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Empirical data analysis of the key performance indicators (download speed, upload speed and latency) of commercial 5G services in Nigeria

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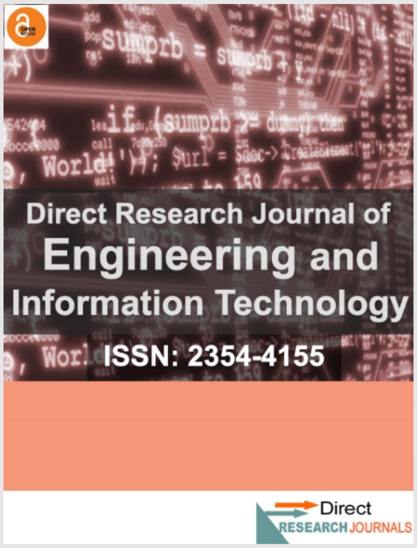
ABSTRACT

The advent of fifth-generation (5G) wireless networks has introduced transformative changes to mobile broadband technology, offering ultra-high data rates, significantly reduced latency, and enhanced network reliability. While 5G has been widely deployed across various regions globally, the practical performance of its commercial deployment often diverges from theoretical expectations due to infrastructural, environmental, and technological constraints. This study presents an empirical performance analysis of commercial 5G services deployed in Nigeria. Field measurements were conducted across three locations (Lagos, Benin and Port Harcourt) using the Ookla Speedtest application to collect key performance indicators (KPIs) such as download speed, upload speed, and latency from three major Mobile Network Operators (MNOs) designated as X, Y and Z. The results were compared to both 4G performance metrics and the International Telecommunication Union (ITU)-specified benchmarks of 20 Gbps download speed and 1 ms latency for ideal 5G networks. Findings reveal that 5G services in Nigeria demonstrate a notable improvement over 4G in terms of speed and latency. X 5G receive the average download speed of 660.65 Mbps in Port Harcourt and low latency of 14.59 ms in Lagos as the best performance among the MNOs. However, the measured download speeds and latency fall significantly short of ITU's ideal targets, with observed values being largely dependent on location. Performance limitations were attributed to infrastructural deficits such as insufficient base station density and the use of mid-band frequencies rather than mmWave bands. Additionally, the study underscores the disparities in service quality among different MNOs and highlights the impact of deployment strategies such as Non-Standalone (NSA) architecture, which relies on existing 4G infrastructure. This research contributes valuable insights into the current state of 5G deployment in Nigeria and provides evidence-based recommendations for optimizing network performance. The findings are crucial for stakeholders, including policymakers, network operators, and technology planners, seeking to enhance connectivity, bridge the digital divide, and support Nigeria's digital transformation through strategic investment in next-generation mobile infrastructure.

Keywords: *Speed, latency, Mobile network operators, Nigeria*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INTRODUCTION

The advent of fifth-generation (5G) wireless networks marks a transformative milestone in global telecommunications, promising unprecedented advancements in speed, capacity, and reliability. Introduced in 2016 as the successor to 4G, 5G offers a dynamic, heterogeneous multi-tier network architecture designed to accommodate a diverse array of applications, including enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC) (Adawudi et al., 2024; Ullah et al., 2019). Its commercial rollout commenced in 2019, enabling revolutionary applications such as autonomous vehicles, smart cities, drones, and remote healthcare systems (Nguyen, 2023; Narayanan et al., 2020). With theoretical benchmarks of up to 20 Gbps in download speeds and latency as low as 1 millisecond, 5G represents a paradigm shift in wireless communication technology (Shorna, 2021; Pang et al., 2023).

The technical foundation of 5G networks is built on high-frequency carrier bands, massive bandwidths, dense antenna arrays, and extensive deployment of base stations (Tekle et al., 2019; Rochman et al., 2024). These innovations address the growing demand for high-speed connectivity fueled by the proliferation of connected devices and data-intensive applications such as ultra-HD video streaming and augmented/virtual reality (VR/AR) (Qamar et al., 2019). Additionally, technologies such as millimeter-wave bands, Massive MIMO systems, high-order modulation techniques like QAM, and advanced network slicing enable 5G to deliver high system capacity while maintaining cost efficiency and flexibility (Justus Rischke et al., 2021; Sharma, 2013).

Despite its transformative potential, the deployment of 5G networks introduces significant challenges. While millimeter-wave frequencies promise extraordinary performance, their limited range and susceptibility to environmental obstructions necessitate dense infrastructure deployment (Clover, 2022; Gieske, 2024). To address these limitations, many mobile network operators prioritize sub-6 GHz bands for initial rollout due to their compatibility with existing LTE infrastructure and broader coverage capabilities. The two principal deployment models outlined by the 3rd Generation Partnership Project (3GPP)—Non-Standalone (NSA) and Standalone (SA) offer distinct approaches to network implementation. NSA leverages existing LTE infrastructure for cost-effective deployment, while SA builds an entirely new architecture to unlock the full capabilities of 5G (Belani et al., 2022).

Globally, empirical studies have highlighted discrepancies between theoretical capabilities and real-world performance of 5G networks. Signal attenuation, cell edge degradation, and infrastructure limitations often result in reduced speeds and variable latency in non-line-of-sight or congested environments (Narayanan et al., 2020; Polese et al., 2020). In technologically advanced regions such as North America, Europe, and parts of Asia, extensive research has been conducted to evaluate key performance indicators (KPIs) such as download speed, upload speed, latency, and reliability across diverse deployment scenarios. For instance, Narayanan et al. (2021) reported maximum download speeds of between 1.6 to 2.0 Gbps in U.S. urban environments, while Shayea et al. (2021) observed average speeds of approximately 512 Mbps in Malaysia. Similarly, Liu et al. (2025) demonstrated the suitability of standalone 5G for industrial applications in China with average download speeds exceeding 600 Mbps and latency as low as 11 milliseconds.

In contrast to these regions, empirical evaluations of 5G performance remain scarce in sub-Saharan Africa, particularly in Nigeria. Although Nigeria has made notable strides toward adopting 5G technology since the Nigerian Communications Commission (NCC) auctioned spectrum slots in the 3.5 GHz band in December 2021 (Akagu et al., 2022), the rollout remains limited to select urban areas. MTN Nigeria launched its 5G services in September 2022 across seven cities, followed by Airtel's deployment in June 2023 (Akintaro, 2024). However, challenges such as infrastructural inadequacies, unreliable power supply, spectrum allocation issues, and public misconceptions have hindered widespread adoption (Garba et al., 2022; Ndinojuo, 2020). Additionally, there is a conspicuous absence of large-scale empirical studies assessing the real-world performance of Nigeria's commercial 5G networks.

This research gap is particularly critical given Nigeria's unique socio-economic landscape. Factors such as high population density, uneven digital literacy levels, infrastructural constraints, and regulatory bottlenecks necessitate context-specific evaluations to inform strategic planning and policy development. Furthermore, understanding the scalability and reliability of 5G networks under Nigeria's environmental conditions is essential for bridging the digital divide and ensuring equitable access to next-generation connectivity.

This study aims to address this gap by critically analyzing the performance metrics of commercial 5G services deployed by major Mobile Network Operators (MNOs) in Nigeria. Using primary data collected through the Ookla Speedtest application across urban and semi-urban environments, the study evaluates KPIs such as download speed, upload speed, and latency for both indoor and outdoor scenarios. The results are benchmarked against ITU-specified standards and compared with existing performance data from Nigeria's legacy 4G networks. By identifying key performance-limiting factors and comparing these metrics with global benchmarks, this research seeks to provide actionable insights for optimizing infrastructure investments and guiding realistic policy frameworks.

The significance of this study extends beyond academic inquiry to practical applications for various stakeholders. For end users, the findings will clarify whether Nigeria's 5G services meet global standards and highlight factors affecting network performance within the local context. For policymakers and telecom operators, the study offers evidence-based recommendations to enhance deployment strategies and address infrastructural limitations. Ultimately, this research contributes to advancing Nigeria's digital transformation by fostering informed decision-making and promoting innovation in telecommunications infrastructure.

The global research underscores the transformative capabilities of 5G networks across diverse applications and industries, the lack of empirical studies focused on Nigeria limits our understanding of its operational realities in this region. By systematically evaluating the performance of commercial 5G deployments within Nigeria's unique socio-economic and infrastructural context, this study aims to fill a critical void in the literature and support the successful implementation of next-generation connectivity.

METHODOLOGY

Research Design

The research employs a comprehensive mixed-methods framework to assess the performance of commercial 5G services within Nigeria. This dual-faceted approach integrates both quantitative and qualitative methodologies to provide a holistic evaluation. The quantitative component focuses on empirical network performance measurements, analyzing metrics such as speed and latency to objectively quantify the service quality. Concurrently, the qualitative dimension delves into the perspectives of the Mobile Network Operators (MNOs). The three MNOs selected for this study and were coded X, Y, and Z.

Study Area

Purposive sampling was employed to select Lagos, Benin, and Port Harcourt as the focus cities for this study, based on their strategic significance in the context of 5G network deployment in Nigeria. These cities were chosen due to their established commercial 5G networks, economic diversity, geographic accessibility, and proximity, which collectively provide a robust foundation for examining the impact of 5G technology. Lagos was selected as it is Nigeria's commercial hub and hosts the headquarters of most Mobile Network Operators (MNOs). Port Harcourt was chosen for its status as a major commercial and oil-producing city, while Benin City was included due to its close proximity to the institution (Iginedion University, Okada). Advanced network performance measurement tools, namely nPerf and Ookla Speed Test, were utilized to identify specific locations within these urban centers where 5G networks are operational across multiple service providers. Figure 1 shows the Mobile Broadband of X Mobile Network Operator (MNO). The black colour represents no network type coverage, blue 2G, green 3G, orange 4G, coral LTE, and violet 5G. For this study, 4G and LTE are considered as the same network type, and the terms are used interchangeably.

Instrument/Tools

This study leverages advanced mobile devices, specifically the Samsung Galaxy A26 5G and Galaxy A05, as User Equipment (UE), to conduct a systematic evaluation of network performance metrics in Nigeria. The Samsung Galaxy A26 5G, identified as Model SM-A266B/DS, operates on Android 15 and incorporates Dual SIM functionality. Notably, it supports 5G connectivity across low-band, mid-band, and mmWave channels, making it a robust choice for assessing the capabilities of next-generation mobile networks. This device was configured as user equipment (UE) with SIM cards from Mobile Network Operators (MNOs) designated as X and Y, two leading telecommunications providers in Nigeria that have deployed 5G technology. On the other hand, the Samsung Galaxy A05, Model SM-A055F/DS, runs on Android 14 and also features Dual SIM capabilities. However, this device is limited to 4G connectivity and was paired with another MNO SIM card, designated as Z, which has yet to roll out 5G services. The data collection was carried out using a commercial Android application developed by BlueLine Labs, Inc. called Ookla SpeedTest, version 5.6.6, installed in two Samsung Galaxy handsets described above.

Measurement Campaign

A data measurement campaign was carried out in May 2025 across three major cities in Nigeria (Lagos, Benin, and Port Harcourt) to evaluate the performance of partially deployed 5G networks alongside existing 4G networks. Data were collected consistently in 3 days in each city. 5G and 4G Key Performance Indicators (KPI) were collected across X and Y MNOs using Samsung Galaxy A26 5G devices, while 4G KPI were collected for Z MNO using Samsung Galaxy A05. Both X and Y 5G utilize the n78 band, which operates at a frequency of 3.5 GHz within the mid-frequency spectrum, indicating a non-standalone (NSA) deployment mode for their 5G infrastructure. The Ookla Speed App installed in the Samsung Galaxy phones was used to measure the key performance Indicators (download speed, upload speed, and latency) of the network type. Before data collection began, prepaid Subscriber Identification Module (SIM) cards were loaded with various data packages. Preliminary testing revealed that the three Mobile Network Operators (MNOs) consumed data at different rates. During the testing period, approximately 580 GB of data was used on X, 360 GB on Y, and 180 GB on Z. To evaluate the key performance

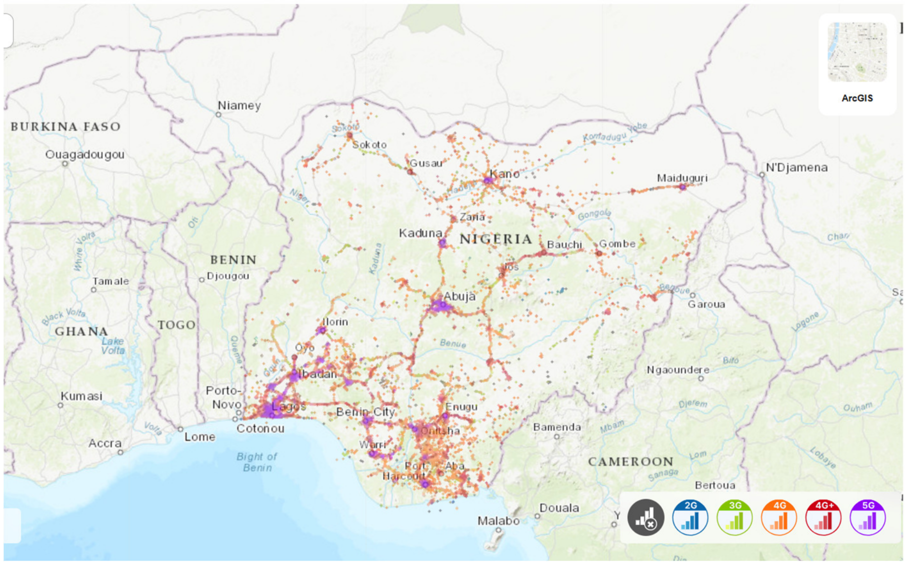
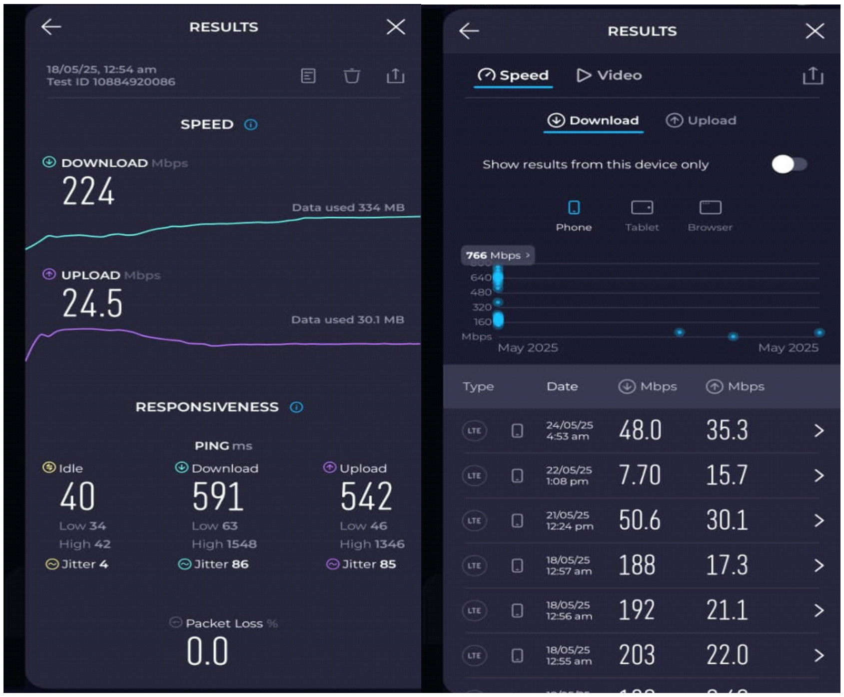


Figure 1. Nigeria map showing the Mobile Broadband of X Mobile Network Operator (Source: https://www.nperf.com/en/map/NG//3196.Airtel/signal?ll=7.580327791330154&lg=3.993580734854745&zoom=7).


RESULTS

18/05/25, 12:54 am
Test ID 10884920086

SPEED

DOWNLOAD Mbps
224
Data used 334 MB

UPLOAD Mbps
24.5
Data used 30.1 MB

RESPONSIVENESS

PING ms

Idle 40, Low 34, High 42, Jitter 4
Download 591, Low 63, High 1548, Jitter 86
Upload 542, Low 46, High 1346, Jitter 85

Packet Loss %
0.0

RESULTS

Speed | Video

Download | Upload

Show results from this device only

Phone | Tablet | Browser

Type	Date	↓ Mbps	↑ Mbps
LTE	24/05/25 4:53 am	48.0	35.3
LTE	22/05/25 1:08 pm	7.70	15.7
LTE	21/05/25 12:24 pm	50.6	30.1
LTE	18/05/25 12:57 am	188	17.3
LTE	18/05/25 12:56 am	192	21.1
LTE	18/05/25 12:55 am	203	22.0

Figure 2. Visual representations of the network performance data obtained from the Ookla Speedtest app.

indices (KPIs) of 5G networks, the Samsung Galaxy A26 5G smartphone was set on 5G as the preferred network mode. This device was utilized to collect empirical data on the performance of both X and Y 5G networks across various geographical locations. In parallel, the same device was reset to operate with 4G as the preferred network type in order to gather 4G performance data for X and Y under similar conditions. Additionally, a Samsung Galaxy A05 smartphone was employed specifically for collecting LTE (4G) performance data from Y. The data collection process involved the use of the Ookla Speedtest application, which provided detailed measurements of download speed, upload speed, and latency. Figure 2 presents the visual representations of the network performance data obtained from the Ookla Speedtest app. A large number of measurements were recorded at each

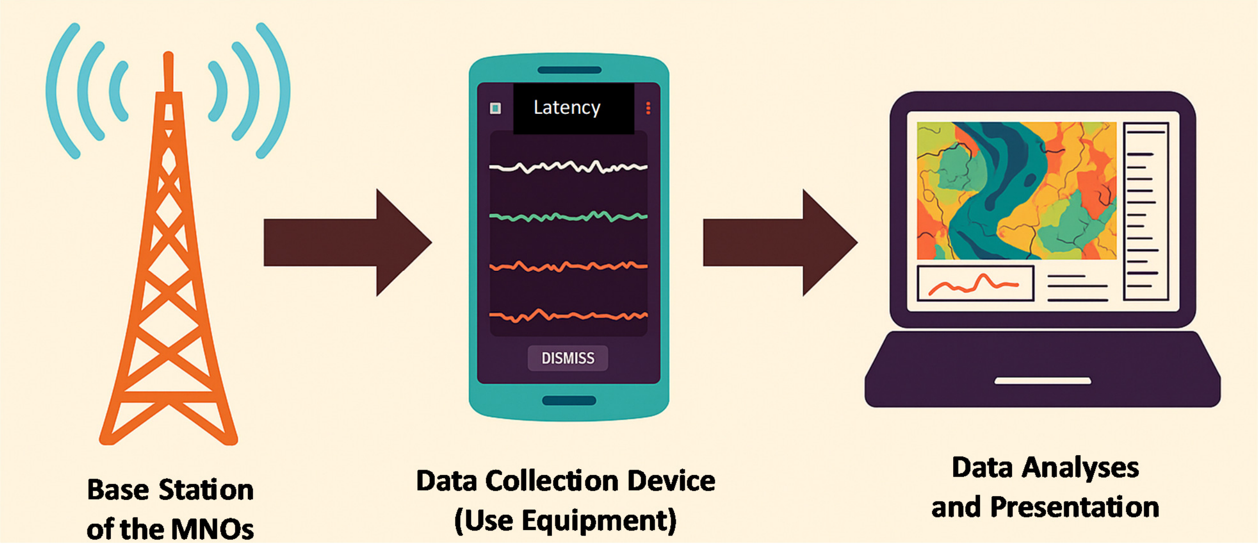


Figure 3. A general methodology for the data collection and analysis (adopted from El-Saleh et al., 2022 with some modification).

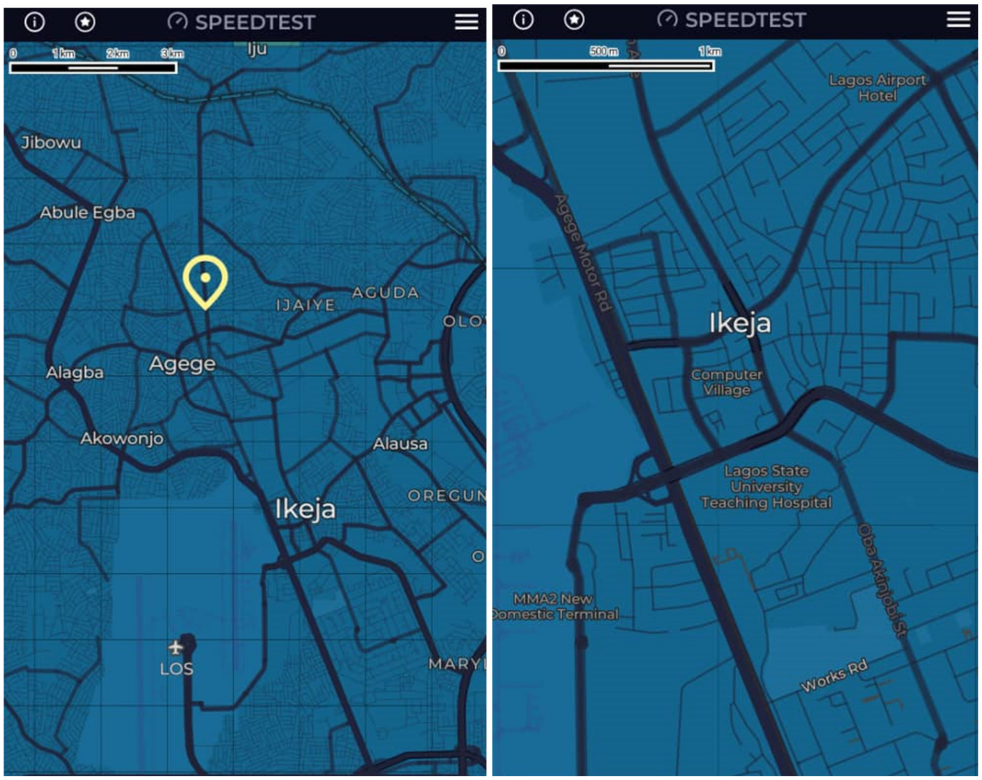


Figure 4. A locational map where data were collected in Lagos (Source: this study)

test location for both LTE and 5G mobile network operators (MNOs) to ensure the reliability and accuracy of the performance analysis. All collected data were systematically logged and stored in Microsoft Excel format to facilitate comprehensive analysis and interpretation. Figure 3 displays the general methodology of the data measurements and analysis. The smartphones collected the data measurements from base stations and then stored them in a log file. In each city, data were collected from a minimum of two locations for each network communication type, ensuring robust spatial representation.

In Lagos

The data collection in Lagos was carried out for three days across three distinct locations (Figure 4) to evaluate the performance of 5G and LTE across different MNOs. At the

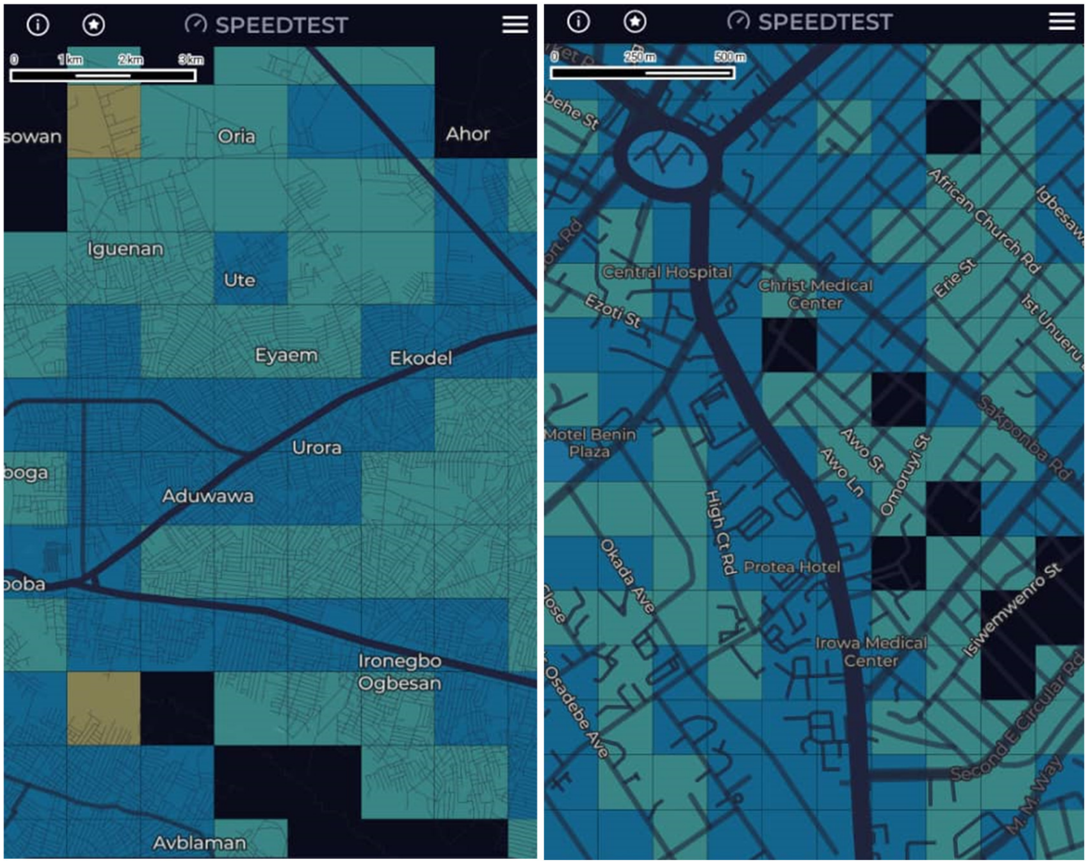


Figure 5. A locational map where data were collected in Benin (Source: this study).

Ogba/Agege Area, data collection focused on both indoor and outdoor environments for X 5G and LTE networks. However, for Y and Z, only LTE data were collected, as 5G services were not available for these operators at this location. At another location, opposite and within the Lagos State University Teaching Hospital in Ikeja, outdoor 5G data were gathered for both X and Y, while LTE data were collected for X, Y, and Z. In a separate location, specifically at Chicken Republic under the Ikeja Bridge, indoor data collection included 5G and LTE for X and Y, whereas only LTE data were collected for Z.

In Benin

In Benin, the research was conducted across two distinct locations (Figure 5) for 3 days to evaluate network performance under varying conditions. At Kada Plaza in Benin City, data collection focused on both indoor 5G and LTE networks for X, whereas only LTE data was gathered for Y and Z, as these providers do not currently support 5G networks in this area. At the second location, data collection took place in a residential building located around Aduwawa, Benin City. Here, both indoor and outdoor measurements were conducted for X 5G and LTE networks during the day to investigate potential variations in network performance based on temporal factors. Additionally, LTE data for Y and Z networks were similarly collected under both indoor and outdoor conditions to ensure consistency in comparative analysis.

In Port Harcourt

In Port Harcourt, data were collected for 3 days for 5G and LTE data for the three MNOs. Some of the locations are shown in (Figure 6). Around UNIPORT Choba Campus, outdoor data for Y 5G and LTE networks were collected; however, indoor data collection was not feasible due to the unavailability of 5G signals in most accessible offices. At another site near Rumokoro Motor Park, outdoor data for Y 5G and LTE networks were gathered. Also, data were collected for X 5G and LTE networks at Rumokoro Motor Park and Peace Mass Park (near Rumokoro Motor Park). Additionally, LTE data for the Z Network was collected in this area. However, every effort to collect indoor data in Port Harcourt proved abortive as 5G signals could not be detected in the places visited.

Data analysis

The data collected for LTE and 5G networks across various cities and locations were store in Microsoft Excell 2016 and analyse using a comprehensive approach

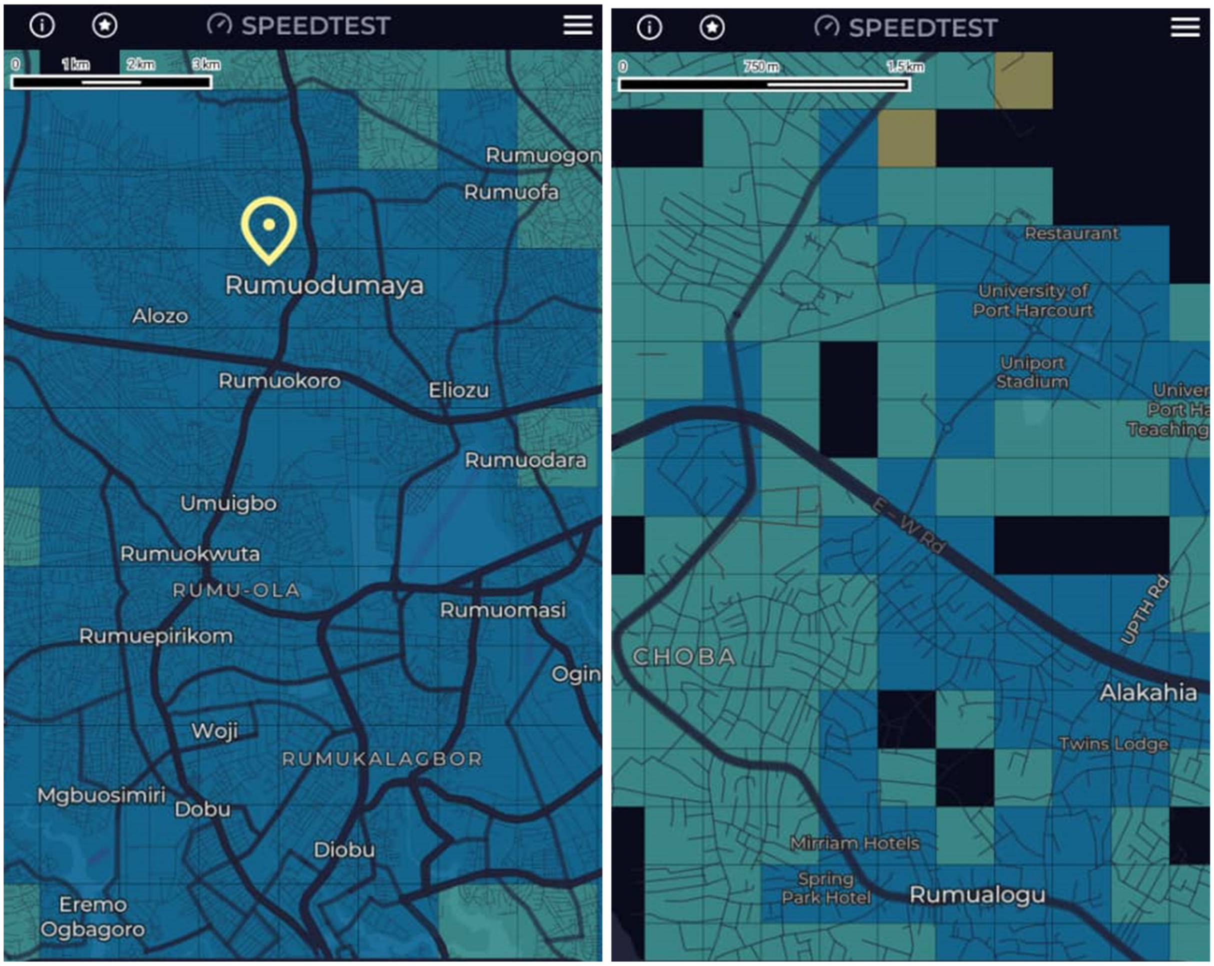


Figure 6. A locational map where the data were collected in Port Harcourt (Source: this study)

involving descriptive statistics, such as mean, median, quartile, and standard deviation. Visualization tools like box plots and bar charts were also used to identify outliers and correlations within the dataset.

RESULTS AND DISCUSSION

Download Speed (DL)

The results obtained in this study clearly demonstrate the superiority of 5G over 4G in terms of download speed (Table 1). For example, X 5G consistently recorded the highest mean download speeds in all three cities, peaking at approximately 660.65 Mbps in Port Harcourt and 642.17 Mbps in indoor Benin. Lagos outdoor values also remained strong at 513.93 Mbps, highlighting reliable performance even in challenging urban environments (Table 1; Figures 7A-E). Comparing the results with those reported in several global studies, Shayea et al. (2021) reported a mean download to be over 850 Mbps for 5G NR, while Narayanan et al. (2020) in the United States reported variable speeds depending on spectrum type and coverage area with a peak download speed exceeding 2 Gbps on mmWave 5G connections. Thus, the Nigerian X 5G deployment aligns favourably with global studies where they recorded higher download speed compared to 4G LTE.

In contrast, Y 5G presented much lower download speeds, particularly in Lagos, where its outdoor mean was only 109.84 Mbps and indoor 151.1 Mbps. Port Harcourt presented a better performance with an average of 369.49 Mbps, though still lower than X 5G (Table 1; Figures 7C). The wide variability within the Y 5G dataset, especially evident in its interquartile range of 297.55 Mbps in Port Harcourt, reflects instability or perhaps inconsistency in deployment maturity. These findings resonate with the year-long performance variability reported by Khan et al. (2025), who found that operator-specific infrastructure limitations significantly affect 5G download performance. Also, Narayanan et al. (2020) recorded a high level of variation in 5G performance.

For 4G networks, X 4G consistently outperformed Y 4G and Z 4G across all cities. In Benin outdoor tests, X 4G achieved a mean of 208.22 Mbps, significantly ahead of Y 4G at 21.5 Mbps and Z 4G at 17.7 Mbps. Similarly, in Port Harcourt, X 4G recorded 123.98 Mbps, Y 4G 63.46 Mbps,

Table 1. Download speed of results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin.

	Download Speed of MNOs (Mbps)				
Descriptive	**X 5G**	**Y 5G**	**X 4G**	**Y 4G**	**Z 4G**
Lagos Outdoor					
Mean	513.93	109.84	50.88	59.79	20.81
Std. Deviation	150.34	25.77	44.06	12.6	9.15
Minimum	268.52	84.42	4.81	26.6	5.39
Maximum	723.45	177.39	118.37	87.16	46.78
Quartile 1	377.16	91.03	8.13	52.1	14.12
Quartile 2	585.91	100.56	35.27	58.86	18.14
Quartile 3	648.42	127.49	91.46	68.35	24.51
Interquartile Range	271.27	36.46	83.33	16.25	10.39
Lagos Indoor					
Mean	448.59	151.1	86.03	39.29	5.73
Std. Deviation	174.36	40.21	67.85	28.64	2.44
Minimum	62.61	52.33	4.48	6.62	2.01
Maximum	787.92	214.27	256.66	82.01	14.39
Quartile 1	377.11	139.65	35.55	11.36	4.49
Quartile 2	419.55	154.9	72.51	49.9	5.26
Quartile 3	491.72	178.78	108.78	67.06	6.19
Interquartile Range	114.61	39.13	73.22	55.7	1.7
Port Harcourt Outdoor					
Mean	660.65	369.49	123.98	63.46	19.96
Std. Deviation	111.33	163.65	64.99	34.34	16.26
Minimum	387.9	101.26	17.82	2.42	1.31
Maximum	901.9	611.7	233.67	120.78	46.54
Quartile 1	595.38	217.15	63.88	30.14	5.44
Quartile 2	672.06	387.16	102.66	67.18	11.18
Quartile 3	738.9	514.7	186.45	92.04	36.72
Interquartile Range	143.52	297.55	122.57	61.9	31.28
Benin Outdoor					
Mean	630.19	-	208.22	21.5	17.7
Std. Deviation	178.92	-	41.31	13.27	6.91
Minimum	287.9	-	90.18	1.61	6.26
Maximum	835.99	-	258.3	43.18	40.15
Quartile 1	535.19	-	190.75	10.84	13.68
Quartile 2	709.92	-	220.29	22.67	16.7
Quartile 3	768.98	-	231.34	32.06	20.17
Interquartile Range	233.79	-	40.59	21.22	6.48
Benin Indoor					
Mean	642.17	-	162.27	49.8	34.85
Std. Deviation	123.29	-	28.59	39.22	20.22
Minimum	182.49	-	100.59	0.49	6.12
Maximum	773.42	-	223.52	111.82	84.5
Quartile 1	627.86	-	143.4	16.74	15.19
Quartile 2	670.3	-	162.34	28.97	37.49
Quartile 3	709.35	-	177.5	87.18	51.9
Interquartile Range	81.49	-	34.1	70.44	36.71

and Z 4G 19.96 Mbps. This spread highlights clear disparities in network quality. These findings are consistent with the results by Rochman et al. (2023), who observed 4G download speeds ranging from 20–140 Mbps in urban environments across the U.S. and Latin America. The particularly high X 4G indoor speed in Lagos (86.03 Mbps) can also be attributed to instances of extreme outliers such as 256.66 Mbps, which skewed the average. Indoor and outdoor environment comparisons revealed noticeable performance variation, especially among lower-tier operators. For example, Z 4G performed significantly worse indoors in Lagos with a mean of 5.73 Mbps, compared to 20.81 Mbps outdoors (Table 1; Figures 7A-B). Such drastic reductions in indoor environments underscore the need for enhanced indoor coverage solutions, as also emphasized by Singh et al. (2024), who noted that attenuation and signal degradation inside buildings often affect Sub-6 GHz 5G and more severe in millimeter wave technologies. X 5G, however, displayed a different trend: indoor performance sometimes matched or exceeded outdoor results. For example, in Benin, X 5G achieved an indoor average of 642.17 Mbps versus

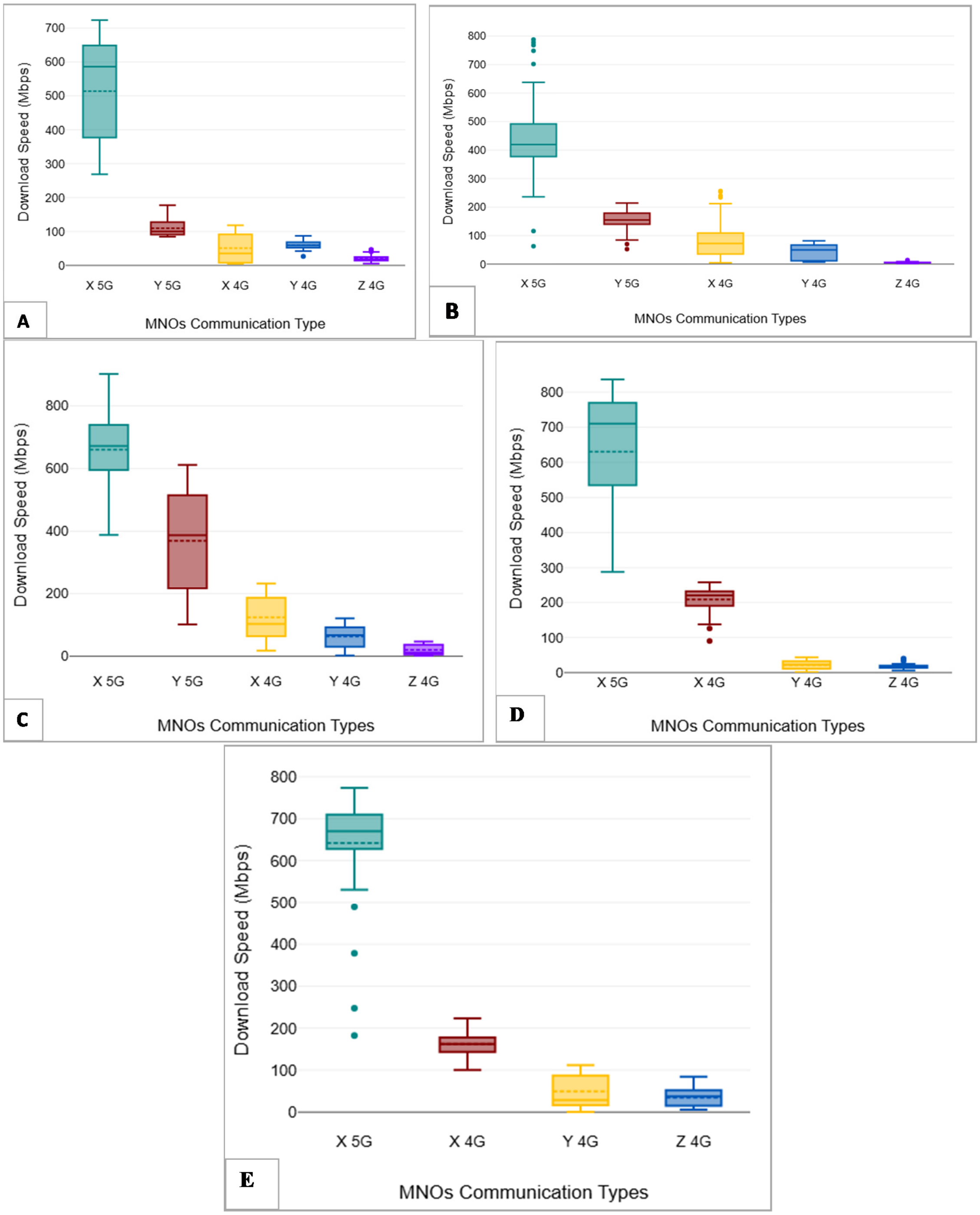


Figure 7. Boxplot showing the download speed results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin: (**A**) Lagos Outdoor; (**B**) Lagos Indoor (**C**) Port Harcourt Outdoor, (**D**) Benin Outdoor, and (**E**). Indoor Benin.

630.19 Mbps outdoors (Table 1; Figures 7D & E), although the outdoor performance still recorded a higher maximum value of 835.99 Mbps against 773.42 Mbps for indoor performance. This suggests robust indoor penetration, likely due to better network design or infrastructure (Maldonado et al., 2021). Outliers were prevalent across datasets and provide insight into service reliability. These inconsistencies indicate volatile user experiences, particularly among lower-performing operators (Table 1; Figure 7A). Xu et al. (2020) and Lashgari et al. (2021) have similarly highlighted that early-stage or partially congested 5G networks tend to suffer from performance jitter and inconsistency due to backhaul limitations or site-specific issues.

Table 2. Upload speed results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin.

Descriptive	**Upload Speed of MNOs (Mbps)**				
	X 5G	**Y 5G**	**X 4G**	**Y 4G**	**Z 4G**
Lagos Outdoor					
Mean	76.94	24.04	68.93	31.8	20.34
Std. Deviation	34.91	11.56	50.97	11.57	3.84
Minimum	30.92	14.82	12.79	16.3	4.03
Maximum	129.75	55.06	123.72	51.42	26.65
Quartile 1	44.77	17.8	17.76	21.66	17.78
Quartile 2	60.71	19.4	67.67	27.19	20.28
Quartile 3	110.93	23.92	119.26	42.02	23.52
Interquartile Range	66.17	6.11	101.5	20.36	5.73
Lagos Indoor					
Mean	45.75	8.26	17.97	16.47	10.00
Std. Deviation	29.26	5.31	8.52	4.76	7.90
Minimum	2.71	1.22	4.84	10.18	0.02
Maximum	81.19	21.46	35.24	33	23.66
Quartile 1	15.98	3.56	10.7	13.27	0.16
Quartile 2	41.29	8.2	15.48	15.67	12.88
Quartile 3	75.42	11.07	25.24	18.18	15.78
Interquartile Range	59.43	7.51	14.54	4.9	15.62
Port Harcourt Outdoor					
Mean	56.34	47.63	15.93	26.81	25.33
Std. Deviation	25.4	19.07	8.75	15.28	9.4
Minimum	0.78	8.14	0.21	6.5	10.83
Maximum	105.7	80.22	39.15	53.49	46.64
Quartile 1	38.55	31.17	10.16	13.74	18.3
Quartile 2	51.78	45.67	14.95	21.94	23.95
Quartile 3	77.48	65.08	22.25	42.91	31.38
Interquartile Range	38.93	33.91	12.09	29.17	13.08
Benin Outdoor					
Mean	99.46	-	53.43	4.09	23.31
Std. Deviation	28.87	-	4.49	3.35	3.15
Minimum	41.26	-	40.74	0.03	19.41
Maximum	147.59	-	59.42	11.93	32.22
Quartile 1	78.62	-	51.7	0.55	20.67
Quartile 2	100.83	-	53.72	4.11	23.1
Quartile 3	121.66	-	57.03	6.45	24.47
Interquartile Range	43.03	-	5.33	5.9	3.8
Benin Indoor					
Mean	38.38	-	21.23	11.32	21.71
Std. Deviation	20.01	-	10.77	8.36	5.28
Minimum	2.38	-	3.20	0.15	14.58
Maximum	82.46	-	54.98	27.31	39.74
Quartile 1	23.74	-	14.61	3.2	18.82
Quartile 2	32.05	-	21.14	10.9	21.3
Quartile 3	54.8	-	24.74	19.23	23.4
Interquartile Range	31.06	-	10.14	16.03	4.58

Another interesting aspect is that despite being a developing market, Nigeria's best-performing 5G network (X 5G) matched performance in more advanced economies. In comparison, studies like that of Pang et al. (2023) recorded 250–700 Mbps in Malaysian Sub-6 GHz trials, and El-Saleh et al. (2022) found averages closer to 300 Mbps in Middle Eastern testbeds. Furthermore, the variability between X 5G and Y 5G in Nigeria mirrors the findings of Zreikat and Mathew (2024), who highlighted inconsistent performance between urban and suburban deployments and among different operators in urban regions, which is directly influenced by base station density, antenna configuration, and local terrain, as suburban areas lacked the dense small-cell infrastructure necessary to consistently support high-throughput, low-latency 5G services. However, variations in the number of active 5G users across Nigeria and other countries contribute to disparities in network performance, often leading to competitive advantages in certain locations. According to Yuan *et al*. (2022), standalone (SA) 5G architecture significantly outperforms 4G across multiple key performance indicators (KPIs). However, they also

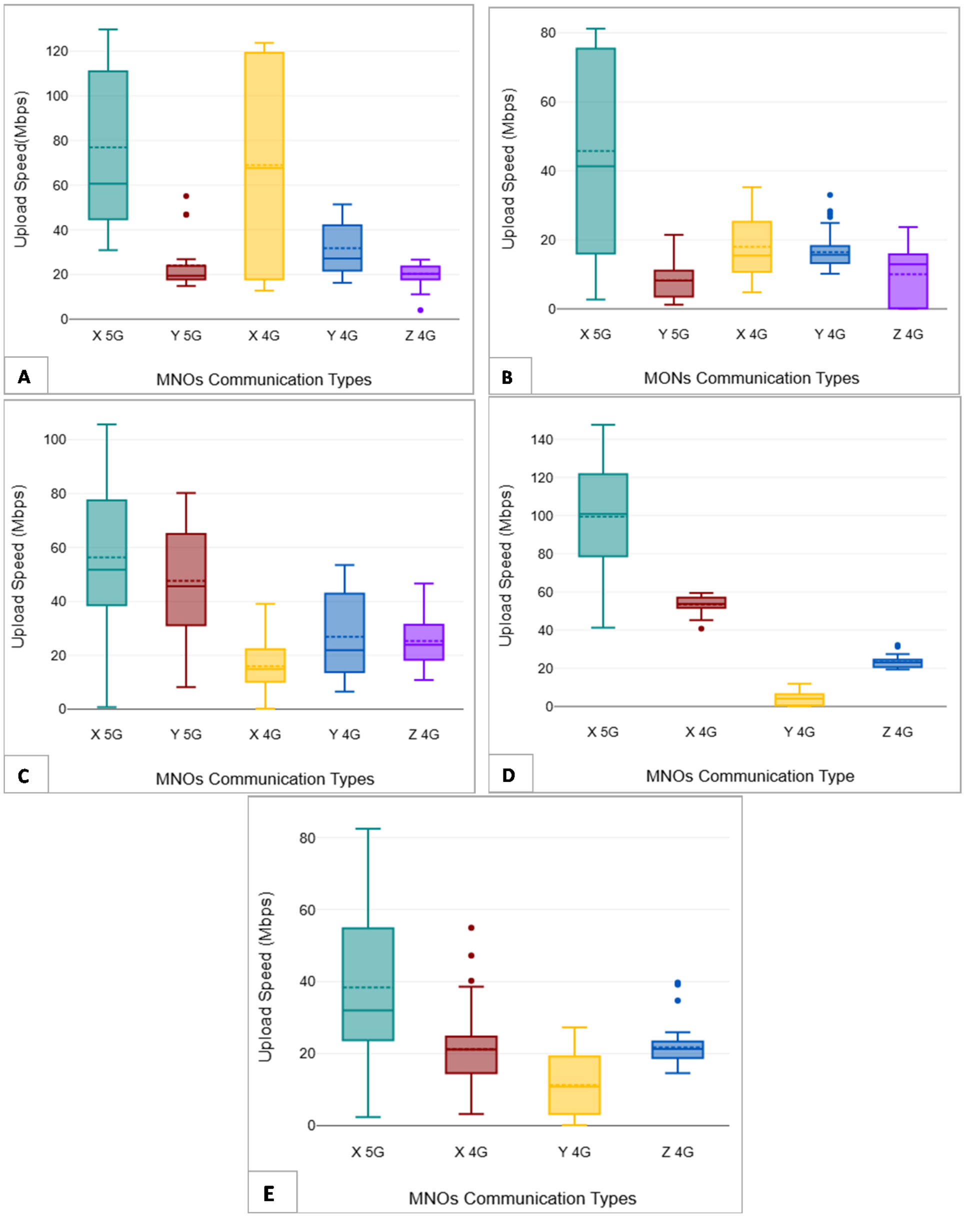


Figure 8. Boxplot showing the upload speed results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin: (**A**) Lagos Outdoor; (**B**) Lagos Indoor (**C**) Port Harcourt Outdoor, (**D**) Benin Outdoor, and (**E**). Indoor Benin.

observed that increased user density on the 5G network can result in a degradation of download throughput due to heightened network load and resource contention.

Overall, the Nigerian data obtained in this study, when 5G is deployed with sufficient resources and technical capacity, as in the case of X 5G, offers significantly improved download speeds that compete favourably with many international benchmarks. Second, substantial disparities exist between operators and environments, with some 5G and 4G networks showing degraded or highly variable performance. These findings reinforce those reported by Narayanan et al. (2020), Shayea et al. (2021), Khan et al. (2025), and Rochman et al. (2023), and they highlight the urgent need for equitable infrastructure development to ensure consistent user experience across regions and technologies.

Upload Speed (UL)

The empirical analysis of upload speed across three major Nigerian cities (Lagos, Port Harcourt, and Benin) reveals significant variability among mobile network operators (MNOs) and communication technologies (4G and 5G), as detailed in Table 2 and Figures 8A–E. Overall, 5G networks, particularly those of operator X, demonstrated superior upload performance compared to 4G, although performance varied notably by location and testing conditions (indoor vs. outdoor).

In Lagos, outdoor measurements showed that X 5G offered the highest upload performance, with a mean of 76.94 Mbps, a maximum of 129.75 Mbps, and a third quartile (Q3) of 110.93 Mbps (Table 2, Figure 8A). This performance substantially surpasses Y 5G, which recorded a mean upload speed of 24.04 Mbps and a Q3 of 23.92 Mbps. The large gap between X 5G and Y 5G confirms a disparity in 5G infrastructure maturity and spectrum utilization. In comparison, X 4G performed exceptionally well for a 4G network, with a mean upload speed of 68.93 Mbps, a Q3 of 119.26 Mbps, and a maximum value of 123.72 Mbps, challenging some 5G offerings in performance. This anomaly suggests that X 4G possibly operates in high-capacity LTE-Advanced Pro mode or within spectrum bands usually reserved for 5G. Meanwhile, Y 4G and Z 4G lagged significantly behind with means of 31.8 Mbps and 20.34 Mbps, respectively.

The indoor performance in Lagos reflected a sharp drop across all technologies due to attenuation and structural interference. X 5G showed a decrease in mean upload speed to 45.75 Mbps, a reduction of over 40% compared to its outdoor value, though it still outperformed all other technologies (Figure 8B). Y 5G recorded a drastically low indoor mean of 8.26 Mbps, confirming its vulnerability to indoor signal degradation. Similar observations were made in Singh et al. (2024), where 5G NR uplink throughput inside buildings was found to be 30–50% lower due to indoor coverage limitations. Among the 4G networks, X 4G delivered a moderate 17.97 Mbps, while Y 4G and Z 4G returned 16.47 Mbps and 10.00 Mbps, respectively, all exhibiting lower variability than 5G. The limited outliers in these 4G results suggest that the performance, while modest, was consistent.

In Port Harcourt, the outdoor performance showed improved results for both X 5G and Y 5G compared to Lagos indoor values. X 5G recorded a mean upload speed of 56.34 Mbps, while Y 5G followed with 47.63 Mbps (Table 2, Figure 8C). The interquartile ranges of 38.93 Mbps and 33.91 Mbps, respectively, indicate moderately wide data distributions, likely due to variations in signal reception and interference in the urban environment. Despite this, these values align with those observed in Xu et al. (2020) and Khan et al. (2025), where average 5G uplink performance across urban deployments ranged between 50 and 80 Mbps. Among 4G operators in Port Harcourt, X 4G had the lowest mean of 15.93 Mbps, while Y 4G and Z 4G delivered relatively higher performance at 26.81 Mbps and 25.33 Mbps, respectively. Notably, Z 4G recorded a Q3 of 31.38 Mbps, higher than that of X 4G, suggesting improved efficiency or upgraded LTE-A configurations.

In Benin, X 5G dominated outdoor upload speed with a remarkably high mean of 99.46 Mbps, and a Q3 of 121.66 Mbps (Table 2, Figure 8D). This performance level surpasses typical urban 5G reported in Shayea et al. (2021) and Belguidoum et al. (2025), who found mean uplink speeds rarely exceeding 85 Mbps in similar environments. The absence of extreme outliers in X 5G's Benin dataset further emphasizes its consistency and robust performance. Surprisingly, X 4G also performed well in Benin, with a mean of 53.43 Mbps, potentially reflecting localized network enhancements or carrier aggregation features. However, Y 4G severely underperformed, with a mean of 4.09 Mbps and multiple outliers below 1 Mbps, indicating congestion or poor backhaul as issues highlighted by Narayanan et al. (2020) in under-resourced 4G deployments. Z 4G, by contrast, exhibited a stable and respectable mean of 23.31 Mbps.

The indoor upload speed results in Benin were similarly telling. X 5G posted a moderate indoor mean of 38.38 Mbps, with Q1 and Q3 values of 23.74 Mbps and 54.80 Mbps, respectively (Table 2, Figure 8E). The distribution included several lower-end outliers, such as 2.38 Mbps, pointing to the typical challenge of maintaining high 5G uplink speeds indoors. X 4G showed relatively good indoor performance with a mean of 21.23 Mbps, while Y 4G lagged again with 11.32 Mbps, including outliers as low as 0.15 Mbps. Z 4G, however, maintained a consistent performance, delivering a mean upload speed of 21.71 Mbps, comparable to X 4G and clearly superior to Y 4G.

These results mirror the broader findings of Rischke et al. (2021), El-Saleh et al. (2022), and Rochman et al. (2023), all of whom highlighted the dominant performance of 5G over 4G, especially in terms of upload throughput. However, this study adds critical granularity by exposing disparities not just between 4G and 5G but between operators within the same generation. The variation in 5G performance, where X 5G consistently outperformed Y 5G, supports the assertions by Lashgari et al. (2021) and Cantero et al. (2023) that infrastructure maturity, spectrum bandwidth, and deployment strategy are key determinants of real-world performance.

The study reinforces the superiority of 5G in upload speed performance across diverse urban settings in Nigeria. However, it also uncovers significant intra-generational inconsistencies, particularly in the 4G domain, where performance often fell below international standards. These disparities underline the importance of robust and standardized infrastructure deployment, especially in expanding urban areas. Furthermore, the sharp decline in indoor performance across all technologies calls for increased investment in indoor signal boosters, standalone 5G architectures, and small-cell deployments, as proposed by Mohamed et al. (2021a) and Singh et al. (2024), to ensure seamless user experience in next-generation mobile broadband networks.

Latency (L)

Results from latency measurements (Table 3 and Figures 9A-E) across Lagos, Port Harcourt, and Benin City reveal operator-specific and location-specific nuances, providing valuable insights into Nigerian commercial deployments. In Lagos outdoor environments, X 5G demonstrated superior performance with a mean latency of 14.59 ms and

Table 3. Latency results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin.

Descriptive	Latency of MNOs (ms)				
	X 5G	**Y 5G**	**X 4G**	**Y 4G**	**Z 4G**
Lagos Outdoor					
Mean	14.59	22.45	17.6	18.25	17.43
Std. Deviation	2.6	6.55	2.92	1.87	3.47
Minimum	11	11	14	16	13
Maximum	23	34	24	25	30
Quartile 1	13	19	15	17	15
Quartile 2	14	21	16	18	16
Quartile 3	16	26	19	19	19
Interquartile Range	3	7	4	2	4
Lagos Indoor					
Mean	20.61	66.13	21.88	42.18	24.57
Std. Deviation	8.94	9.24	8.54	22.44	9.96
Minimum	13	46	14	16	16
Maximum	39	91	43	75	52
Quartile 1	15	59	16	19	17
Quartile 2	17	67	18	32	19
Quartile 3	19	71	26	64	34
Interquartile Range	4	11.5	10	45	17
Port Harcourt Outdoor					
Mean	24.86	32.21	33.17	32.66	31
Std. Deviation	2.24	5.96	3.77	5.47	5.17
Minimum	22	22	27	27	25
Maximum	34	50	44	55	45
Quartile 1	24	29	30	29	27
Quartile 2	24	31	33	31	29
Quartile 3	25	35	35	35	33
Interquartile Range	1	6	5	6	6
Benin City Outdoor					
Mean	30.24	-	30.46	32.92	23.62
Std. Deviation	2.19	-	3.84	9.81	6.19
Minimum	27	-	28	20	16
Maximum	35	-	42	68	37
Quartile 1	28	-	28	27	19
Quartile 2	30	-	29	32	21
Quartile 3	31	-	30	35	29
Interquartile Range	3	-	2	8	10
Benin City Indoor					
Mean	33.02	-	36.18	36.76	27.62
Std. Deviation	2.87	-	3.54	7.64	7.04
Minimum	25	-	30	22	18
Maximum	42	-	45	60	39
Quartile 1	32	-	33	34	20
Quartile 2	32	-	38	36	28
Quartile 3	34	-	38	39	32
Interquartile Range	2	-	5	5	12

minimal variability (IQR = 3 ms), indicating a stable network optimized for low-latency communication. Y 5G exhibited higher latency (mean: 22.45 ms), with variability and outliers exceeding 30 ms, reflecting inconsistent performance. Comparatively, X 4G and Z 4G performed better than Y 4G, with mean latencies of 17.6 ms and 17.43 ms, respectively. These findings align with global benchmarks by Narayanan et al. (2020) and Fezeu et al. (2023), which report commercial 5G latency ranging from 15 ms to 30 ms in North American deployments.

Indoor latency in Lagos showed significant degradation across all operators and technologies. X 5G latency increased to 20.61 ms indoors, while Y 5G surged to 66.13 ms with extreme outliers (91 ms), likely due to poor signal propagation or suboptimal handover mechanisms (Table 3 and Figures 9B). Similar indoor performance challenges were noted by Singh et al. (2024) and Mohamed et al. (2021a), emphasizing the importance of small-cell deployments and distributed antenna systems for mitigating latency issues in sub-6 GHz and mmWave bands.

Port Harcourt outdoor latency values were universally higher than Lagos. X 5G recorded a mean latency of 24.86 ms, followed by Y 5G at 32.21 ms (Table 3 and Figure 9C). The higher latency observed aligns with findings by Khan et al. (2025) and Soós et al. (2020), who reported elevated

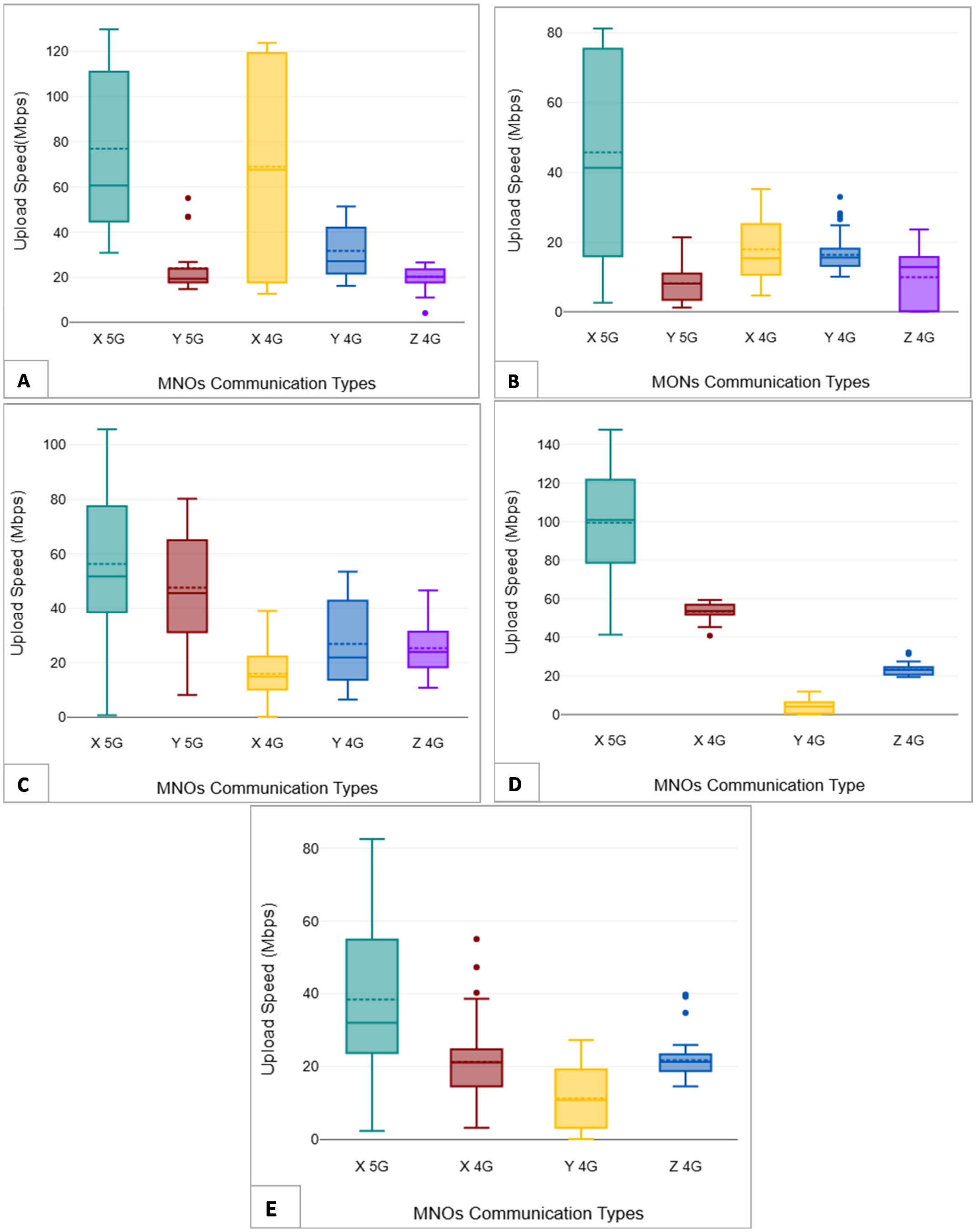


Figure 8. Boxplot showing the upload speed results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin: (**A)** Lagos Outdoor; (**B)** Lagos Indoor (**C)** Port Harcourt Outdoor, (**D)** Benin Outdoor, and (**E).** Indoor Benin.

latency in under-provisioned or early-stage deployments. Despite this, X 5G maintained relative stability with fewer outliers compared to other operators. In Benin City, outdoor X 5G latency reached 30.24 ms, higher than Lagos and Port Harcourt but stable (IQR = 3 ms). Surprisingly, Z 4G posted lower latency (23.62 ms) compared to Y 4G (32.92 ms), reflecting potential bottlenecks in network infrastructure or interference zones (Table 3 and Figure 9D). Similar anomalies were reported by Shayea et al. (2021) in Malaysian urban deployments, where LTE occasionally outperformed early-stage 5G under optimized conditions. Indoor latency in Benin City further underscored variability; X 5G recorded a mean latency of 33.02 ms, consistent with outdoor values, while Y 4G and X 4G posted latencies of 36.76 ms and 36.18 ms, respectively. Z 4G exhibited instability with a wider spread (IQR = 12 ms) and outliers reaching up to 60 ms (Table 3 and Figure 9E), echoing observations by Coll-Perales et al. (2022) and Milovanovic & Bojkovic (2023) on deployment density impacts.

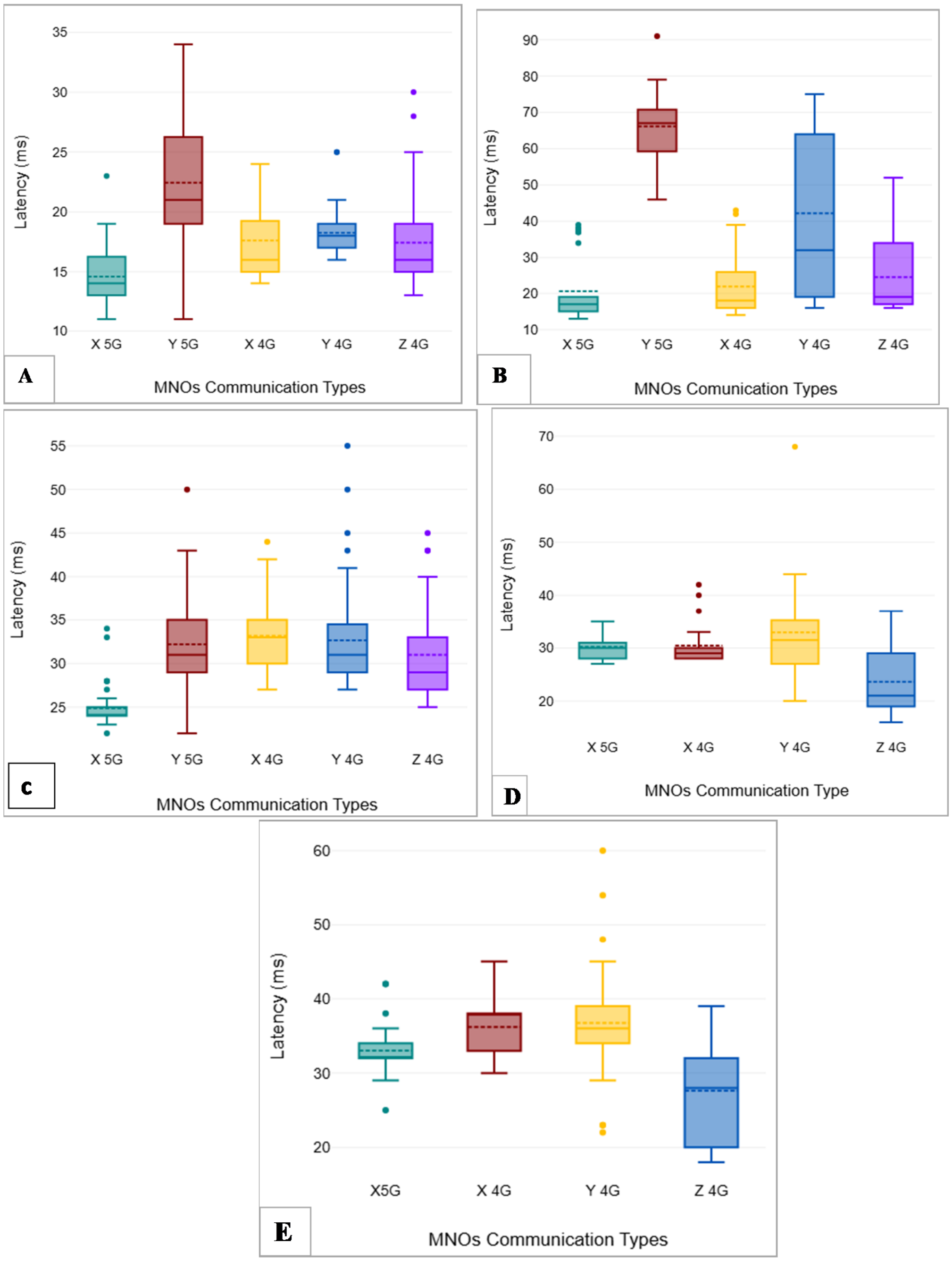


Figure 9. Boxplot showing the latency results of 4G and 5G MNOs in Lagos, Port Harcourt and Benin: **(A)** Lagos Outdoor, **(B)** Lagos Indoor, **(C)** Port Harcourt Outdoor, **(D)** Benin Outdoor, and **(E)** Benin Indoor.

Across all cities, outdoor environments generally favored lower latency for 5G networks, particularly X 5G, which achieved a best-case performance of 14.59 ms in Lagos, aligning with benchmarks from Rochman et al. (2023) and Ding et al. (2021). Indoor environments consistently exhibited higher latency, especially for Y 5G in Lagos (mean: 66.13 ms), supporting Lashgari et al.'s (2021) assertion that Ultra-Reliable Low-Latency Communication (URLLC) remains aspirational without dense infrastructure and network slicing.These findings highlight the need for continued investment in small-cell deployments, spectrum harmonization, and optimization strategies to fully realize the low-latency potential of 5G networks in Nigeria and other emerging markets.

Achieving uniform performance will require technological upgrades alongside strategic deployment planning, as emphasized by El-Saleh et al. (2022), Xu et al. (2020), and Larrabeiti et al. (2023).

Table 4. Summary results of the of download speed, upload speed, and latency of 4G and 5G MNOs in Lagos, Port Harcourt and Benin.

Cities		Download Speed (Mbps)				Upload Speed (Mbps)				Latency (ms)			
	MNOs	**Mean**	**SD**	**Q2**	**IQR**	**Mean**	**SD**	**Q2**	**IQR**	**Mean**	**SD**	**Q2**	**IQR**
Lagos	X 5G	513.93	150.34	585.91	271.27	76.94	34.91	60.71	66.17	14.59	2.6	14	3
	Y 5G	109.84	25.77	100.56	36.46	24.04	11.56	19.4	6.11	22.45	6.55	21	7
	X 4G	50.88	44.06	35.27	83.33	68.93	50.97	67.67	101.5	17.6	2.92	16	4
	Y 4G	59.79	12.6	58.86	16.25	31.8	11.57	27.19	20.36	18.25	1.87	18	2
	Z 4G	20.81	9.15	18.14	10.39	20.34	3.84	20.28	5.73	17.43	3.47	16	4
Port Harcourt	X 5G	660.65	111.33	672.06	143.52	56.34	25.4	51.78	38.93	24.86	2.24	24	1
	Y 5G	369.49	163.65	387.16	297.55	47.63	19.07	45.67	33.91	32.21	5.96	31	6
	X 4G	123.98	64.99	102.66	122.57	15.93	8.75	14.95	12.09	33.17	3.77	33	5
	Y 4G	63.46	34.34	67.18	61.9	26.81	15.28	21.94	29.17	32.66	5.47	31	6
	Z 4G	19.96	16.26	11.18	31.28	25.33	9.4	23.95	13.08	31.00	5.17	29	6
Benin	X 5G	630.19	178.92	709.92	233.79	99.46	28.87	100.83	43.03	30.24	2.19	30	3
	X 4G	208.22	41.31	220.29	40.59	53.43	4.49	53.72	5.33	30.46	3.84	29	2
	Y 4G	21.5	13.27	22.67	21.22	4.09	3.35	4.11	5.9	32.92	9.81	32	8
	Z 4G	17.7	6.91	16.7	6.48	23.31	3.15	23.1	3.8	23.62	6.19	21	10

Evaluating 5G Performance in Nigeria: Current Achievements and Challenges

The deployment of 5G networks in Nigeria marks a significant milestone in the country's telecommunications evolution, offering notable advancements over legacy 4G systems. However, a detailed analysis reveals that while progress has been made, the current state of 5G in Nigeria remains far from achieving the ideal benchmarks outlined by global standards such as the International Telecommunication Union's (ITU) IMT-2020 framework (Mohyeldin, 2016).

The performance evaluation of commercial 5G in Nigeria, as illustrated in Table 4 and Figure 4, demonstrates clear improvements in key performance indicators (KPIs) such as download speed, upload speed, and latency. Download speeds for 5G networks significantly outperformed those of 4G across all tested locations. For example, X 5G in Port Harcourt achieved the highest average download speed of 660.65 Mbps, followed closely by Benin at 630.19 Mbps and Lagos at 513.93 Mbps. Even Y 5G, with lower throughput compared to X 5G, demonstrated substantial performance gains, particularly in Port Harcourt with 369.49 Mbps. These findings align with global observations by Mohamed et al. (2021b), Narayanan et al. (2020), and Rochman et al. (2023), who reported higher throughput capacities for 5G networks relative to their 4G counterparts.

Upload speeds also showcased 5G's superiority, with X 5G in Benin recording the highest value at 99.46 Mbps, followed by Lagos and Port Harcourt at 76.94 Mbps and 56.34 Mbps, respectively. These gains are consistent with findings by Khan et al. (2025), which highlight uplink performance improvements during early 5G deployments. However, latency improvements remain modest, with X 5G in Lagos achieving the lowest latency at 14.59 ms, still far above the 1 ms thresholds required for ultra-reliable applications such as autonomous driving or remote surgery (Lashgari et al., 2021; Fezeu et al., 2023). This mirrors global trends observed in non-standalone (NSA) architectures, where latency reductions are often constrained by reliance on existing 4G infrastructure.

Despite these achievements, optimized 4G deployments occasionally rival or surpass certain 5G configurations under specific conditions. For instance, X 4G in Benin recorded an average download speed of 208.22 Mbps, which exceeded Y 5G's performance in Lagos at 109.84 Mbps. This observation corroborates findings by Rochman et al. (2023), who noted that high-performance mid-band 4G networks can deliver throughput comparable to underperforming 5G setups, particularly when deployment challenges or environmental factors hinder the latter.

While Nigeria's 5G networks have demonstrated progress, they remain significantly below the ideal targets set by the ITU's IMT-2020 standard (Mohyeldin, 2016). The highest average download speed recorded (660.65 Mbps), is only about 3.3% of the peak target of 20 Gbps envisioned for 5G networks globally. Similarly, latency figures, even at their best (14.59 ms in Lagos), are far above the ultra-low latency benchmark of 1 ms required for next-generation applications.

Several factors contribute to these gaps. Limited spectrum availability, primarily in the Sub-6GHz band rather than the faster mmWave frequencies, restricts achievable throughput. Additionally, incomplete fiber backhaul infrastructure and sparse deployment of small cells further limit network capacity and coverage, echoing observations by Rochman et al. (2024) and Yuan et al. (2022). The reliance on NSA architecture compounds these issues, as it inherently lacks the full capabilities of standalone (SA) deployments that leverage dedicated 5G cores.

Performance variability is another critical concern. High interquartile ranges (IQRs) in download speeds, for instance, 297.55 Mbps for Y 5G in Port Harcourt (Table 4), highlight inconsistent user experiences across time and

Figure 10. Bar chart showing the summary results of download speed, upload speed, and latency of 4G and 5G MNOs in Lagos, Port Harcourt and Benin.

locations. This variability contrasts sharply with the more stable performance of mature 4G networks (Fernández-Berrueta et al., 2023; Narayanan et al., 2020). Moreover, low user density on Nigeria's nascent 5G networks may temporarily inflate performance metrics, giving a misleading impression of network capacity. As more Nigerians adopt 5G-compatible devices and user density increases, congestion could degrade both speed and latency unless infrastructure scales accordingly, a trend projected by Yuan et al. (2022). Environmental factors further exacerbate performance limitations. Indoor testing in Port Harcourt revealed difficulties in maintaining consistent 5G connectivity due to obstructions such as walls or glass, a phenomenon widely documented by Rochman et al. (2024) and Yuan et al. (2022). These findings underscore the need for network densification through expanded small-cell deployments and standalone architectures to mitigate signal attenuation and enhance coverage reliability. Additionally, device compatibility remains a bottleneck for widespread adoption and optimal utilization of 5G capabilities. A significant portion of Nigerian users still rely on devices incompatible with 5G technology, limiting network utilization and reducing contention, a short-term advantage that may dissipate as device penetration increases.

Conclusion and Recommendation

The deployment of 5G in Nigeria offers significant promise but faces notable challenges. Non-standalone 5G shows improved performance over 4G, though variability and limited coverage highlight infrastructural shortcomings. Transitioning to standalone architecture and optimizing mid-band spectrum are key to achieving ideal benchmarks like 20 Gbps download speeds and 1 ms latency. Growing adoption of 5G devices underscores the need for research into network scalability under heavy user loads. While early implementation shows potential for enhanced connectivity and user experience, addressing current limitations is essential to fully realize the transformative benefits of 5G technology in Nigeria. To bridge the gap between current performance levels and international standards, the stakeholders should consider the following:

1. The Nigerian government, through the Nigerian Communications Commission (NCC), should provide an enabling environment for the telecom sector to thrive and attract investment. This involves ensuring transparent regulatory frameworks, facilitating timely spectrum allocation, supporting infrastructure development, and reducing operational barriers. Such measures will foster innovation, enhance 5G deployment, and drive economic growth.
2. There should be continuous infrastructure investment and accelerated deployment of the 5G network, including in Non-Standalone (NSA) mode, to rapidly expand coverage, which will ensure broader accessibility and smoother transition to full Standalone (SA) 5G.
3. Broader-spectrum resources, including high-frequency bands such as millimeter wave (mmWave), should be allocated to Mobile Network Operators (MNOs) to enable them to deliver the full performance potential of 5G networks.
4. The expansion of backhaul and small-cell infrastructure is vital for meeting 5G's high data and low-latency demands. Upgraded backhaul ensures efficient data transport, while small cells improve coverage and capacity in dense or indoor areas. Together, they support scalable and reliable 5G deployment.
5. Increasing the market availability of affordable 5G-compatible devices will significantly boost user adoption and enhance network utilization. Wider access to cost-effective 5G smartphones and terminals lowers the entry barrier for consumers, accelerating demand for 5G services. This, in turn, encourages further investment in infrastructure and service innovation.

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