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Quality of Service in 4g and 5g Network: A Comparative Study of Urban and Rural Performance

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ABSTRACT: Poor network quality remains a major challenge in Nigeria, especially in rural areas where limited infrastructure, weak coverage, and lower base-station density reduce the Quality of Service (QoS) experienced by users. Although 5G promises major improvements over 4G, its comparative performance across urban and rural Nigerian environments is still not sufficiently understood. This study therefore evaluated and compared the QoS performance of 4G and 5G networks in selected urban and rural locations in Nigeria. A simulation-based methodology was adopted using OMNeT++ 5.6 with the INET framework. Four locations were considered: Asaba and Warri as urban environments, and Igbide and Aviara as rural environments. The analysis focused on key QoS metrics, namely throughput, latency, jitter, packet loss, signal-to-noise ratio (SNR), and bit error rate (BER). Different mobility and propagation models were used to reflect the characteristics of urban and rural deployment conditions. The results showed that 5G consistently achieved much higher throughput, stronger signal quality, and lower BER than 4G in all study locations. In the urban areas, 5G throughput reached 429.30 Mbps compared to 99.99 Mbps for 4G, while in the rural areas it reached 198.41 Mbps compared to 49.99 Mbps. In addition, 5G recorded markedly lower latency, jitter, and packet loss in the rural scenarios, although some urban delay-related metrics were less favorable than expected. The Research concludes that 5G offers clear advantages over 4G in capacity, transmission quality, and overall service delivery, but its full QoS benefits depend on deployment conditions, infrastructure readiness, and network optimization.

KEYWORDS: Latency, Qos Metric, OMNer++, Signal-to-noise Ratio, INET framework

1. INTRODUCTION

Mobile communication networks have become indispensable to economic activity, education, commerce, and social interaction, but their usefulness depends less on nominal coverage than on the Quality of Service (QoS) actually experienced by users. In practical terms, a network is judged by whether it can deliver acceptable throughput, latency, jitter, packet loss, and signal quality under real operating conditions. This is why the transition from 4G to 5G should not be framed as a simple generational upgrade. Although 5G is widely associated with higher capacity, lower delay, and more flexible resource allocation, recent work shows that mobile broadband performance is strongly shaped by deployment environment, user density, propagation conditions, and measurement methodology rather than by technology label alone (El-Saleh et al., 2023). Likewise, simulation evidence from urban-suburban 5G systems shows that performance changes significantly across environments, meaning that the presumed superiority of 5G must be tested in context rather than assumed in principle (Zreikat & Mathew, 2024).

That argument is particularly important in Nigeria, where mobile broadband carries much of the burden of digital access in the absence of extensive fixed-network infrastructure. Yet the Nigerian evidence base already suggests that network quality is spatially uneven. In Warri, propagation-focused analysis showed that signal behaviour is highly dependent on local environmental characteristics, with the Okumura–Hata model performing much better than free-space assumptions for the area under study (Anamonye et al., 2016). More recent measurement work in Ughelli further showed that user-relevant QoS indicators such as latency and packet loss vary substantially across operators and connection modes, with all tested networks exceeding the recommended latency threshold for 4G LTE in that study (Peter et al., 2025). Similarly, field measurements along the Ethiope River Banks revealed pronounced signal degradation with distance and clear inter-operator differences, reinforcing the point that location-specific conditions materially shape service quality in Delta State (Edogbeji et al., 2025). At a broader national scale, recent assessments from North-Central and South-West Nigeria also report persistent QoS gaps, including weak speed performance, high latency, inconsistent coverage, and shortfalls relative to expected service levels (Abdullahi & Abdulhamid, 2025; Akinlabi et al., 2026).

The problem, therefore, is not that QoS has been ignored in the literature, but that the available evidence remains fragmented. Much of the Nigerian work is either operator-specific, location-specific, or based on direct field measurements that do not allow controlled comparison of 4G and 5G under matched assumptions. At the same time, broader 4G/5G studies confirm the importance of environment-sensitive evaluation but are not tailored to the Nigerian urban-rural setting (El-Saleh et al., 2023; Zreikat & Mathew, 2024). This leaves an important gap: it is still not sufficiently clear how far the QoS advantage of 5G over 4G holds when both technologies are examined side by side across Nigerian urban and rural environments using the same simulation logic, propagation assumptions, and mobility conditions. That gap matters because rural connectivity cannot be assessed with urban expectations, and even recent rural-network simulation research emphasizes that cost-effective 5G deployment in low-density areas requires models designed specifically for rural realities rather than borrowed assumptions from dense metropolitan systems (Ferreira et al., 2023). In other words, the key unresolved issue is not whether 5G is theoretically better than 4G, but whether that advantage remains meaningful, balanced, and deployment-relevant across the contrasting conditions that define Nigerian telecommunication access. Against this background, the aim of this study is to compare the Quality of Service of 4G and 5G networks in selected urban and rural areas in Nigeria using a simulation-based framework. By evaluating key QoS indicators across contrasting environments, the study seeks to provide a more context-sensitive assessment of next-generation mobile performance and a clearer basis for planning, optimization, and digital inclusion.

2. REVIEW OF RELATED WORK

Several studies have examined the performance of mobile networks from different methodological angles, but the literature still shows an uneven balance between prediction-oriented studies, field measurements, environment-specific evaluations, and deployment-optimization research. This means the field has generated useful insights about 4G and 5G performance, yet it has not fully resolved how QoS behaves when the two technologies are compared under the same controlled conditions across contrasting environments.

Malekzadeh (2023) claimed that 5G performance can be predicted and optimized before deployment by modelling the relationship between key network factors and QoS outcomes. The study used NS-3 to generate a simulated 5G dataset and then applied a multivariate linear regression framework in Python to predict performance under different factor combinations. The results showed high predictive accuracy, reported at about 95%, with low prediction errors, suggesting that machine-learning-assisted planning can support better pre-deployment decisions. The limitation, however, is that the work focused on 5G performance prediction rather than a direct comparative evaluation of 4G and 5G, and it was not designed around a Nigerian urban-rural context.

Shayea et al. (2024) argued that realistic mobile broadband assessment must be based on user-relevant metrics such as coverage, speed, latency, and service satisfaction rather than on network claims alone. Their method was an outdoor drive-test campaign conducted over two months in Malaysia, Singapore, and Thailand using an unlocked smartphone to collect 3G and 4G data across dense urban and urban areas. The study found that 4G consistently outperformed 3G in coverage and latency, with substantial improvements in end-to-end RTT and download speed across the tested territories. The gap in this work is that it stops at 3G–4G comparison and uses field conditions that are useful for deployment planning, but it does not provide a 4G–5G side-by-side assessment or a controlled simulation framework for contrasting urban and rural scenarios.

Polak et al. (2024) maintained that 4G/5G performance should be evaluated in difficult operational environments rather than only in conventional urban spaces, since challenging settings can materially reshape signal behaviour and network load. Their method relied on a cost-effective portable measurement system used for long-term KPI monitoring in a heavy-industry factory environment, with the resulting dataset made publicly available to support reproducibility. The results showed that both the industrial environment and time of day influenced 4G/5G performance, thereby demonstrating that environment-specific measurement is essential for interpreting signal quality and throughput behaviour. The main limitation is that the study concentrated on a factory setting and signal-coverage-oriented KPIs, so although it deepens understanding of harsh environments, it does not directly compare 4G and 5G QoS across broad urban and rural settings.

Banerjee et al. (2024) claimed that many existing 5G evaluations are too narrow because they rely either on instantaneous speed tests or core-network perspectives that do not adequately show whether current 5G deployments can support real smart-city applications. To address this, they used a real-world pilot smart-city application deployed on 11 waste-collection trucks over a six-month period and combined application-specific and application-independent network evaluation. Their results showed that 5G could support mobile video-streaming services, but also revealed substantial performance variability that could make present deployments unsuitable for applications requiring higher data intensity or near-real-time responsiveness. The gap here is that the study assessed 5G in a live application environment, but did not compare it directly with 4G under matched assumptions, nor did it focus on rural deployment disparities.

Galinski et al. (2025) argued that end-to-end QoS in contemporary cellular systems must be studied empirically, especially for latency-sensitive vehicular and edge-computing applications. Their method involved extensive drive tests in Bratislava, Slovakia, comparing 4G LTE and 5G NSA performance using empirical cumulative distribution functions of throughput and latency under mobility and varying coverage conditions. The results showed significant variability in end-to-end QoS across scenarios and offered useful evidence on how current networks support latency-sensitive services in real motion environments. However, the study is limited by its focus on urban vehicular scenarios and real-world operator behaviour, which makes it strong empirically but less suitable for controlled urban-rural comparison across fixed scenario assumptions.

Kar et al. (2025) contended that achieving high throughput together with reliable low latency in 5G requires more than dense deployment; it also depends on smarter resource management and multi-connectivity strategies. Their method used Simu5G and realistic channel models from 3GPP TR 38.901 to simulate ultra-dense network and NR-DC deployment scenarios under multiple mobility patterns. The results showed that throughput decreased and packet loss increased with higher speed, but that NR-DC improved performance relative to mmWave-only ultra-dense deployment, helping 5G better meet the requirements of high-throughput and low-latency applications. The limitation is that the study focused entirely on optimizing 5G architecture rather than comparing 5G with 4G, and it addressed deployment efficiency more than broader QoS contrasts between urban and rural areas.

Taken together, these studies show that the literature has advanced in four important directions: predictive modelling, empirical measurement, harsh-environment assessment, and 5G deployment optimization. Even so, the evidence remains fragmented. Some studies focus only on 5G, some compare older generations such as 3G and 4G, some are tied to specialized environments like factories or vehicular corridors, and others emphasize optimization rather than side-by-side QoS comparison. What is still insufficiently addressed is a controlled comparison of 4G and 5G using the same performance indicators and the same modelling logic across both urban and rural conditions. That is the gap addressed in this study. In the present work, OMNeT++-based simulation was used to compare 4G and 5G networks in representative Nigerian urban and rural scenarios through throughput, latency, jitter, packet loss, SNR, and BER, so as to show not only whether 5G performs better than 4G, but also how that advantage changes with environment.

3. METHODOLOGY

3.1 Study design and simulation environment

This study adopted a simulation-based design to evaluate and compare the Quality of Service (QoS) performance of 4G and 5G networks in selected urban and rural areas in Nigeria. Four representative locations were considered: Asaba and Warri as urban environments, and Aviara and Igbide as rural environments. These locations were selected to reflect differences in population density, base-station availability, user mobility, and expected traffic intensity between urban and rural settings. The network scenarios were implemented in OMNeT++ 5.6 using the INET framework, while output data were processed and visualized in Python. The simulation approach made it possible to reproduce controlled network conditions and evaluate throughput, latency, jitter, packet loss, signal strength, and bit error rate (BER) under comparable settings.

3.2 Study locations and scenario representation

The selected study areas were used to represent typical telecommunication conditions in Nigeria. Asaba and Warri were modeled as urban environments with relatively higher infrastructure density and user activity, while Aviara and Igbide were modeled as rural environments with sparse infrastructure and lower user density. Table 1 summarizes the location characteristics used to parameterize the simulation scenarios.

Table 1. Characteristics of the selected study locations

Location	Environment	Population	Population density (per km²)	Base stations
Asaba	Urban	500,000	1500	15
Warri	Urban	1,076,120	2500	20
Aviara	Rural	10,000	50	2
Igbide	Rural	15,000	100	3

3.3 Network modelling assumptions

To capture the differences between urban and rural deployment conditions, distinct mobility and propagation models were applied. Urban users were modeled with the Random Waypoint Mobility Model to reflect more frequent movement and handoff conditions, whereas rural users were modeled with a Static Mobility Model to represent relatively low mobility. For radio propagation, the Rayleigh fading model was used for urban scenarios because of multipath effects caused by buildings and other obstructions, while the Okumura–Hata model was used for rural scenarios to represent longer-range propagation over less obstructed terrain.

Four scenarios were simulated: 4G-urban, 4G-rural, 5G-urban, and 5G-rural. The 4G scenarios were configured around a carrier frequency of 2.6 GHz and 20 MHz bandwidth, while the 5G scenarios used sub-6 GHz and/or 28 GHz frequency assumptions with wider bandwidth allocations to reflect higher-capacity deployments. Transmission power was maintained at 43 dBm across scenarios for consistency.

Table 2. Summary of simulation scenarios and key parameters

Scenario	Representative location	Carrier frequency	Bandwidth	Propagation model	Mobility model
4G Urban	Asaba/Warri	2.6 GHz	20 MHz	Rayleigh fading	Random Waypoint
4G Rural	Aviara/Igbide	2.6 GHz	20 MHz	Okumura–Hata	Static
5G Urban	Asaba/Warri	2.6 GHz / 28 GHz	100 MHz to 1 GHz	Rayleigh fading	Random Waypoint
5G Rural	Aviara/Igbide	Sub-6 GHz	100 MHz	Okumura–Hata	Static

3.4 Simulation procedure

Each of the four scenarios was executed in OMNeT++ for a simulated period of 12 days to capture variations in traffic load, signal conditions, and user behavior. Urban scenarios were assigned relatively higher traffic demand and greater mobility, while rural scenarios were modeled with lower traffic intensity and fewer active users. During each run, the simulator continuously monitored user-to-base-station interactions and recorded QoS behaviour as network conditions changed. To improve result consistency, the simulations were repeated multiple times and the output records were aggregated for analysis.

3.5 QoS metrics and data analysis

The performance evaluation focused on six QoS indicators: throughput, latency, jitter, packet loss, signal strength, and BER. OMNeT++ generated scalar files for summary statistics and vector files for time-series behaviour during the simulations. Average throughput was computed as the volume of successfully transmitted data divided by transmission time, latency as end-to-end packet delay, packet loss as the percentage of packets not successfully delivered, and jitter as the variation in successive packet arrival times. The exported results were further analyzed in Python using Matplotlib, where line plots and bar charts were produced to compare 4G and 5G performance across urban and rural environments.

4. RESULTS AND DISCUSSION

This section presents and interprets the simulated Quality of Service (QoS) performance of 4G and 5G networks across the selected urban and rural environments. The discussion covers throughput, latency, jitter, packet loss, signal-to-noise ratio (SNR), and bit error rate (BER). The overall numerical summary is presented in Table 3, while Figures 1–6 illustrate the metric-by-metric comparison between 4G and 5G across the study locations.

4.1 Overview of observed QoS performance

The summary of the observed QoS metrics for all locations is presented in Table 3. In general, 5G achieved better overall performance than 4G across most of the evaluated indicators. The most consistent gains were observed in throughput, SNR, and BER, while the behaviour of latency, jitter, and packet loss varied between urban and rural environments. This suggests that although 5G offers clear technical advantages, the scale of improvement depends on the deployment environment and traffic conditions.

Table 3. Summary of observed QoS metrics

Location	Network	Average Throughput (Mbps)	Average Latency (ms)	Average Jitter (ms)	Average Packet Loss (%)	Average SNR (dB)	Average BER
Asaba	4G	99.99	20.00	5.00	0.50	15	1.0×10^{-4}
Asaba	5G	429.30	33.53	13.05	0.67	30	1.0×10^{-6}
Warri	4G	99.99	20.00	5.00	0.50	18	1.5×10^{-4}
Warri	5G	429.30	33.53	13.05	0.67	28	1.2×10^{-6}
Igbide	4G	49.99	40.05	10.03	1.00	10	2.0×10^{-4}
Igbide	5G	198.41	16.19	3.59	0.22	25	1.5×10^{-6}
Aviara	4G	49.99	40.05	10.03	1.00	8	2.5×10^{-4}
Aviara	5G	198.41	16.19	3.59	0.22	22	2.0×10^{-6}

4.2 Throughput performance

The throughput results show that 5G delivered a substantial increase in data transmission capacity in both urban and rural environments. As shown in Figure 1, the urban locations recorded the highest throughput values, with 5G reaching 429.30 Mbps in both Asaba and Warri, compared with 99.99 Mbps for 4G. This represents slightly more than a fourfold increase and reflects the much higher bandwidth and traffic-handling capability of 5G in dense urban settings.

A similar pattern is visible in the rural locations, where 5G achieved 198.41 Mbps in both Igbide and Aviara, while 4G remained at 49.99 Mbps. Although the rural values are lower than those of the urban areas, the proportional improvement remains very significant. This indicates that 5G can still deliver major capacity gains even where infrastructure is relatively sparse. The contrast between urban and rural throughput also suggests that base-station density and deployment conditions continue to shape achievable network performance.

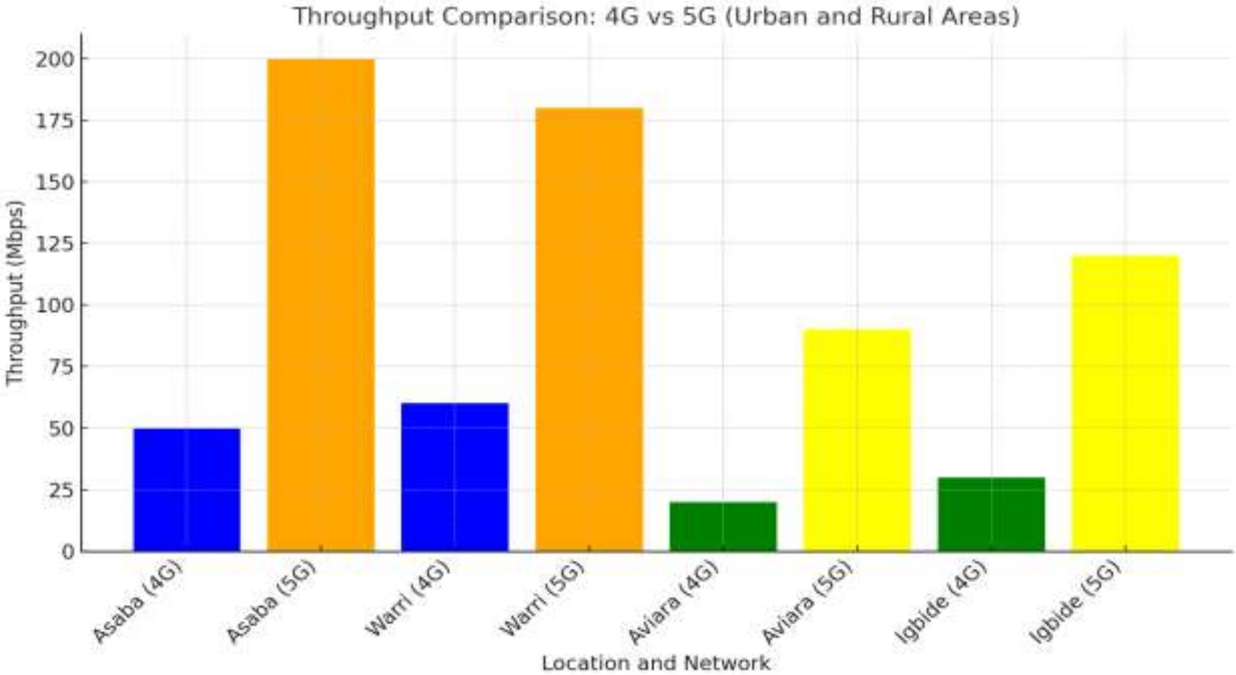

Figure 1: Throughput comparison of 4G and 5G across Asaba, Warri, Igbide, and Aviara]

4.3 Latency performance

Latency results reveal a more nuanced pattern. In the rural scenarios, 5G clearly outperformed 4G, reducing average latency from 40.05 ms to 16.19 ms in both Igbide and Aviara. As illustrated in Figure 2, this reduction is substantial and points to a more responsive communication experience in rural settings. Such improvement is especially relevant for applications requiring faster response times, including online meetings, remote monitoring, and interactive digital services.

In contrast, the urban results show that 5G recorded 33.53 ms latency in both Asaba and Warri, whereas 4G recorded 20.00 ms. This means that the urban 5G scenarios did not achieve lower latency than 4G. The pattern visible in Figure 2 suggests that higher-generation network technology does not always guarantee better performance in every QoS metric. Under dense traffic conditions, factors such as scheduling overhead, network load, and deployment configuration may reduce the expected latency advantage of 5G.

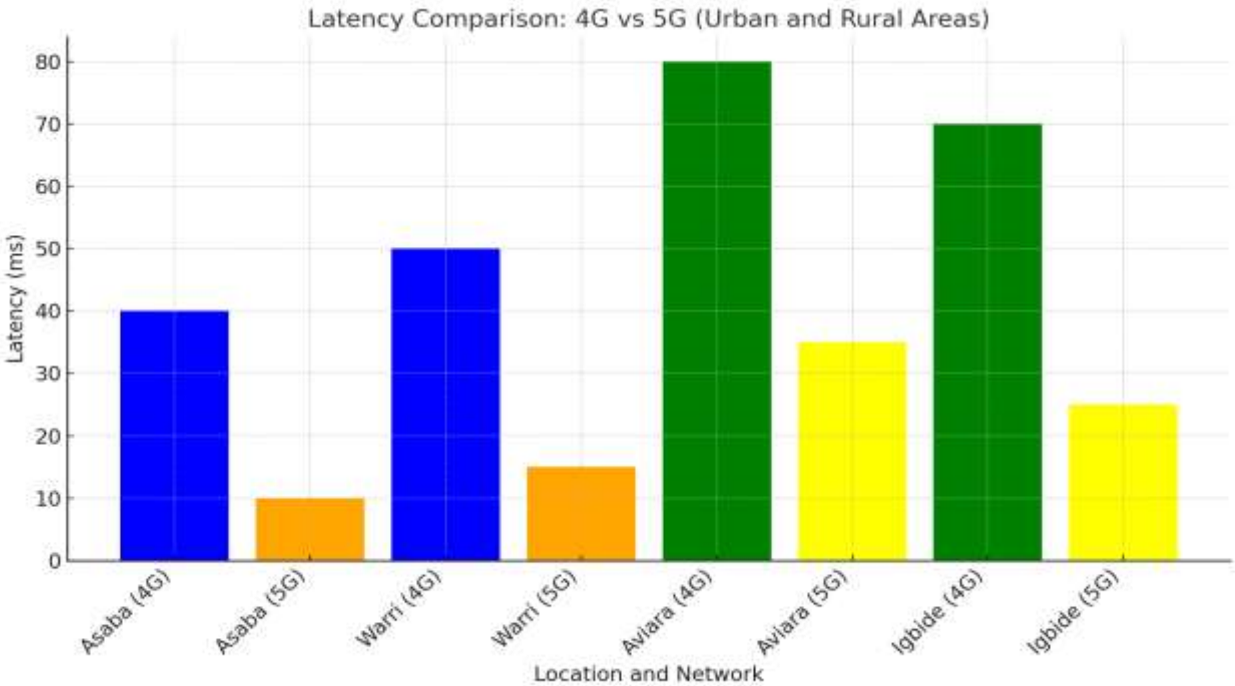

Figure 2: Latency comparison of 4G and 5G across the study locations]

4.4 Jitter performance

The jitter results follow a trend similar to latency. In the rural environments, 5G reduced jitter from 10.03 ms in 4G to 3.59 ms, indicating more stable packet delivery. As seen in Figure 3, this suggests that 5G provided a smoother and more consistent communication experience in the rural scenarios. Lower jitter is particularly important for voice calls, video conferencing, and streaming services, where irregular packet arrival can degrade service quality.

However, the urban results show the reverse pattern. In both Asaba and Warri, 5G recorded 13.05 ms jitter, compared with 5.00 ms for 4G. The comparison in Figure 3 makes this difference clear. Although 5G achieved much higher throughput in the same locations, it did not translate into lower jitter under the simulated urban conditions. This implies that service stability may still be affected by user density, signalling demand, and operational complexity in high-traffic environments.

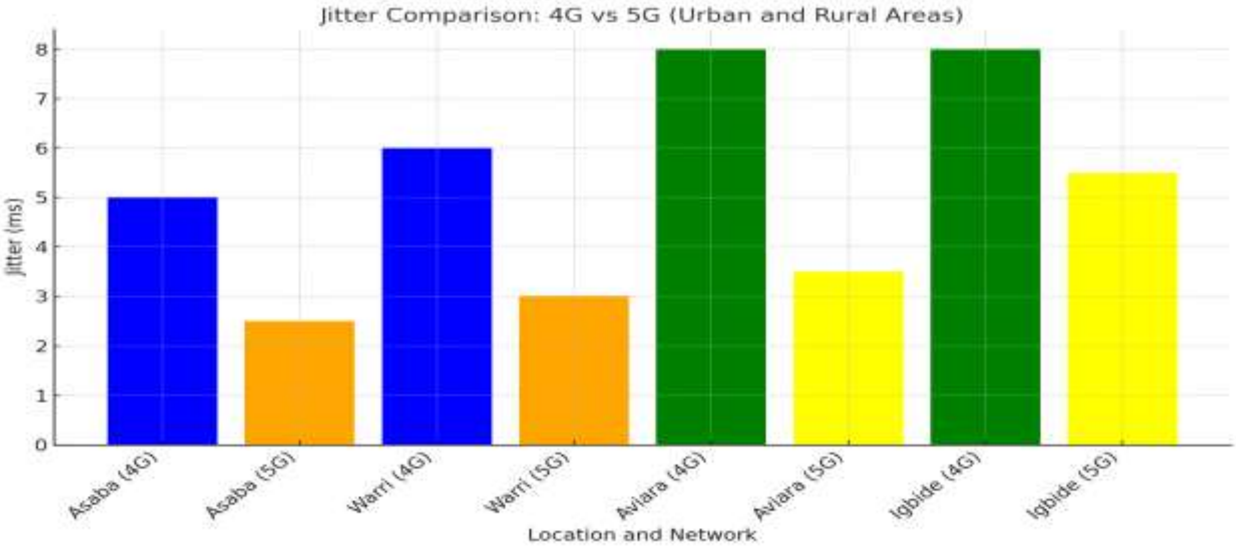

Figure 3: Jitter comparison of 4G and 5G across the study locations

4.5 Packet-loss performance

Packet-loss results also show that the advantage of 5G was more pronounced in the rural settings. In Igbide and Aviara, 5G reduced packet loss from 1.00% to 0.22%, indicating more efficient packet delivery and better transmission reliability. This trend is clearly illustrated in Figure 4, where the rural 5G bars fall well below their 4G counterparts. Lower packet loss reduces retransmissions and improves the reliability of digital services.

In the urban locations, the pattern was less favorable to 5G. Both Asaba and Warri recorded 0.67% packet loss for 5G, compared with 0.50% for 4G. While the difference is relatively small, Figure 4 shows that 5G did not provide a reliability advantage in these urban scenarios. This suggests that in dense environments, performance gains in speed may not automatically be matched by gains in packet delivery unless traffic engineering and network optimization are also addressed.

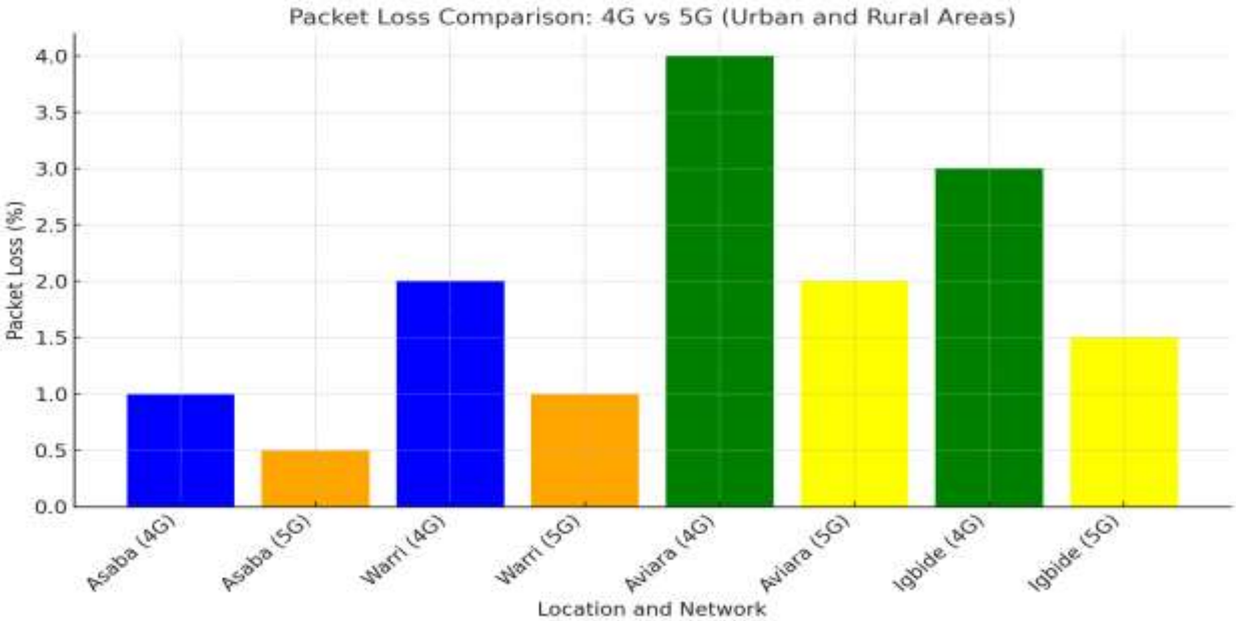

Figure 4: Packet-loss comparison of 4G and 5G across the study locations

4.6 Bit error rate and signal quality

The BER results strongly favor 5G across all study locations. In Asaba and Warri, 5G achieved BER values in the order of 10^{-6}, while 4G remained in the order of 10^{-4}. A similar difference was observed in Igbide and Aviara. As shown in Figure 5, the gap between the two technologies is very wide, confirming that 5G offered much better transmission fidelity than 4G.

The SNR values in Table 3 further explain this result. In both urban and rural areas, 5G recorded substantially higher SNR than 4G, indicating stronger signal quality and more robust communication links. The combined interpretation of Table 3 and Figure 5 shows that 5G provided a more reliable physical-layer transmission environment, which is consistent with the much lower BER values observed across all locations.

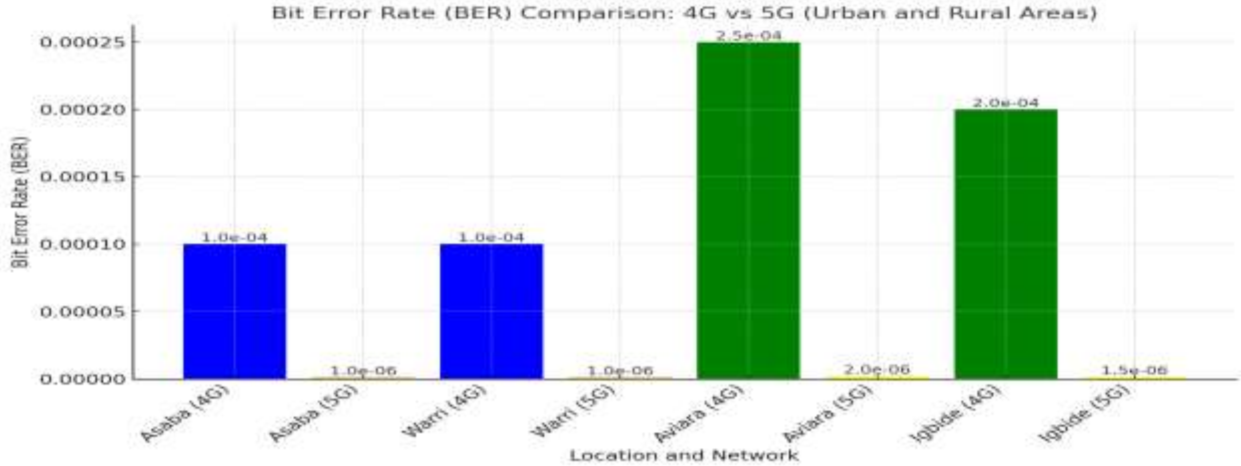

Figure 5: BER comparison of 4G and 5G across the study locations

4.7 Comparative discussion and practical implications

When the results are considered together, a clear pattern emerges. 5G showed its strongest and most consistent advantages in throughput, BER, and signal quality, while its gains in latency, jitter, and packet loss were more dependent on the deployment environment. This overall comparison is summarized visually in Figure 6. The figure shows that rural 5G produced a more balanced performance improvement across the main QoS indicators, whereas urban 5G delivered very strong gains in speed and signal strength but did not outperform 4G in every real-time service metric.

This has important practical implications. First, it suggests that the benefits of 5G should not be judged only by peak speed. Second, it shows that rural deployment may yield especially meaningful improvements because gains occur not only in throughput but also in responsiveness and reliability. Third, the mixed urban results indicate that infrastructure upgrade alone is not sufficient; efficient network planning, optimization, and traffic management are also necessary if the full QoS benefits of 5G are to be realized. In the Nigerian context, this means that 5G expansion has the potential to support both urban capacity growth and rural digital inclusion, provided deployment is carefully aligned with local conditions.

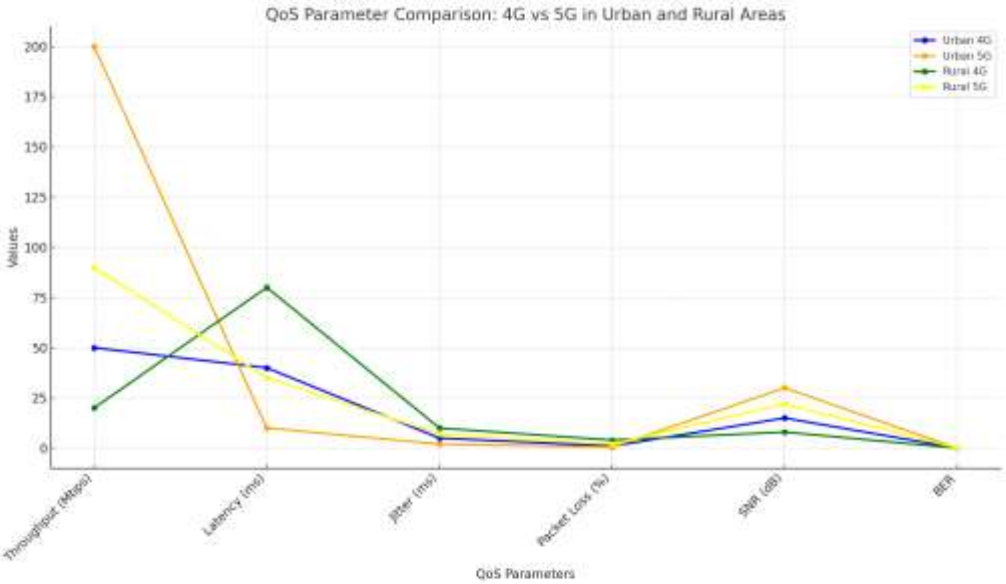

Figure 6: Overall QoS comparison of 4G and 5G for throughput, latency, jitter, packet loss, SNR, and BER

4.8 Key insight from the results

The central insight from the study is that 5G is clearly superior to 4G in network capacity and transmission quality, but its QoS advantages are environment-dependent. The figures show that 5G consistently improved throughput and BER across all locations, while the urban and rural comparisons reveal that latency-related improvements were not uniform. This means that the practical benefits of next-generation mobile networks are shaped not only by the technology itself, but also by user density, infrastructure readiness, and deployment strategy.

5. CONCLUSION

This study evaluated and compared the Quality of Service performance of 4G and 5G networks in selected urban and rural environments in Nigeria using simulation-based analysis. The results showed that 5G generally outperformed 4G across the examined locations, with the most consistent advantages observed in throughput, signal quality, and transmission reliability. In both urban and rural scenarios, 5G delivered substantially higher throughput and much lower bit error rates, confirming its stronger capacity and better physical-layer performance. The higher SNR values obtained for 5G further support its improved link quality relative to 4G. The findings also showed that the benefits of 5G are not uniform across all QoS indicators and environments. In the rural locations, 5G provided clear improvements not only in throughput, but also in latency, jitter, and packet loss, indicating a more stable and responsive network under sparse deployment conditions. In the urban locations, however, although 5G achieved much higher throughput and better signal conditions, some delay-related indicators were less favorable than those of 4G in the simulated scenarios. This suggests that the superiority of 5G depends not only on the underlying technology, but also on deployment design, traffic conditions, and network optimization.

Overall, the study confirms that 5G has strong potential to enhance mobile network performance in Nigeria, particularly in terms of capacity, reliability, and service quality. More importantly, the results suggest that 5G can play a significant role in improving connectivity in underserved rural areas if supported with adequate infrastructure planning and deployment strategy. The study therefore concludes that while 5G is a more capable technology than 4G, its full QoS benefits can only be realized when implementation is aligned with the specific operational realities of both urban and rural environments.

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