent MNOs, namely Airtel, Glo (Globacom), 9Mobile (formerly Etisalat), and MTN, recognized as leaders in LTE/4G service provision within the Nigerian telecommunications industry. These MNOs hold assignments on the 2.1 GHz frequency spectrum, as regulated by the Nigerian NCC, as presented in Table 1. Their selection was based on their established presence and influence in the market, making them representative subjects for comprehensive evaluation and comparison in this study.

A-NGN offers 2G, 3G, and 4G LTE services across North-Central Nigeria [27]. B-NGN, the second-largest MNO, extends its coverage with similar services, emphasizing network expansion and service enhancement [28]. C-NGN, focuses on network optimization and modernization to deliver voice and data services [29]. D-NGN, the largest MNO, invests heavily in network infrastructure and technology upgrades, ensuring comprehensive 2G, 3G, and 4G LTE coverage in the region [29].

All four major MNOs utilize the Partial Usage of Sub-Channels (PUSc) 1x3x3 reuse scheme across their deployed networks. This scheme, illustrated in Fig. 2, employs three sector antennas and utilizes only one radio frequency (RF) channel for all sectors. Within this scheme, three distinct sets of tones are allocated, each corresponding to a sector of a Base Station (BS). This design significantly reduces inter-cell interference and minimizes outage areas within the cell. Moreover, RF planning is simplified as segments are assigned to sectors while maintaining the same RF channel across all Base Stations (BS) [30].

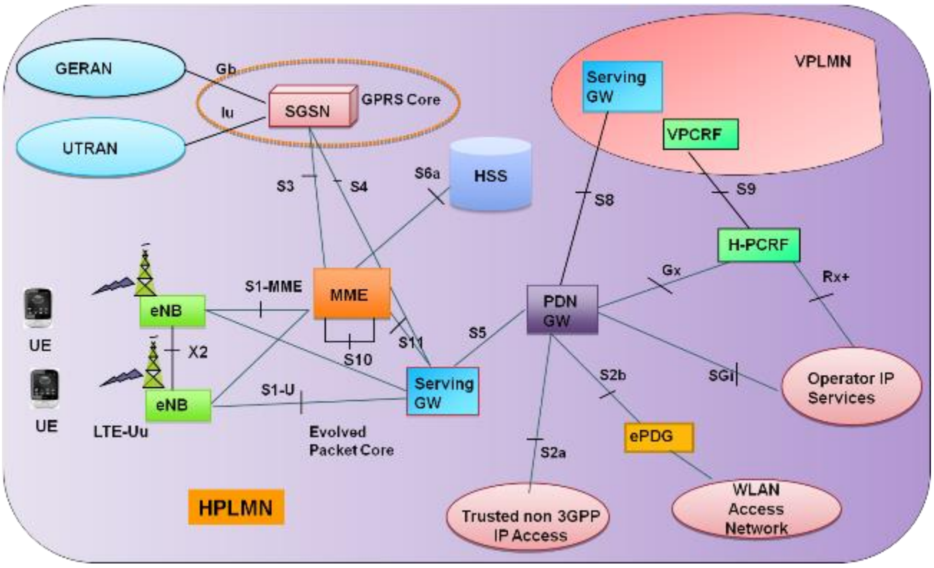

Fig. 1. LTE Evolved System Architecture [16]

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

Operator		MTN	Globacom	9Mobile	Airtel
Code		**D-NGN**	**B-NGN**	**C-NGN**	**A-NGN**
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

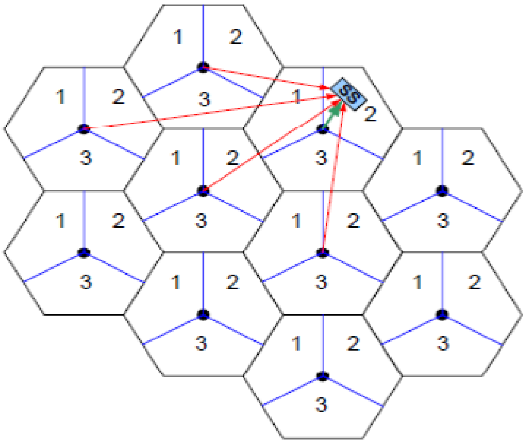

Fig. 2. Partial Usage of Sub-Channels (PUSc) 1x3x3 Frequency Reuse Scheme [30]

2.6 The Targeted KPIs

Network Speed: Network speed, measured in bits per second (bps), reflects the rate at which data is transmitted over a network. In the context of the drive test, the measurements are configured to take account of all types of data transmission, including voice calls, text messages, internet browsing, video/audio streaming, online gaming, and other digital activities. Mathematically, network speed can be expressed as the ratio of (all types of) data transmission to the time taken for transmission:

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

Packet Loss: Packet loss is the percentage of packets that are transmitted but not received at their destination. It is typically expressed as a percentage. The expression for packet loss can be represented as:

$$\text{Packet Loss (\%)} = \left(\frac{\text{Number of Lost Packets}}{\text{Total Number of Packets}}\right) \text{x } 100 \quad (2)$$

Latency: Latency refers to the time delay between the transmission of a data packet and its reception at the destination. It is typically measured in milliseconds (ms). The mathematical expression for latency can be represented as:

$$Latency = Time\ for\ Packet\ to\ Reach\ Destination - Time\ of\ Transmission \quad (3)$$

Uptime: Uptime refers to the percentage of time that the MNO is operational and available for use. It is expressed as a percentage. The mathematical expression for uptime can be represented as:

$$\text{Uptime (\%)} = \frac{\text{(Total Time − Downtime)}}{\text{Total Time}} \text{ x } 100 \quad (4)$$

Network Coverage: This study utilized the Okumura-Hata and Walfisch-Ikegami Models within the G-Net Solutions Pack to estimate MNOs coverage areas, accounting for handovers/handoffs. Leveraging the Okumura-Hata Model's considerations of signal strength, frequency, terrain, and structures, accurate network coverage assessments were made. The software monitored signal parameters during handovers, logging transitions and analyzing signal strength and quality. Advanced algorithms and Okumura-Hata Model-specific simulations improved coverage estimation accuracy.

Signal Power: Signal power signifies the strength or intensity of the signal transmitted or received in a network, measured in decibels (dB). The Okumura-Hata and Walfisch-Ikegami Models were combined for comprehensive signal power determination. By selecting this model combination and considering environmental factors, the software computed signal power at each measurement point during drive tests. This facilitated the determination of mean signal power for each MNO across the coverage area, enabling an efficient and accurate determination of signal power.

2.7 Okumura-Hata Model

For the drive test the Okumura-Hata Model was calibrated as follows:

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

Where:
$\mathrm{PL}_{\text{free space}}$ 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:

$$\mathrm{PL} = \mathrm{A} + \mathrm{B}\log(\mathrm{d}) + \mathrm{C} \quad (6)$$

Where:
A, B and C are factors dependent on both frequency and antenna height, and:
$\mathrm{A} = 69.55 + 26.16\log(\mathrm{F_C}) - 13.82\log(\mathrm{h_b}) - \mathrm{a}(\mathrm{h_m})$

$B = 44.9 - 6.55\log(h_b)\log d$

In this context:
F_C = Frequency in MHz
d = distance in km
h_b = Base Station Height
h_m = MS/UE Height

The function $a(h_m)$ and factor C vary according to the environment:

For small and medium-sized cities;

$$a(h_m) = (1.1\log(F_c) - 0.7)h_m - (1.56\log(F_c) - 0.8) \quad (7a)$$

$C = 0$

In metropolitan areas;

$$a(h_m) = \begin{cases} 8.29(\log(1.54h_m)^2) - 1.1 & \text{for frequencies} \leq 200\text{MHz} \\ 3.2(\log(11.75h_m)^2) - 4.97 & \text{for frequencies} \geq 400\text{MHz} \end{cases} \quad (7b)$$

$C = 0$

For suburban environment:

$$C = -2[log(F_c/28)]^2 - 5.4 \quad (7c)$$

In rural areas:

$$C = -4.78[log(F_c)]^2 + 18.33\,log(F_c) - 40.98 \quad (7d)$$

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

2.8 Cost 231 Walfisch-Ikegami Model

The Cost 231 Walfisch-Ikegami model 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:

$$PL_{NLOS} = \begin{cases} L_0 + L_{rts} & L_{rts} + L_{ms} > 0 \\ L_0 & L_{rts} + L_{ms} \leq 0 \end{cases} \quad (8)$$

The average transmission losses are given by:

$$L_0 = 32.4 + 20\log d + 20\log f \quad (9)$$

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

$$L_{ms} = L_{bsh} + k_a + k_d\log d + k_f\log f + 9\log B \quad (11)$$

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

$$L_{bsh} = \begin{cases} -18\log(1 + \Delta h) & \text{for } h_{base} > h_{roof} \\ 0 & \text{for } h_{base} > h_{roof} \end{cases} \quad (12)$$

The factor k_a is given by:

$$k_a = \begin{cases} 54 & h_{roof} > h_{base} \\ 54 + 0.8\Delta h_b & d \geq 0.5 \text{ and } h_{roof} \leq h_{base} \\ 54 + 0.8\Delta h_b \frac{d}{0.5} & d < 0.5 \text{ and } h_{roof} \leq h_{base} \end{cases} \quad (13)$$

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:

$$k_f = -4 + \begin{cases} 0.7\left(\frac{f}{925} - 1\right) & \text{medium} - \text{sized and suburban areas} \\ 1.5\left(\frac{f}{925} - 1\right) & \text{metropolitan areas} \end{cases} \quad (14)$$

The distance factor k_d is given by:

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

The orientation factor L_{ori} is given by:

$$L_{ori} = \begin{cases} -10 + 0.35\phi & \text{for } 0° \leq \phi \leq 35° \\ 2.5 + 0.075(\phi - 35°) & \text{for } 35° \leq \phi < 55° \\ 4.0 - 0.11(\phi - 55°) & \text{for } 55° \leq \phi < 90° \end{cases} \quad (16)$$

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:

$$PL_{LOS} = 42.6 + 26 \log d + 20 \log f \quad (17)$$

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.

3. METHODS

3.1 The Study Location

The North-Central region of Nigeria, within which the cities of Abuja, Lafia and Makurdi are located, and; which comprises six states (including the capital cities captured in this study); is rich in mineral resources and boasting a diverse ethnic and cultural population, the region serves as a hub for academic and research activities. Covering 105,863 km² with undulating terrain and a tropical savanna climate, it is characterized by an average temperature of 26°C and an annual rainfall of approximately 1,100 mm. Major water bodies include the Niger and Benue rivers.

3.2 Drive Test Execution

The 4G/LTE network drive test spanned three locations in North-Central—Abuja, Lafia and Makurdi. The meticulous approach involved route planning, vehicle setup, device configuration, and drive test execution simultaneously in each location. Infinix 693, ATouch 105, and Infinix Note-4 Android phones, securely mounted in vehicles, connected to HP ProBook Folio Laptops with G-Net Solutions Pro software, ensuring precise data collection. The G-Net Solutions Pro pack provides a robust toolkit for signal power estimation during drive tests, featuring advanced propagation models like Okumura-Hata, COST 231 Hata, Walfisch-Ikegami, and Free Space Path Loss. Users can choose individual models or combine them to suit specific environmental conditions; ensuring precise performance metrics calculation tailored to the measurement campaign's needs. Key parameters like network speed, packet loss, latency, uptime, coverage, and signal power were monitored. Drive tests, executed at optimal speeds of 10kmph, collected these vital metrics along with GPS coordinates, and timestamps.

3.3 Route Planning

The test objectives and areas of interest in each location were determined, with comprehensive routes planned to cover designated test locations. Each location covered approximately a 1.5km radius from identified cell towers. GPS coordinates for each measurement site were noted. Tests were conducted simultaneously at consistent speeds, starting from predetermined locations and following planned routes. Adequate time was allocated at each location for data capture.

3.4 GPS Coordinates

The GPS coordinates represent the geographical locations captured during drive tests conducted in Abuja, Lafia, and Makurdi. These coordinates mark the boundaries covering the drive test locations, providing valuable spatial information.

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
Makurdi: 7°43'15.98" N, 8°31'21.56" E; 7°44'12.58" N, 8°31'24.01" E; 7°43'56.34" N, 8°33'09.54" E; 7°43'03.62" N, 8°33'00.34" E

3.5 Time Stamps

All time stamps were covered by the duration of 3 hours between 12.00 noon and 15.00pm for 3 days (January 3rd, 2024 – January 6th, 2024). For each test day, drive tests covered a period of data measurements divided into 3,600 time-steps, with each time-step sized at 1 second; and scaled to 1:150 units. At each time step, the serving cell of each UE was prioritized to be the first line of measurement, followed by the most prominent neighboring cell in terms of signal density, followed by the next; and so on.

3.6 Configuration Parameters

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

3.7 Database Setup

The required scripts for the database setup were obtained from http://www.gyokovsolutions.com/downloads/scripts/scripts.rar. A local server with PHP and MySQL support was established, and a new database was created on the master station computer at the Lafia test location. The "create_table.txt" script was executed to create a 'measurements' table in the database. "test_insert.php" script validated record insertion; server details were configured appropriately. "insert.php" script facilitated measurement record insertion; server details were configured accordingly.

3.8 Reporting Server Configuration

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

Table 2. Configuration Parameters for the Drive Test

Parameter	Description
Carrier Frequency	1910-2150 MHz
System Bandwidth	10 MHz
OFDM Symbol Time	102.8 ms (Average)
Transmit Power	44 dBm (Average)
Receiver Sensitivity	-110 dBm (Average)
Mobile Receiver Height	Up to 3 m (Average)
Base Station Antenna Height	35 m (Average)
Transmitter Antenna Gain	19 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

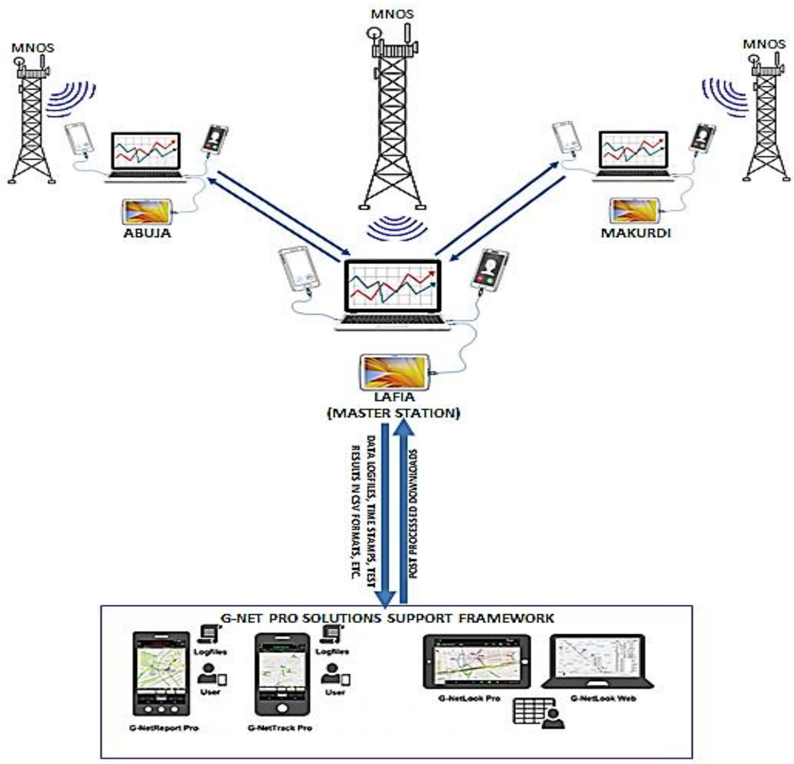

Fig. 3. Drive Test Set-up for the measurement of KPIs across Multiple MNOs

3.9 Data Collection

During drive tests, G-Net Solutions Pro software in each vehicle collected network performance metrics, including signal strength, call quality, data speed, coverage, GPS coordinates, and timestamps. Post-test, meticulous data processing involved setting up a database and reporting server for G-Net Solutions Pro. Database setup included creating tables, test record insertion, and configuring server parameters. The reporting server of G-NetReport Pro was linked to the configured database server for streamlined data analysis. Data cleaning procedures were enacted to remove outliers, ensuring the integrity of the collected information. Data was prepared and exported in a suitable format for analysis and evaluation of network performance across the designated test locations. This comprehensive methodology, documented in Abuja, Lafia and Makurdi, provide a robust dataset for in-depth analysis using descriptive statistics. Descriptive statistics provide a concise summary of the main characteristics of the dataset, making it easier to understand and interpret the findings. The method allows for a straightforward analysis of the general trends observed in the data, which is essential for drawing meaningful conclusions about the performance of the LTE/4G networks. Because the selected KPIs each consist of specific metrics with varying methods of determination, descriptive statistics offer a robust and versatile approach for analyzing and summarizing the data in this study, providing valuable insights into the performance of LTE/4G networks in North-Central Nigeria. Fig. 3 illustrates the drive test setup for each of the three test locations across the North-Central region.

4. RESULTS AND DISCUSSION

The signal density visualizations in Figs. 4 through 6 depict the distribution and strength of signals from each MNO across the measurement sites within the test locations. In this context, signal density indicates how many signal sources or transmitters are present in a specific geographical area. This also includes the strength or coverage of signals from those sources, with higher signal density implying more robust coverage or a higher number of access points.

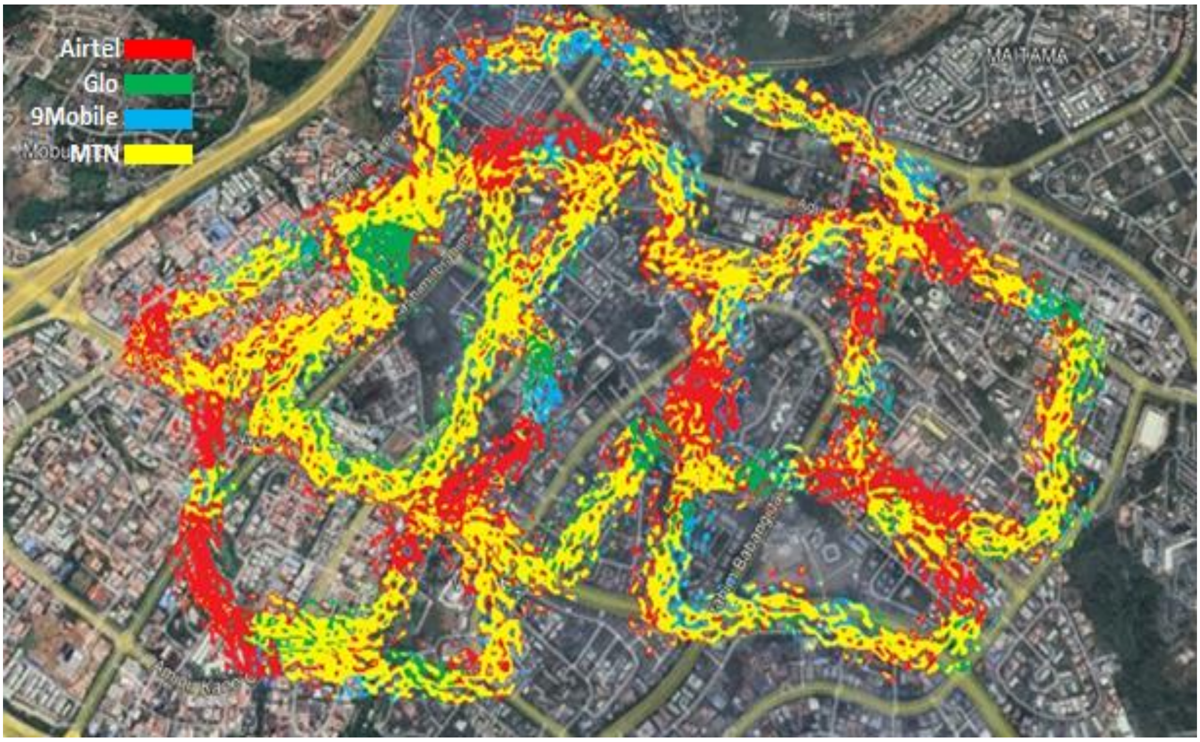

Fig. 4. Visualization for Signal Density of the MNOs in Abuja

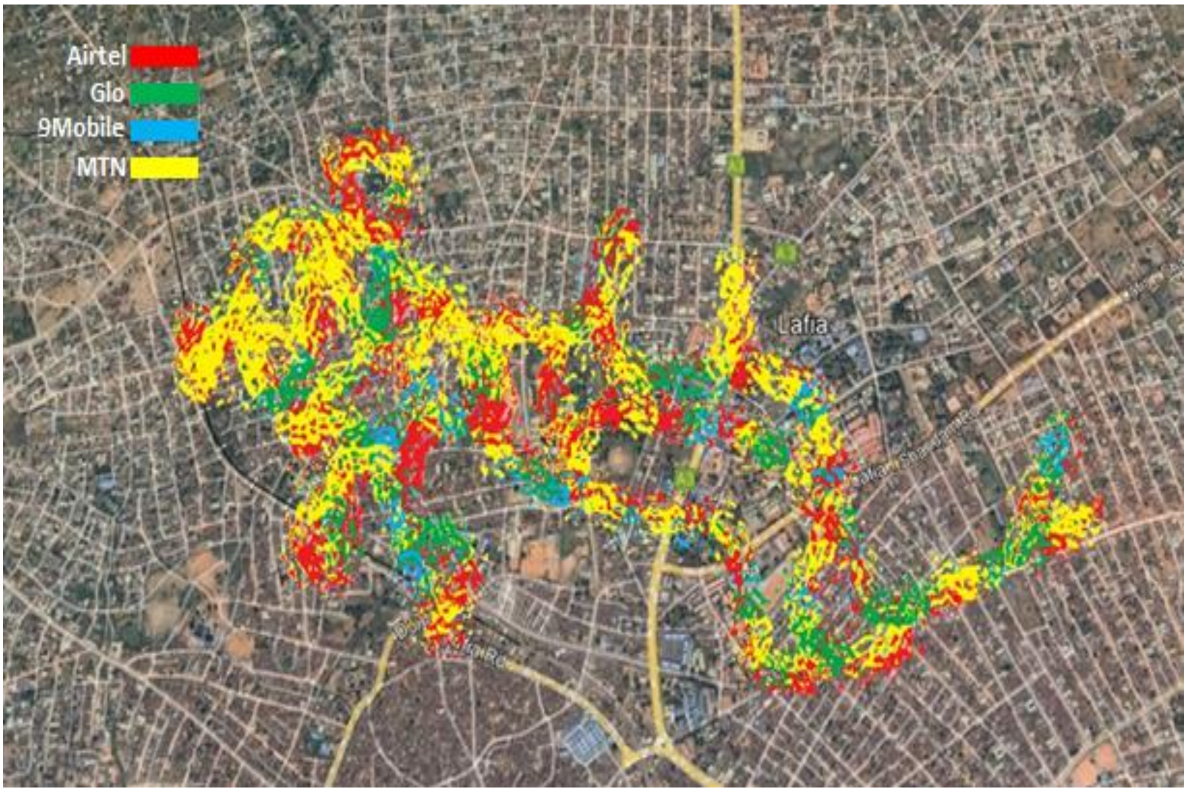

Fig. 5. Visualization for Signal Density of the MNOs in Lafia

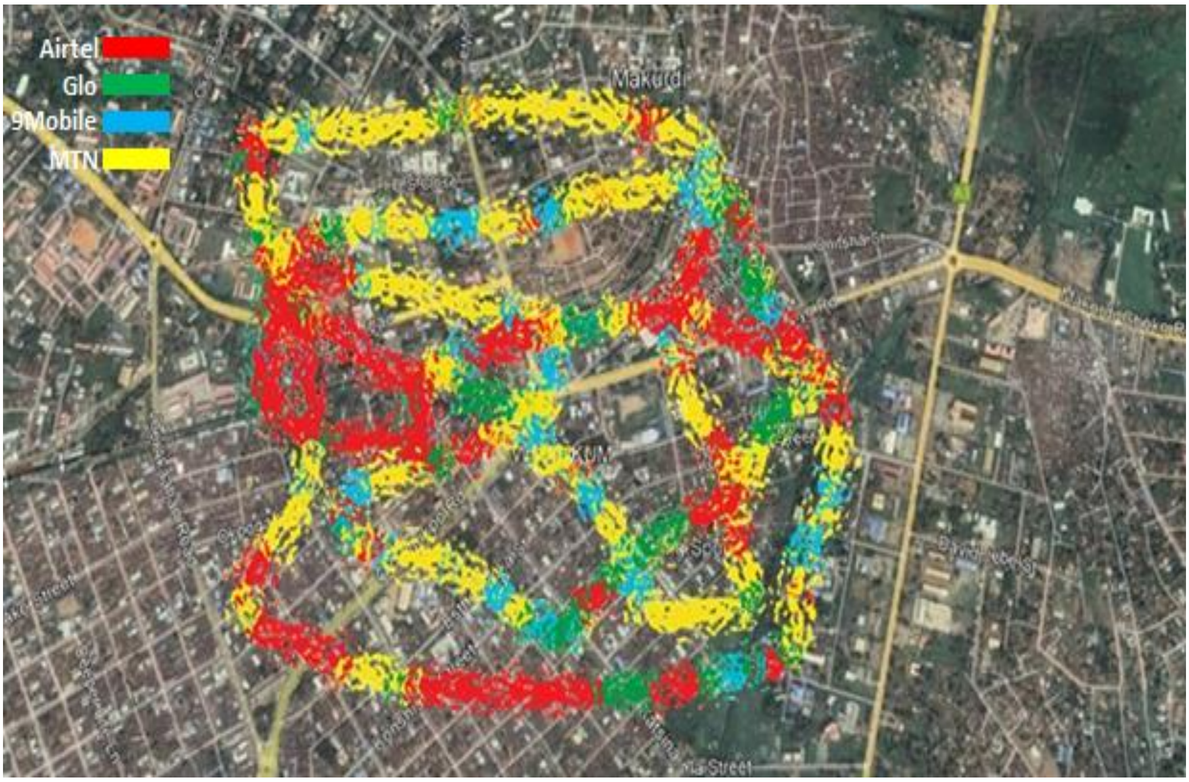

Fig. 6. Visualization for Signal Density of the MNOs in Makurdi

Table 3. Network Speed Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
Mean Network Speed (Mbps)	9.320	6.765	6.638	9.543
Minimum Network Speed (Mbps)	1.962	1.424	1.397	2.000
Maximum Network Speed (Mbps)	18.641	13.530	13.275	19.000
Sum of Network Speed (Mbps)	652.432	473.547	464.642	668.000
Variance of Network Speed (Mbps)	24.852	13.092	12.605	25.817
Standard Deviation of Network Speed (Mbps)	4.985	3.618	3.550	5.081
Mode of Network Speed (Mbps)	3.924	7.833	4.891	11.000
Confidence Level	1.189	0.863	0.847	1.212

In network speed analysis (Table 3), D-NGN emerged as the frontrunner showcasing the highest mean (9.543Mbps) and maximum speed (19.000Mbps), coupled with the most dependable estimates. A-NGN followed suit closely with a mean speed of 9.320Mbps. While B-NGN and C-NGN demonstrated competitive performance, their metrics slightly trailed behind (as shown in Fig. 7).

The packet loss analysis (Table 4) revealed that D-NGN had the highest mean packet loss percentage (2.007%), followed by B-NGN (1.939%), A-NGN (1.743%), and C-NGN (0.121%). In terms of minimum packet loss, C-NGN exhibited the lowest value (0.065%), while B-NGN had the highest (1.228%).D-NGN also recorded the highest maximum packet loss at 2.500% (Fig. 8). Variance and standard deviation were generally low across all providers, indicating relatively consistent performance in packet loss. Confidence levels were similar among A-NGN, C-NGN, and B-NGN, with B-NGN having a slightly higher confidence level. However, D-NGN had the lowest confidence level. The higher sum of network speeds for D-NGN suggests a larger data throughput footprint, which could contribute to its higher packet loss percentages owing to the larger volume of data being transmitted.

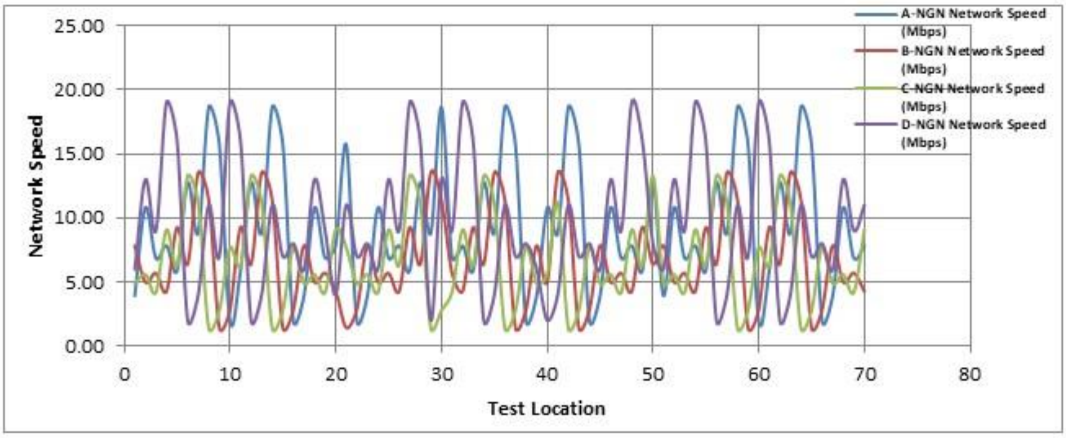

Fig. 7. Network Speed across MNOs

Table 4. Packet Loss Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
Mean Packet Loss (%)	1.743	1.939	0.121	2.007
Minimum Packet Loss (%)	0.295	1.228	0.065	1.300
Maximum Packet Loss (%)	2.456	2.559	0.163	2.500
Sum of Packet Loss (%)	122.002	135.741	8.439	140.500
Variance of Packet Loss (%)	0.333	0.145	0.001	0.096
Standard Deviation (%)	0.577	0.381	0.029	0.309
Mode of Packet Loss (%)	1.965	2.047	0.130	2.000
Confidence Level	0.138	0.091	0.007	0.07

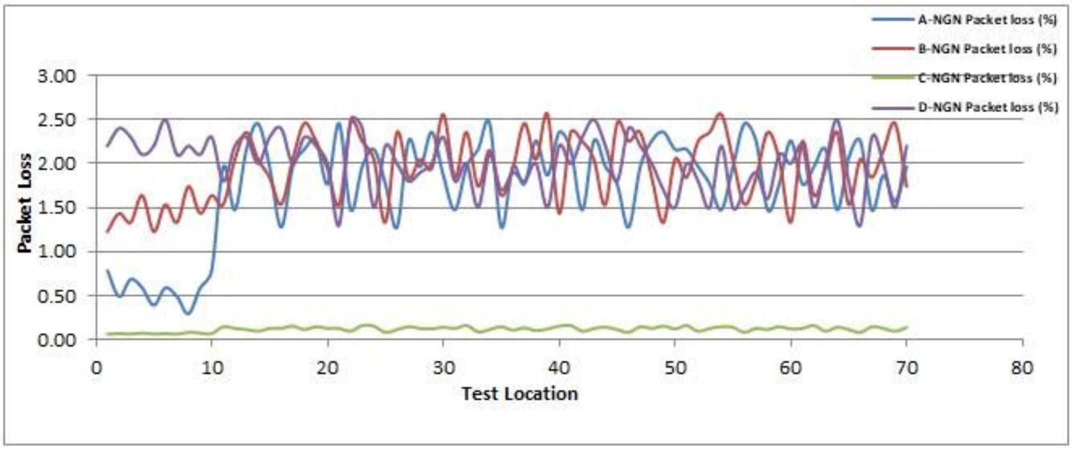

Fig. 8. Packet Loss across MNOs

Table 5. Latency Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
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

The latency analysis (Table 5) underscores D-NGN superiority with the lowest mean latency at 25.921ms and the smallest minimum latency at 17.500ms, followed closely by Airtel with a mean latency of 41.381ms. C-NGN falls between D-NGN and A-NGN with a mean latency of 35.340ms, while B-NGN exhibits the highest mean latency at 44.070ms and the highest minimum latency at 31.224ms. Lower latency values, as seen with D-NGN (Fig. 9), enhance user experiences, particularly in gaming and video streaming, ensuring smoother operations. Conversely, higher latency values, as demonstrated by B-NGN, may lead to delays and slower data transfer speeds, diminishing user satisfaction.

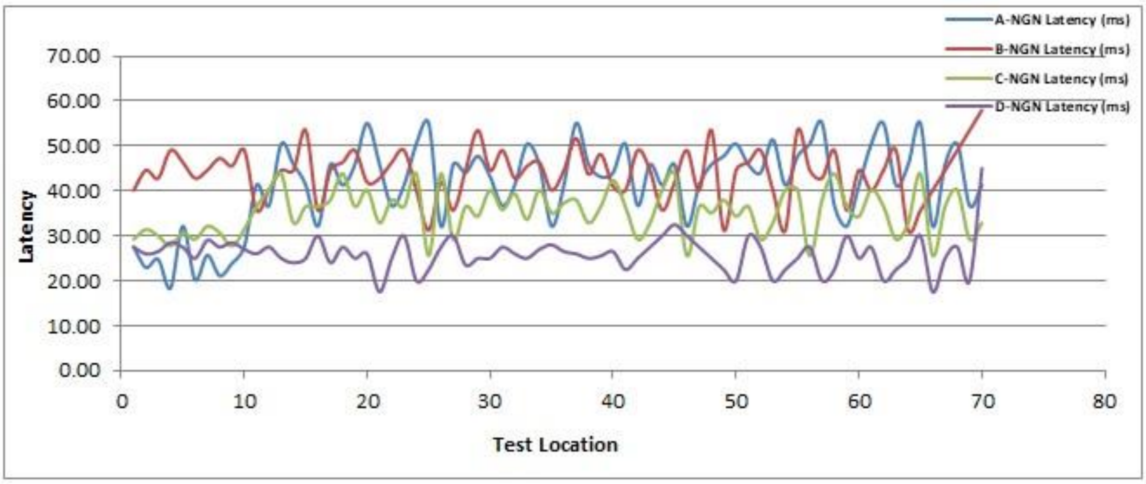

Fig. 9. Latency across MNOs

Table 6. Uptime Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
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

The uptime analysis reveals D-NGN dominance with the highest mean uptime (Table 6) of 97.714%, followed by A-NGN at 79.569%. B-NGN and C-NGN show lower mean uptimes. A-NGN also boasts the highest minimum uptime at 78.082%, while D-NGN records the highest maximum uptime at 99.000%. Although variance and standard deviation metrics suggest consistent uptime performance across all providers, D-NGN exhibits slightly more variability. Overall, D-NGN and A-NGN emerge as stronger performers in network reliability (Fig. 10), highlighting the crucial role of uptime in ensuring satisfactory user experiences.

The analysis of network coverage percentages (Table 7) highlights D-NGN superiority with the highest mean coverage at 87.514%, followed by A-NGN (75.284%), C-NGN (64.479%), and B-NGN (60.731%). A-NGN records the highest minimum coverage at 67.552%, while D-NGN boasts the highest maximum coverage at 95.000%. Variance and standard deviation metrics suggest relatively consistent coverage performance across all providers, with D-NGN exhibiting slightly higher variability (Fig. 11). D-NGN also has the highest confidence level, indicating more reliable coverage estimates. Overall, D-NGN demonstrates the strongest network coverage performance, emphasizing its significant footprint and reliability in providing network access.

In signal power analysis (Table 8), A-NGN demonstrates the highest mean signal power (-61.867dBm), followed by B-NGN (-65.599dBm), and then D-NGN (-68.214dBm). A-NGN also records the highest minimum signal power (-66.414dBm), while B-NGN has the highest maximum signal power (-55.075dBm) as illustrated in Fig. 12. These metrics highlight variations in signal strength among providers, crucial for ensuring reliable connectivity and user satisfaction.

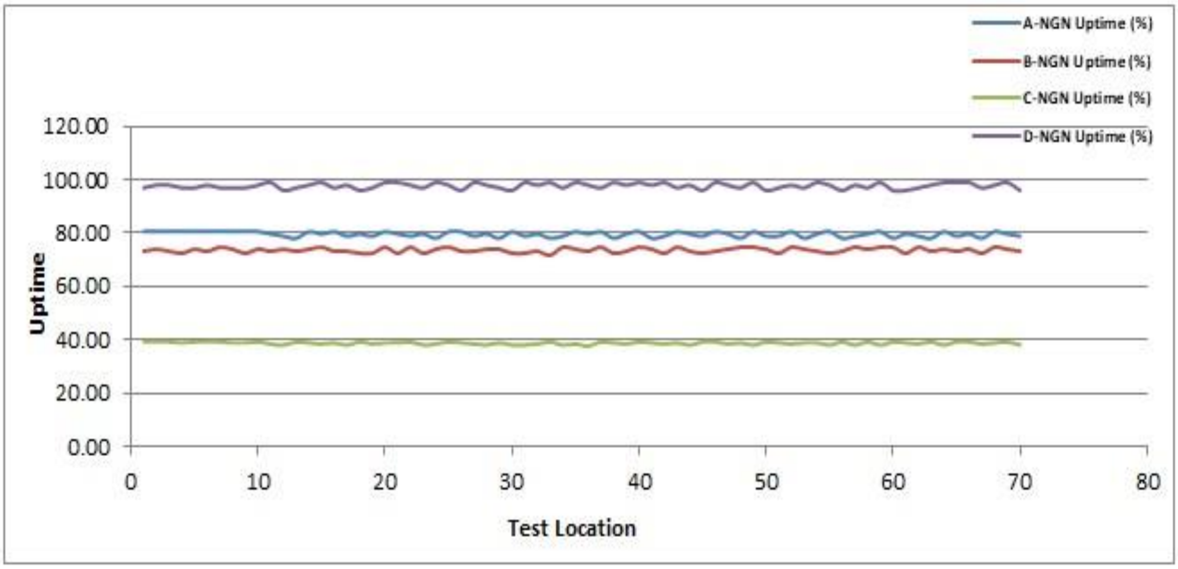

Fig. 10. Uptime across MNOs

Table 7. Network Coverage Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
Mean Network Coverage (%)	75.284	60.731	64.479	87.514
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

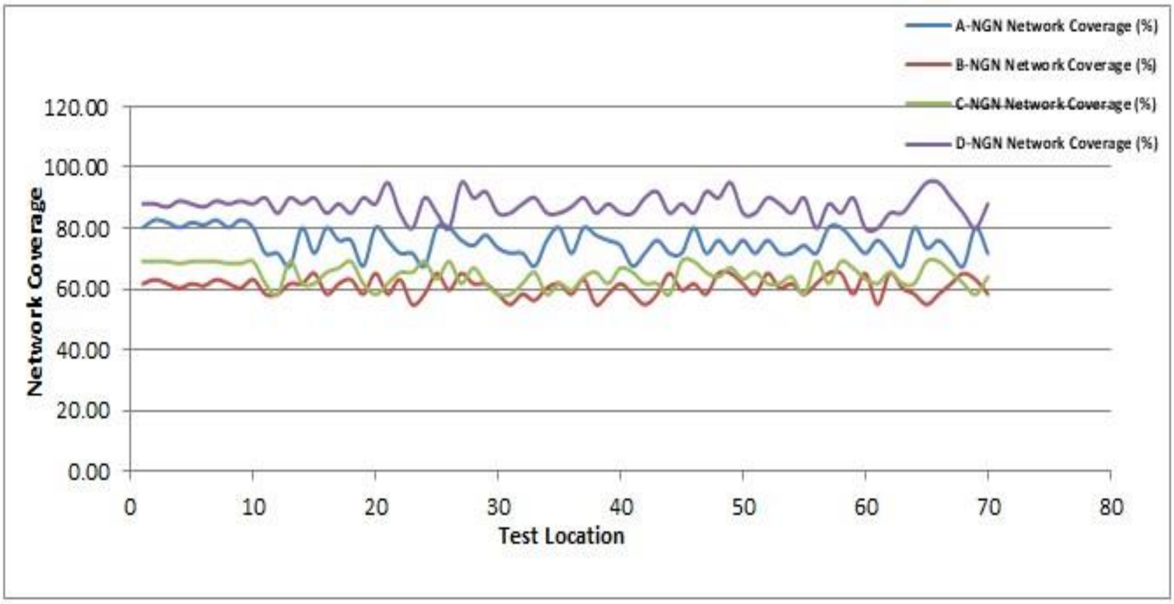

Fig. 11. Network Coverage across all MNOS

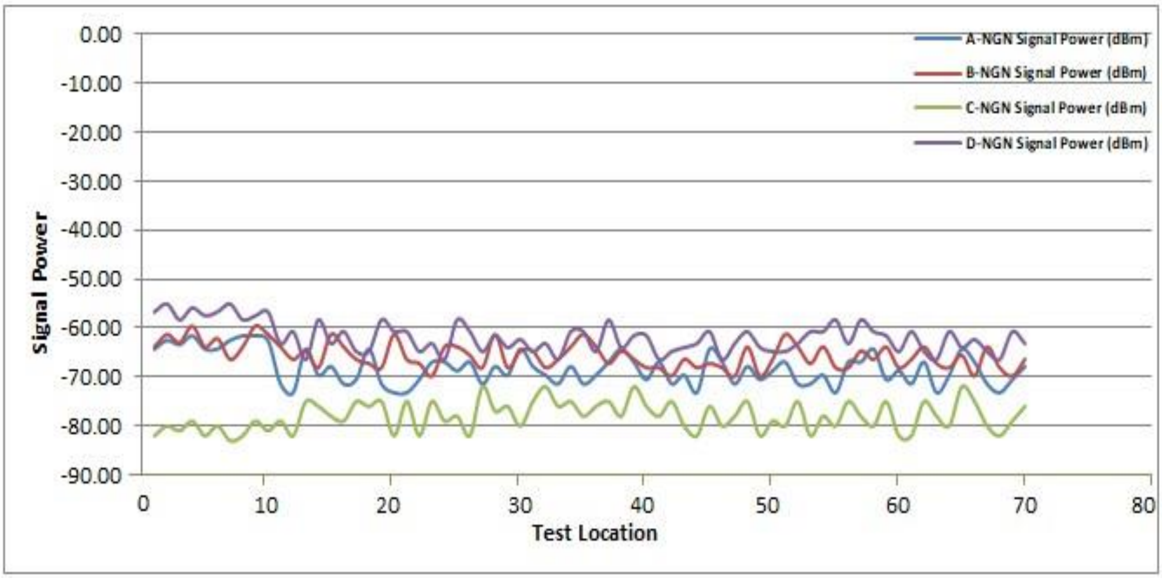

Fig. 12. Signal Power across MNOs

Table 8. Signal Power Statistics

Statistics	A-NGN	B-NGN	C-NGN	D-NGN
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

4.1 Discussion

The drive tests revealed that D-NGN consistently led in network speed, coverage, and signal quality across the study locations, with a mean network speed of 9.543Mbps, the lowest mean latency of 25.921ms, the highest mean uptime of 97.714%, the broadest coverage at 87.514%, and robust signal power averaging -68.214dBm. A-NGN also demonstrated strong performance, particularly in urban areas, with a mean speed of 9.320Mbps and a mean latency of 41.381ms. In contrast, B-NGN and C-NGN showed relatively lower metrics, particularly in suburban and rural regions. Notably, the latency and packet loss varied significantly across locations, with Makurdi exhibiting the highest latency among the cities tested. Coverage maps highlighted potential network gaps, providing a visual representation of signal strength across routes. The dominance of D-NGN in this study aligns with the findings of El-Saleh et al. (2023), who reported a network speed range of 7.5 to 18Mbps, with a mean of 10Mbps, and a mean latency of 30ms. Similarly, our findings of D-NGN's low latency and high uptime are similar to Yadav et al. (2022) findings on LTE-4G networks, where static nodes exhibited delays of 10 to 30ms. The findings on latency metrics observed for D-NGN align with Kuboye (2021) whose assessment of QoS-Aware Proportional Fair scheduling, revealed throughput between 7 and 12Mbps and latency between 20 and 30ms.

Additionally, the high coverage and signal power metrics for D-NGN in our study are consistent with the results reported by Oje and Edeki (2021), where RSRP ranged from -80 to -65dBm. Moreover, the signal strength observed for D-NGN aligns with the RSSI values of -70 to -60dBm found by Imoize and Adegbite (2018). These correlations underscore the robustness of our findings while situating them within the broader context of network performance research across similar metrics.

5. 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, we obtained reliable metrics across KPIs. D-NGN emerged as the top performer, demonstrating superior network speed, latency, uptime, coverage, and signal power. A-NGN showed competitive performance, while B-NGN and C-NGN slightly lagged behind in certain metrics. Telecommunications providers in the North-Central region should prioritize investments in network infrastructure to enhance 4G/LTE performance, focusing on reducing latency and improving coverage in suburban and rural areas. These improvements could significantly enhance user experience, support broader connectivity, and align with emerging demands for high-quality mobile services in both urban and non-urban settings.

The methodology of this study prioritized generalized metrics over specific ones for several reasons. Firstly, generalized metrics provide a comprehensive overview of network performance, allowing for a holistic assessment that encompasses various aspects of service quality. This approach enables a more inclusive evaluation that considers the overall user experience, rather than focusing solely on isolated metrics. Additionally, generalized metrics are more accessible and interpretable, facilitating easier comparisons across different MNOs and enhancing the study's applicability and relevance. By emphasizing generalized metrics, the study aims to provide insights that reflect real-world user perceptions and experiences, contributing to more informed decision-making and policy development in the telecommunications sector.

Despite its insights, the study has limitations, such as the inability to capture real-time variations and the focus solely on 4G/LTE networks. The study offers valuable insights for stakeholders to enhance network quality and user satisfaction in North-Central Nigeria. Future research could address limitations and explore the interplay between different network technologies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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