Performance Evaluation of National Mobile Broadband Networks in a High-Mobility Suburban Environment

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ABSTRACT
The fact that the liberalization of the Nigerian telecommunications sector and the deployment of broadband technologies have brought tremendous socio-economic growth opportunities cannot be over emphasized. It has been reported in 2020 that 78% and 45% coverage have been achieved for 3G and 4G services respectively. Though 4G coverage is available to 37% of the population, download speeds in the country have been noted to be generally uncompetitive with other countries in the same income bracket. Despite the huge investments, achievements and projections in mobile broadband infrastructure as well as the increased subscription, network performance evaluation reports are not readily available and accessible to subscribers and other stakeholders. Nigerian mobile subscribers still complain of poor network connections, even after paying so much for Internet services. This work therefore, presents a user-centric performance evaluation of National mobile broadband networks in a high-mobility suburban environment. Static test approach was adopted in measuring the mobile broadband performance obtainable from the four major mobile network operators (MNOs) in Choba, Rivers State, Nigeria. Measurements were carried out during the morning, afternoon and evening hours within the study coverage area for one week. Three quality of service (QoS) metrics, download speed, upload speed and latency of 3G and 4G networks were measured. The data obtained were aggregated and analyzed using Microsoft Excel. The results show that there is no dominant MNO for both 3G and 4G services in the coverage area in terms of the measured performance metrics. The findings provide the necessary insight to guide the mobile network operators towards achieving the benchmarks set by the Nigerian Communications Commission (NCC). Hence, the work presents additional information into the existing body of knowledge in the Nigerian telecommunication industry as well as references to assist subscribers, researchers and network operators to achieve better: success, quality of service, quality of experience, service penetration/acceptability and revenue in their activities/operations.

General Terms
Performance evaluation, mobile broadband, broadband infrastructure, mobile network, quality of service

Keywords
Network performance, performance monitoring, static test, download speed, upload speed, latency, evaluation reports

1. INTRODUCTION
Following the liberalization of the Nigerian telecommunications sector in the year 2000, the nature of everyday business has changed, thereby bringing significant improvements in the lives of Nigerians [1]. The introduction of mobile broadband into the sector has provided the framework for more consistent, dependable, cost-effective and high-speed connection to the Internet. The Nigerian mobile broadband sector is driven largely by four major mobile network operators (MNOs), namely: MTN, Globacom, Airtel and 9Mobile. Most Nigerians now own mobile devices and are subscribed to one or more networks. Thus, Nigeria has become the largest mobile telecommunications market in Africa, largely based on rapid development following the successful auction of digital mobile licenses (DMLs) in 2001. As at December 2019, the market served over 184 million mobile lines, with 126 million of those lines (68%) connected to the Internet and running on second generation (2G+), third generation (3G) and fourth generation (4G) mobile networks. The over 184 million mobile subscribers were distributed across the networks of MTN, Globacom, Airtel and 9Mobile, each having 37.31%, 28.05%, 27.23% and 7.41% market share respectively. The number of subscribers has since increased from 184,699.409 in 2019 to 204,601,313 as at December 2020. This is an increase of 19,901,904 subscriptions, representing about 10.78% increase in total subscription within the period under consideration [2, 3].

Despite the huge investments, achievements and projections in mobile broadband infrastructure as well as the increased subscription, network performance evaluation reports are not readily available and accessible to subscribers and other stakeholders. One would have expected the mobile network operators to regularly publish the performance data derived at the user end to encourage more patronage. Nigerian mobile subscribers still complain of poor network connections, even after paying so much for Internet services. Sustained monitoring and evaluation of mobile broadband performance is a win-win venture. Results from the exercise guide regulators in policy making, help MNOs to improve their services through guided investments and properly guide users in making right choices of the network of subscription based on their needs and resources.

It is against this backdrop that this work presents a user-centric performance evaluation of National mobile broadband networks in a high-mobility suburban environment. Static test methodology was adopted in measuring the mobile broadband performance obtainable from the four major MNOs in Choba, Rivers State, Nigeria. Measurements were carried out during the morning, afternoon and evening hours within the study coverage area for one week. Three quality of service (QoS) metrics, download speed, upload speed and latency of 3G and 4G networks were measured. The data obtained were

aggregated and analyzed using Microsoft Excel. The results show that there is no dominant MNO for both 3G and 4G services in the coverage area in terms of the measured performance metrics.

2. DEVELOPMENT OF TELECOMMUNICATIONS INFRASTRUCTURE IN NIGERIA

Telecommunications infrastructure represents the basic physical structures and facilities necessary for the provision of voice and data transmission through channels such as copper wire, optical fibers and wireless communication. The facilities in Nigeria were first established in 1886 by the colonial administration. At independence in 1960, with a population of roughly 40 million people, the country only had about 18,724 phone lines for use. This translated to a teledensity of about 0.5 telephone lines per 1,000 people. The telephone network consisted of 121 exchanges of which 116 were of the manual (magneto) type and only 5 were automatic. However, in 2002, Nigeria added 1.3 million new mobile customers and reported the highest annual growth rate (369 percent) in the world [1, 4, 5].

Telecommunication services in the country have since grown from a teledensity of lower than 1% on fixed wireline and wireless networks before the DML auctions in 2001, to reach approximately 89% population coverage for voice services in 2019. Teledensity has increased from 96.76% as at December 2019 to 107.18% by December 31st 2020. Broadband penetration increased from 37.80% as at December 2019 to 45.02% as at December, 2020. Similarly, broadband subscriptions increased from 72,153,824 subscriptions in December 2019 to 89,941,222 subscriptions as at December, 2020. Internet Usage increased in the volume of data consumed in the year end December 2021 when compared with the year ended December 2020. The total volume of data consumed by subscribers increased to 353,118.89TB as at December 2021 from 209,917.40TB as at December 2020. This represents an increase of 68.2% in data consumption within the period. Nigeria's broadband usage has continued on the rise, moving up from 40.9% in February 2022 to 44.5% in July 2022, a figure considered hopeful for achieving the national broadband target of 70% in 2025. Internet services in Nigeria are currently provided on 2G, 3G, and increasingly 4G mobile networks. It has been reported in 2020 that 78% and 45% coverage have been achieved for 3G and 4G services respectively. Though 4G coverage is available to 37% of the population, download speeds in the country have been noted to be generally uncompetitive with other countries in the same income bracket [2, 3, 6, 7, 8].

3. MOBILE BROADBAND PERFORMANCE MONITORING AND ANALYSIS IN NIGERIA

Since mobile broadband networks have become a critical player in the socio-economic wellbeing of the nation, there is need to encourage independent and unbiased assessment of their robustness and performance. A typical source of such information is active end-to-end network performance measurements. It has been reported that there is no wrong or right method for measuring network performance because each approach has its advantages and drawbacks. Various methods are implemented based on resource availability, type of access: wired or mobile (wireless), etc. The most important factor is for the adopted measurement approach to produce a rich data set which when aggregated will reflect the true nature of broadband performance [9, 10]. To this end, several researchers have carried out studies on mobile broadband performance monitoring and measurements for 2G, 3G and 4G networks using the following quality of service metrics: throughput (download and upload speeds), latency, packet loss, jitter, domain name service (DNS) lookup and network key performance indicators (KPIs). [10, 11, 12, 13, 14, 15, 16, 17]

4. MATERIALS AND METHODS

4.1 Study Area

The study was carried out at Choba, Rivers State, Nigeria, precisely in the University of Port Harcourt. The measurement environment is located on Latitude 4° 53' 26"N and longitude 6° 54' 12"E. The area is classified as a suburban environment and has a high mobility of persons due to the presence of a tertiary institution, the University of Port Harcourt.

4.2 Measurement Parameters

The measurement parameters for the study are download speed, upload speed and latency**.** Download speed describes how fast images, text, videos, music and other online data from an Internet server are received. Upload speed describes how quickly or fast, information or data can be sent from a device to the internet. These data transfer speeds measure the capacity of a user's broadband connection in megabits per second (Mbps) and have become the most commonly cited metric of interest for determining the quality of broadband offering [10, 18]. Latency is the time it takes a data packet to travel or be transferred from a source to a particular destination. It is also known as delay and measured in milliseconds. Latency affects real-time traffic such as voice and business/mission-critical data (B/MCD), thereby impairing the quality of service (QoS) and quality of experience (QoE) obtainable from broadband networks [19, 20, 21, 22, 23].

4.3 Data Collection and Analysis

The data for the study were collected through a static test. 3G and 4G mobile broadband performance measurements were carried out with a mobile web application (nPerf speed test). The performance metrics considered in the study are download speed, upload speed and latency. Measurement samples were collected within a week. Data were collected from real time assessment of the network performance at different times of the day: morning (0800 – 1100 hours), afternoon (1200 – 1600 hours) and evening (1700 – 2100 hours). The averaged measurements obtained from the study are shown in Tables 1 to 3. They measurements sufficiently repeated to enhance the reliability and validity of results obtained.

5. RESULTS AND DISCUSSIONS

This section presents the results obtained from field measurements using download speed, upload speed and latency performance metrics for the four major mobile network operators (MNOs) in Nigeria. In a study such as this, the best values of performance metrics cannot predict the optimal performance of a network over a period of time. Hence, statistical average values of several samples of measurements obtained over a long period of time are used in analysis. To this end, the peak and average data transfer speeds as well as the average latency are considered in the following analysis.

Table 1: 3G/4G Peak download/upload speed measurements (Mbps) for all MNOs

Network Operators	Peak download speed (Mbps)		Peak upload speed (Mbps)	
	3G	4G	3G	4G
MNO-1	5.29	35.94	1.21	1.65
MNO-2	2.82	3.50	1.22	1.32
MNO-3	8.38	21.86	1.43	0.92
MNO-4	0.92	1.17	0.68	0.55

5.1 Analysis of Peak Download and Upload Speeds

Figures 1 and 2 (plotted from Table 1), show the peak data transfer speeds for 3G and 4G networks offered by the four major MNOs, identified in this work as MNO-1, MNO-2, MNO-3 and MNO-4. The results are the maximum values obtained by measurement under static conditions. From the 3G peak download speed of Figure 1, MNO-3 offered the best service with 8.38Mbps. MNO-1, MNO-2 and MNO-4 had peak download speeds of 5.29Mbps, 2.82Mbps and 0.92Mbps respectively. For the 3G peak upload speed, MNO-3, MNO-2, MNO-1 and MNO-4 recorded 1,43Mbps, 1.22Mbps, 1,21Mbps and 0.68Mbps respectively. The results therefore show that MNO-3 had the best data transfer speeds, relative to other MNOs, for the 3G network. MNO-4 recorded the least service performance.

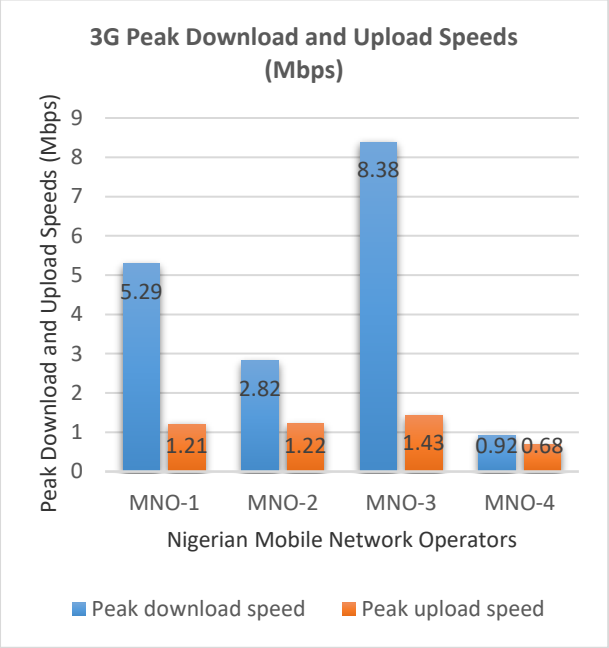

Fig 1: 3G Peak Download and Upload speeds for all MNOs (higher is better)

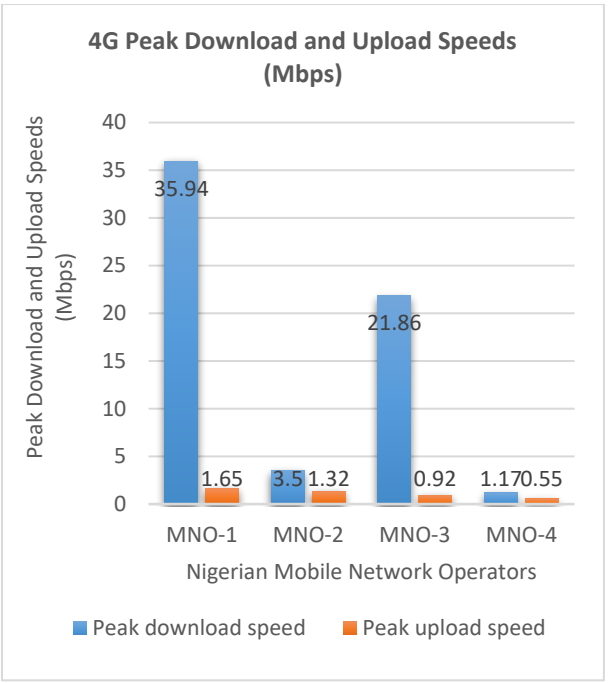

Fig 2: 4G Peak Download and Upload speeds for all MNOs (higher is better)

Figure 2 presents the measured 4G peak download and upload speeds. The results show that MNO-1 offered the best service with 35.94Mbps for download and 1.65Mbps for upload. MNO-4 recorded the least data transfer speeds of 1.17Mbps and 0.55Mbps for download and upload respectively. MNO-3 and MNO-2 had 21.86Mbps and 3.50Mbps respectively for download as well as 0.92Mbps and 1.32Mbps respectively for upload.

Table 2: 3G/4G Average download/upload speed measurements (Mbps) for all MNOs

Network Operators	Average download speed (Mbps)		Average upload speed (Mbps)	
	3G	4G	3G	4G
MNO-1	3.78	27.11	1.07	1.51
MNO-2	1.76	2.34	0.92	1.02
MNO-3	6.40	13.63	0.98	0.72
MNO-4	0.56	0.85	0.50	0.44

5.2 Analysis of Average Download and Upload Speeds

Figures 3 and 4 (plotted from Table 2), present the average download and upload speeds for 3G and 4G networks respectively. For the 3G average download speed, MNO-3 recorded the best service with 6.40Mbps while MNO-4 had the least with 0.56Mbps. MNO-1 and MNO-2 had 3.78Mbps and 1.76Mbps respectively. However, MNO-1 recorded the highest average upload speed of 1.07Mbps while MNO-3, MNO-2 and MNO-4 had 0.98Mbps, 0.92Mbps and 0.50Mbps respectively. MNO-4 therefore offered the least service performance.

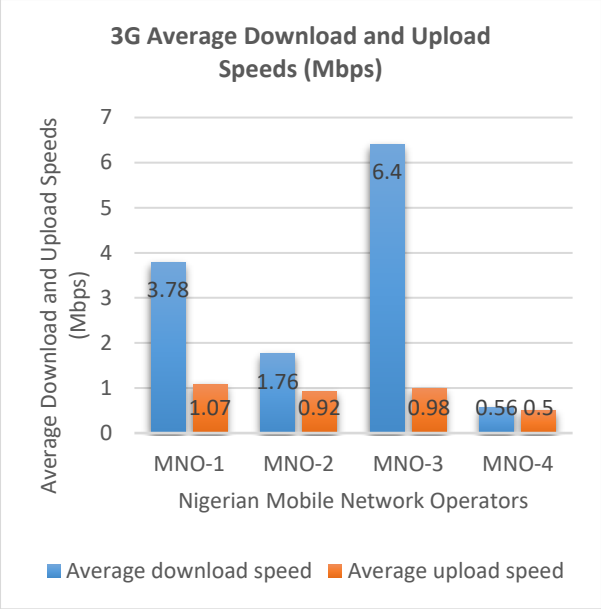

Fig 3: 3G Average Download and Upload speeds for all MNOs (higher is better)

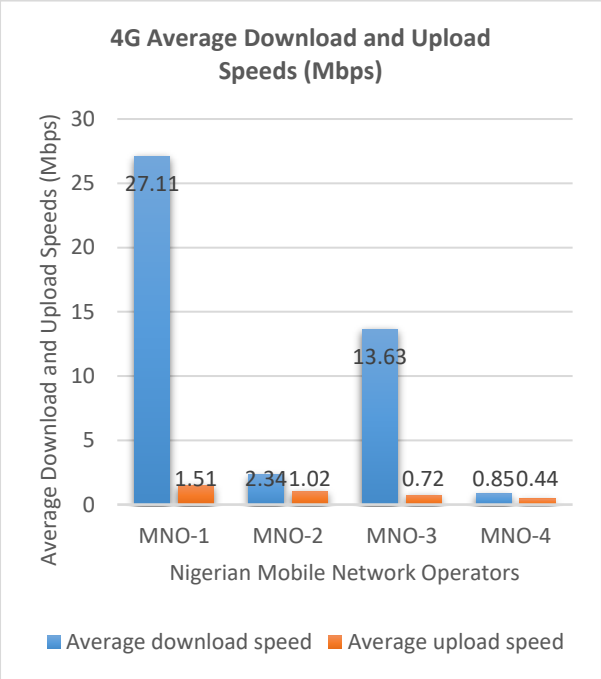

Fig 4: 4G Average Download and Upload speeds for all MNOs (higher is better)

In Figure 4, MNO-1 recorded the best 4G average download speed of 27.11Mbps, followed by MNO-3 with 13.63Mbps. MNO-2 and MNO-4 had 2.34Mbps and 0.85Mbps respectively. For average 4G upload speed, MNO-1, MN)-2, MNO-3 and MNO-4 recorded 1.51Mbps, 1.02Mbps, 0.72Mbps and 0.44Mbps respectively. The results therefore show that MNO-1 had the best data transfer speeds, relative to other MNOs, for the 4G network. MNO-4 delivered the least service performance.

Table 3: 3G/4G Average latency measurements (ms) for all MNOs

Network Operator	Latency (ms) Morning		Latency (ms) Afternoon		Latency (ms) Evening	
	3G	4G	3G	4G	3G	4G
MNO-1	235	244	260	240	251	237
MNO-2	239	237	257	237	235	289
MNO-3	234	229	240	632	238	472
MNO-4	647	692	690	633	281	664

5.3 Analysis of Average Latency

The 3G and 4G average latency results obtained for the four major mobile network operators are given in Figures 5 to 7 and plotted from Table 3. For the purpose of this analysis, the values measured for 3G are compared with those obtained for 4G network during different periods (morning, afternoon and evening) of the day.

The results in Figure 5 show that during the morning hours of the day, MNO-3 had the least average latency of 234ms while MNO-4 had the highest value of 647ms on the 3G network. MNO-1 and MNO-2 had 235ms and 239ms respectively. Within the same period of time, MNO-3 also recorded the least value of average latency of 229ms on the 4G network. MNO-4 also recorded the highest value of 692ms while MNO-2 and MNO-1 had 237ms and 244ms respectively. The results therefore show that MNO-3 ranked the most responsive network compared to the other MNOs. MNO-4 was the least responsive.

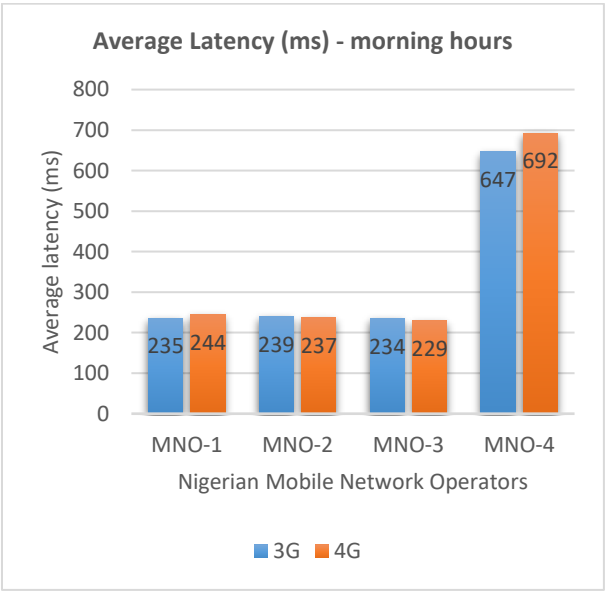

Fig 5: Average 3G and 4G Latency (ms) for all MNOs – morning hours (lower is better)

The results in Figure 6 show that during the afternoon hours of the day, MNO-3 recorded the least average latency of 240ms while MNO-4 had the highest value of 690ms, for the 3G network. MNO-2 and MNO-1 had 257ms and 260ms respectively. On the 4G network, MNO-2, MNO-1, MNO-3 and MNO-4 recorded 237ms, 240ms, 632ms and 633ms respectively. Hence, MNO-3 was the most responsive while MNO-4 was least responsive for both 3G and 4G networks.

During the evening hours as shown in Figure 7, MNO-2 recorded the least average latency of 235ms while MNO-4 had

the highest value of 281ms, on the 3G network. MNO-3 and MNO-1 had 238ms and 251ms respectively. For the 4G network, MNO-1 recorded the least value of 237ms while MNO-4 had the highest value of 664ms. MNO-2 and MNO-3 had 289ms and 472ms respectively. Hence, MNO-2 was the most responsive on the 3G network, MNO-1 was most responsive on the 4G network while MNO-4 was again the least responsive for both 3G and 4G networks.

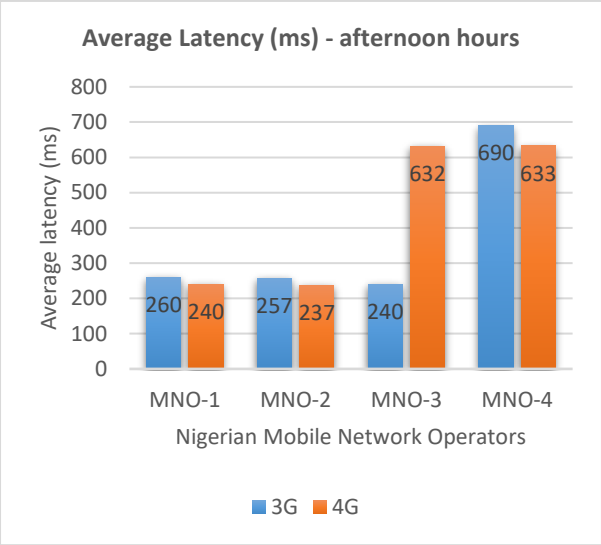

Fig 6: Average 3G and 4G Latency (ms) for all MNOs – afternoon hours (lower is better)

The overall average latency results show that MNO-4 is the least responsive on both 3G and 4G networks. Again, it can be observed that there is no dominant MNO for all the periods of the day. This could be alluded to the fact that the study area hosts an academic institution. Majority of users, generating the bulk of the traffic are engaged in academic activities during particular periods of the day.

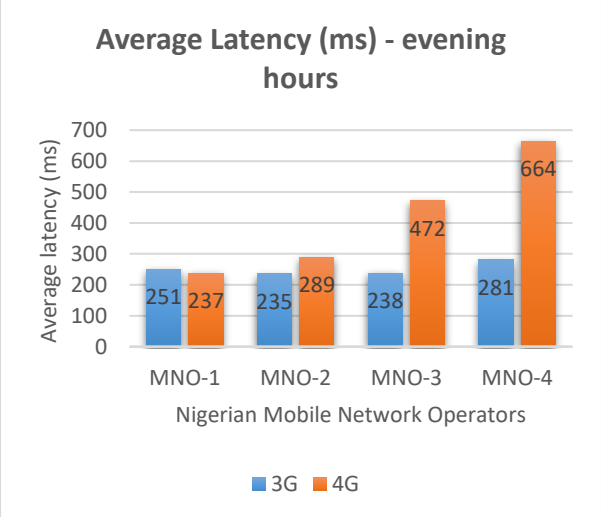

Fig 7: Average 3G and 4G Latency (ms) for all MNOs – evening hours (lower is better)

6. CONCLUSIONS

The results obtained from the analysis of peak download and upload speeds show that MNO-3 had the best peak data transfer speeds, relative to other MNOs, for the 3G network. The results from the average download and upload speed analysis show that MNO-1 had the best average data transfer speeds, relative to other MNOs, for the 4G network. The results for average latency during the morning hours show that MNO-3 recorded the least value and therefore ranked the most responsive network compared to the other MNOs. These results therefore show that there is no dominant MNO for both 3G and 4G services in the coverage area in terms of the measured performance metrics. MNO-4 performed relatively poor on all the measured metrics.

The findings provide the necessary insight to guide the mobile network operators towards achieving the benchmarks set by the Nigerian Communications Commission (NCC). Hence, the work presents additional information into the existing body of knowledge in the Nigerian telecommunication industry as well as references to assist subscribers, researchers and network operators to achieve better: success, quality of service, quality of experience, service penetration/acceptability and revenue in their activities/operations.

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