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A Comparative Study of User Experienced Mobile Broadband Performance

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Abstract
Even though the proliferation of handheld mobile communication devices has deepened Internet and broadband penetration in Nigeria, users of such services may not have detailed quantitative performance comparison between the services provided by different network operators. The study here reported is therefore an attempt to bridge the information gap. A measurement testbed based on the Raspberry Pi platform was developed to autonomously measure the mobile broadband performance of third generation (3G) and fourth generation (4G) broadband networks of the four major mobile network operators in the country. Under static access conditions, the system was set up to measure the upload throughput, download throughput and latency from a user-centric perspective. The measurements were taken by simultaneously sampling the networks of four mobile broadband service providers (9Mobile, Airtel, Globacom and MTN) over a period of three weeks in the city of Uyo, Nigeria. The results obtained revealed that Airtel achieved the highest peak download rate for 3G throughput, and this was only 1.41 Mbps higher than the least performing MNO. Also, it was found that MTN's download rate peaked at 35.06 Mbps, and this was over 300% of the rate achieved by the fourth rated network in terms of the 4G download throughput metric. The measurement results also revealed that peak usage periods, defined as the hours between 7pm and 11pm, witnessed higher variability in throughput rates than other periods.

Keywords: 3G, 4G, Measurements, Raspberry Pi, Mobile Broadband, Download Throughput, Upload Throughput, Latency

1.0 INTRODUCTION

The Internet era started in 1983 and its usage has risen exponentially since then [1]. This has been caused by a proliferation in the use of smart and mobile devices, which can connect to the Internet anywhere and on the go, and has increased the population that can now have access to the Internet. Traditional dial-up access, which was an earlier method of accessing the Internet, was not robust enough to accommodate the increasing number of connections due to a myriad of bottlenecks [2]. Broadband, with its improved characteristics, proved to be a substantial solution that has since replaced the old-fashioned dial-up access. Broadband can transfer data with a speed that surpasses 256 kbps, whereas the dial-up access was limited to about 56 kbps [2]. This robust capacity and other notable characteristics allow broadband to offer a consistent, dependable, cost-effective and high-speed connection to the Internet.

Mobile broadband (MBB) allows high-speed connection to the Internet via mobile phones, tablets, laptop computers and other numerous mobile digital devices [2-3]. MBB services are delivered on the go to mobile devices by Mobile Network Operators (MNOs). In Nigeria, four major MNOs are licensed to provide MBB services to end-users [4]. These MNOs, over the last decade, have built infrastructure that provides coverage to larger areas, leading to a corresponding increase in the number of subscribers and a remarkable rise in broadband penetration in Nigeria. Data published by the Nigerian Communications Commission (NCC) as of September 2021 shows that Nigeria has over 140 million active subscribers for different kinds of Internet services [4]. Out of this, over 76 million subscribe for broadband services, and the broadband penetration rate is estimated to be 40.01%. It is also worthy of note that 99.80% of broadband subscribers access the Internet with mobile devices [4].

Since the number of broadband users keeps increasing, the performance of MBB network operators should be freely available to subscribers, industry stakeholders, technology companies and other interested parties. Unfortunately, this is not the case for Nigerian MNOs, especially for performance data derived at the user end. From the foregoing problem, the objective of this work is to fill this information gap by developing an infrastructure to uncover the performance of MBB networks in Nigeria

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from a user-centric perspective. The MBB performance delivered by the four licensed MNOs in Nigeria is measured and analyzed under static conditions. This paper particularly focuses on three MBB performance metrics, the upload throughput, download throughput and latency of the third generation (3G) and the fourth generation (4G) networks.

The rest of the paper is organized as follows. Section 2 discusses the state of mobile broadband adoption and penetration in Nigeria. It also highlights the mobile broadband measurement methods and reviews related works. Section 3 discusses the methodology and approach adopted for the study while section 4 presents the results and compares the performances of the different mobile network operators (MNOs). Section 5 concludes the paper.

2.0 LITERATURE REVIEW

Mobile communication technologies have steadily evolved from the first generation (1G) analogue communication systems to the recently deployed superfast and ultra-reliable fifth generation (5G) system. However, the journey to realizing MBB performance began with the adoption of second generation (2G) mobile communication systems, which were first deployed in 1991 [5]. These systems were progressively improved and this led to 3G, 4G and today's 5G networks respectively.

2.1 Development of Mobile Broadband Services in Nigeria

The beginning of mobile broadband in Nigeria can be traced to the introduction of the Global System for Mobile communications (GSM). GSM is a 2G system and its services started in Nigeria in 2001 with ECONET wireless and MTN Nigeria being the first two MNOs to obtain full operational licenses [6]. However, extensive uptake of mobile broadband in the country did not commence until 3G licenses were granted to the MNOs in 2007 [7]. Since then, the uptake of mobile broadband has grown tremendously and the Nigerian Communications Commission (NCC) reports that Nigeria achieved 78% and 45% coverage in 2020 for 3G and 4G services respectively. Currently, there are four MNOs that offer mobile broadband services in Nigeria namely: 9mobile, Airtel, Globacom and MTN [4].

2.2 Measurements of Mobile Broadband Performance

The performance of mobile broadband is usually determined by measuring the end-to-end service delivery as experienced by subscribers. The measurements when taken over an extended period of time allow for average and peak figures to be determined [2]. The common measurement metrics used are throughput, latency, packet loss and jitter [3], [8]. These metrics can be measured in both mobile and static use cases.

Throughput refers to the actual amount of data that is successfully sent or received over a communication network or link. Latency portrays how responsive a network is and it is defined as the time it takes for data packets to be transmitted from their source to the expected destination. Packet loss, which is mostly caused by network congestion, describes the percentage of data packets not reaching their destination after they have been sent across a network while jitter describes the difference or inconsistencies in latency between packet flow from one end-user to another [3], [8]. These metrics can be measured by adopting the physical measurement method in form of a drive test, where the measurement equipment is mounted on moving vehicles and programmed to systematically take the measurement [9].

Similarly, a crowd-sourced user equipment-based measurement approach that relies on voluntary participation by the users can also be adopted. The later method allows a user to download and install a test application on their mobile devices to automatically carry out repeated network performance testing [9-10]. Speedtest by Ookla [11], SamKnows' Crowdsource App [12], and FCC Speed Test App [13], are some of the widely used mobile applications for crowdsourced user-centric MBB performance measurements. Another notable MBB measurement method, which is the one also adopted for this research, is to develop a testbed with multiple nodes deployed at different locations. This type of measurement is more robust, accurate and can be configured with fairness to all MNOs. Some of such well known MBB measurement testbeds developed are described in [14] and [15].

2.3 Related Works

Several works have been carried out to uncover the performance of MBB services. One of such research carried out in Nigeria is reported in [2], where a host and crowd-sourced based approach was employed to evaluate the MBB performance. In the study, a custom-built Java and Extensive Markup Language application was developed to measure selected performance metrics. The results obtained revealed that 3G throughput fell below the lower limit for industry standards by 10% while 2G throughput was above the upper limit by 60%. They also inferred from data collected that performance across the different networks deteriorates at peak periods and improves at off-peak periods by as much as 69%. However, the research did not study the performance of 4G MBB networks and no dedicated hardware testbed was developed for taking measurements.

Another significant MBB measurement carried out in Nigeria is reported in [16]. The measurement was taken in only the city of Okada in Southwestern Nigeria and was limited to three out of the four major MNOs offering MBB services. Also, the work did not mention the MBB technology adopted and only took measurements over fourteen-day periods for clear sky and rainy conditions. The results revealed that only one out of the three MNOs constantly reached higher levels of throughput both during rainy and clear sky conditions.

Other notable broadband measurements include those undertaken by industry regulators such as the USA's Federal Communications Commission (FCC) [17], the UK's Office of Communication (OFCOM) [18-20], the Canadian Radio-Television and Telecommunications Commission (CTTC) [21] and the Australian Competition and Consumer Commission (ACCC) [22]. A common feature of such measurements is that they do not develop dedicated measurement testbeds.

Among the MBB measurements that use testbeds, the Nornet Edge (NNE) platform presented in [14] stands out. The NNE platform reportedly has 400 fully programmable and multi-homed nodes placed at different locations in Norway. The NNE measurement nodes consist of custom made single-board computers that run a standard Linux operating system, with up to five modems to access the services of different MNOs. The NNE core consists of a set of servers for collection and storing data emanating from the remote nodes.

3.0 METHODOLOGY

In this study, we adopted a user-centric physical measurement method where a dedicated testing infrastructure was developed and to autonomously measure the upload throughput, download throughput and latency. The measurement method adopted is similar to that of the NORNET platform [14] and relies on a novel Raspberry Pi-based MBB measurement testbed as shown in Figure 1. The framework for this simplified infrastructure was first proposed in [23]. Details of the materials used, configuration, testing and subsequent operation of the testbed has been reported in [24].

As can be observed in Figure 1, the testbed comprises two parts. The first part is the remote measurement node and this has the Raspberry Pi as the core component. The second part is the MBB measurement testbed core and this serves as a back office to collate data collected by the remote nodes, storage of such data and monitoring the operation of the remote nodes. Communication between both parts is enabled via the Internet.

3.1 Configuration of Raspberry Pi Node for MBB Measurements

The overall configuration of the Raspberry Pi node for MBB measurement follows the sequence presented in the flowchart of Figure 2.

The Raspberry nodes were configured to achieve multihoming for 3G and 4G MBB measurements. For 3G network measurements, USB modems were used alongside SIM cards from all the MNOs, while the use of retrofitted MiFi modules with speeds of up to 150Mbps as the user interface was incorporated for 4G networks. Scripts were then written in Python to achieve and automate the multihoming function and thus autonomously and continuously sample the MBB performance of the four major MNOs.

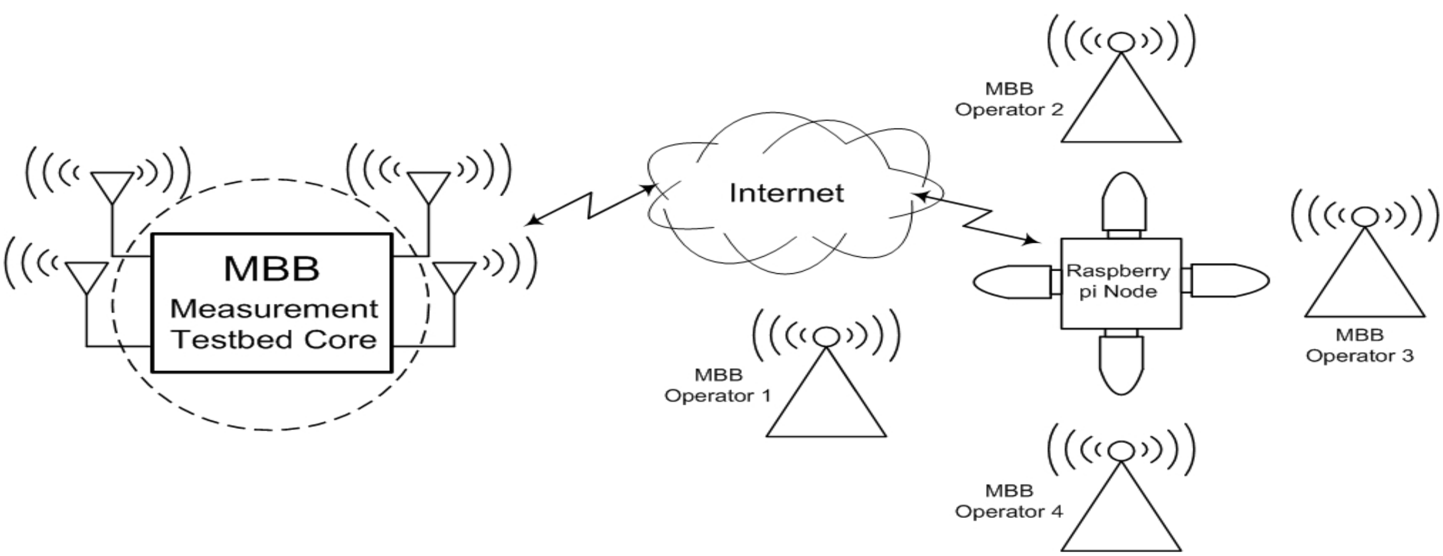

Figure 1: Model for MBB Measurement Testbed

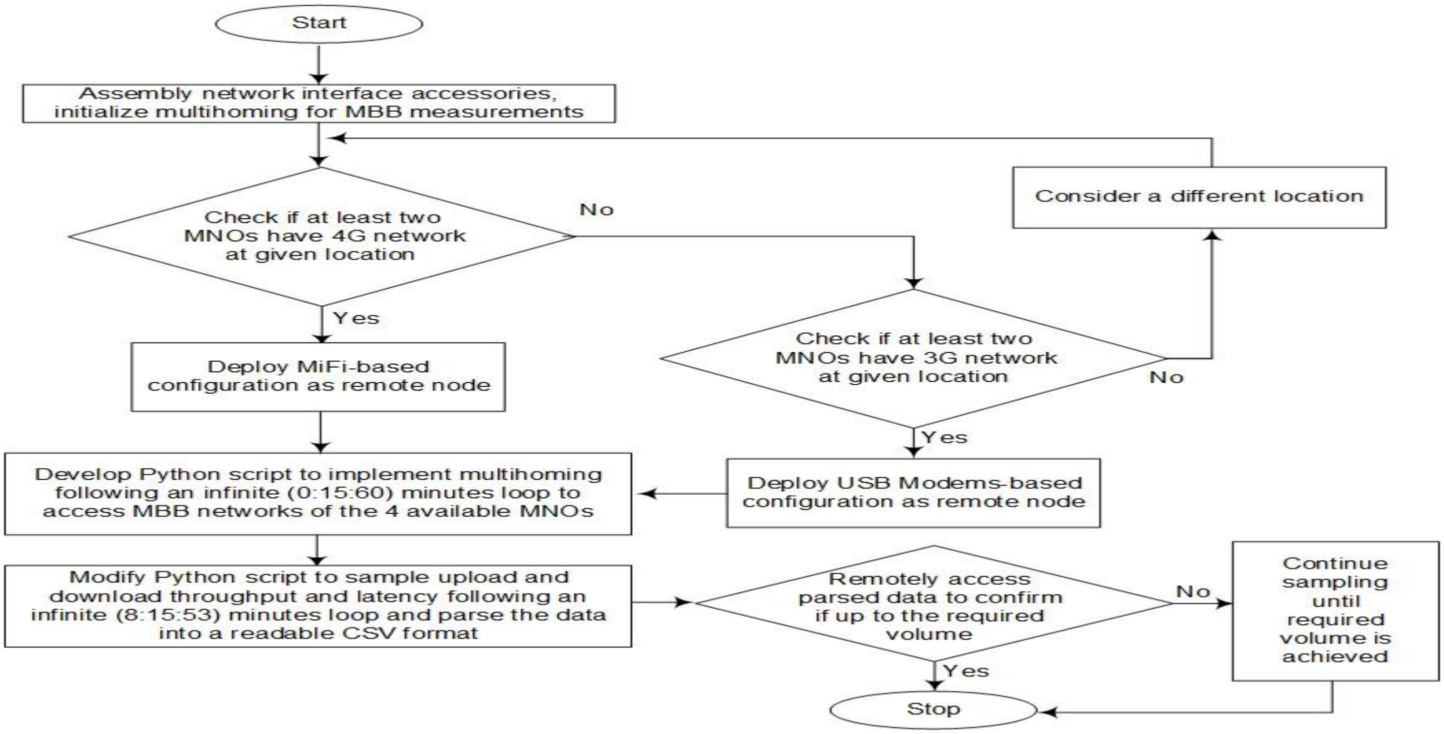

Figure 2: Configuration Methodology for Remote Node Operation

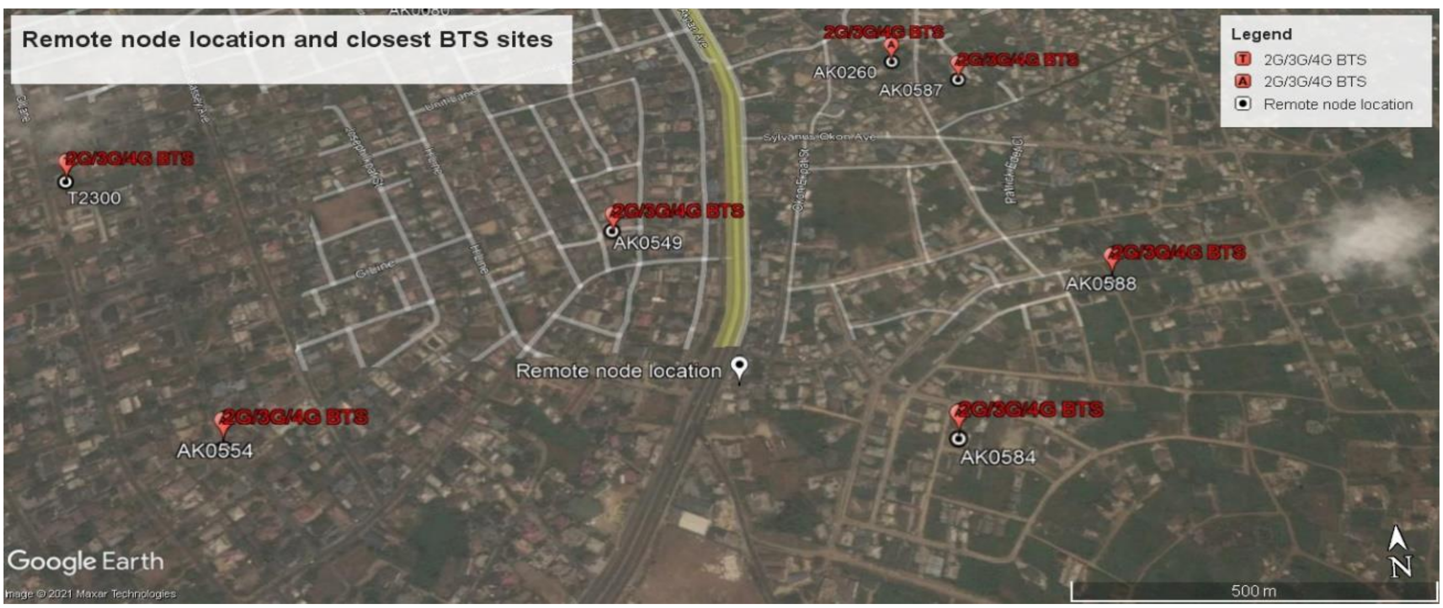

Figure 3: Remote Node Location and Closest BTS Sites

3.2 Measurement Approach, Location, Assumptions and Limitations

The location in Uyo where the remote measurement was deployed can be described as low density urban and situated at latitude 5.013° N and longitude 7.954° E. The closest BTS to the remote measurement node was less than 500m as can be seen in the Google Earth [26] rendition of the measurement area as shown Figure 3. It is therefore assumed that the results obtained from the measurements can be replicated in other locations of similar characteristics.

Each measurement instance (download or upload throughput and latency) was achieved by sending chunks of data between the measurement node and a Speedtest server via the nearest available base transceiver station. There were two major limitations to the measurement approach. The first is that the results obtained were dependent on the type of network access devices (modem). This limitation

was mitigated by ensuring that all the MNOs were subjected to virtually the same measurement conditions in terms of mode of connection (3G or 4G) and type of connecting devices. This enabled us to assume equality of treatment and fairness of results across all the MNOs.
The second limitation is based on the observation that measurements initiated at the node end only represent snapshots of the network at the specific time at which measurements are taken. As such, sampled values were found to vary continuously, leading to the need to sample at higher frequencies to achieve a more robust and granular data set. This led to data handling and storage problems. This limitation was overcome by compromising between high frequency sampling over a short duration of time and lower frequency sampling over a longer duration of time. As such, the method adopted relied on sampling every thirty minutes over a duration of three weeks (between October 2021 and November 2021) under static usage/measurement conditions.

4.0 RESULTS AND DISCUSSIONS

The sampled values for upload throughput, download throughput and latency for the four major MNOs in Nigeria were obtained and analyzed using MS Excel. These are presented in the following subsections.

4.1 Peak Upload and Download Throughput

The result presented in Figures 4 and 5 shows the peak throughput for 3G and 4G networks of the four major MNOs. The results are the maximum values measured over a three-week period from at least 1021 samples for each network. The measurements were done under static conditions. For the peak 3G download throughput, Airtel achieved the best result with 10.07Mbps closely followed by 9mobile as shown in Figure 4. MTN and Glo recorded peak download throughput of 9.77Mbps and 8.66Mbps respectively. Similarly, Airtel and GLO measured of 4.93Mbps and 4.30Mbps respectively for peak 3G upload throughput. The results presented for the 3G network shows that Airtel has the best throughput rates for both uplink and downlink.

The peak download and upload throughput measured for the 4G networks are presented in Figure 5. MTN recorded the highest peak throughput of 35.06Mbps for download and 32.47 Mbps for upload, while 9mobile had the lowest peak throughput rates of 10.58Mbps and 2.91Mbps for download and upload respectively. However, since there exists a significant difference in performance especially for the 4G network, it is also important to compare the average throughput recorded by the MNOs to have a holistic picture of their performance over a period of time.

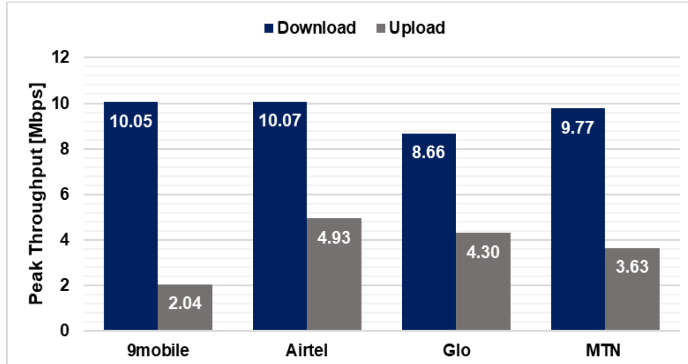

Figure 4: Peak Download and Upload Throughput for all MNOs using 3G

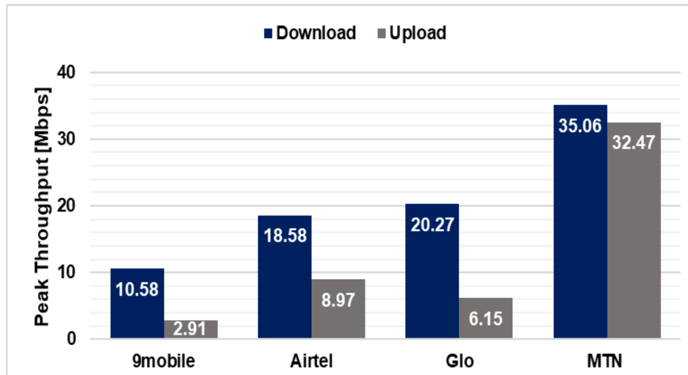

Figure 5: Peak Download and Upload Throughput for all MNOs using 4G

4.2 Average Download and Upload Throughput

Figure 6 shows the average throughput for the 3G network while that of the 4G network is shown in Figure 7. The results represent the average of hundreds of samples collected over the entire period of measurement for the four major MNOs. The result in Figure 6 shows that the MNO with the fastest average 3G download throughput recorded was Airtel, at 4.72Mbps while Glo recorded the lowest average download throughput of 3.28Mbps. 9mobile and MTN recorded average download throughput of 4.62Mbps and 3.91Mbps respectively. The results indicate that Airtel consistently delivered a faster upload throughput of 3.19Mbps on the 3G network compared to MNOs.

Figure 7 shows how the different MNOs performed on the 4G network. MTN shows superiority compared to other MNOs, with average download and upload throughput reaching 18.01Mbps and 17.49Mbps respectively. The average throughput values for 9mobile, Airtel and Glo range from 4.63Mbps to 5.66Mbps for upload and 1.56Mbps to 3.21Mbps for download. The result shows that MTN is more than three times faster than the other MNOs for average download throughput and up to five times faster for upload throughput.

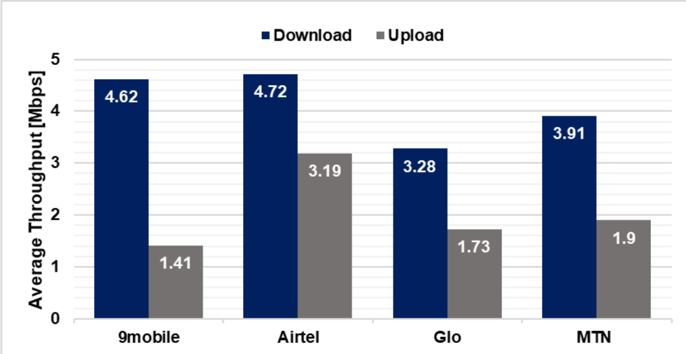

Figure 6: Average Download and Upload Throughput for all MNOs using 3G

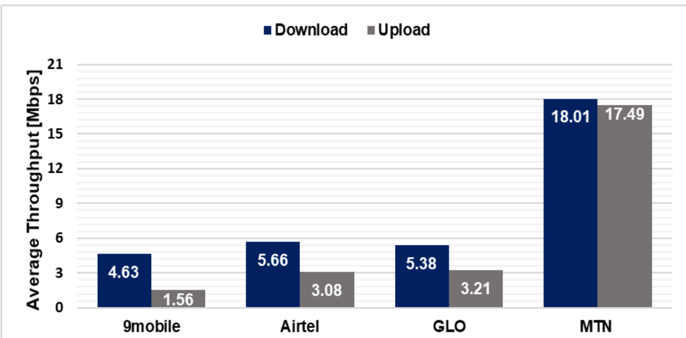

Figure 7: Average Download and Upload Throughput for all MNOs using 4G

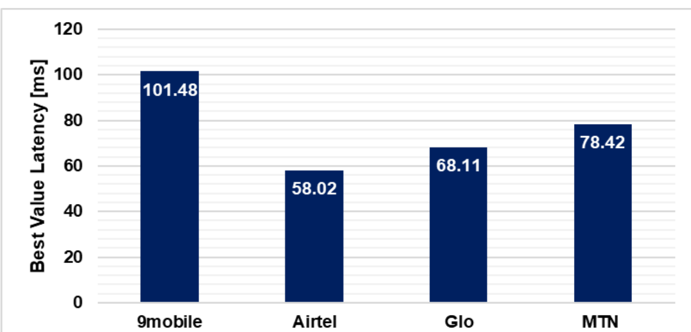

Figure 8: Best Value Latency on the 3G Network (Lower is better)

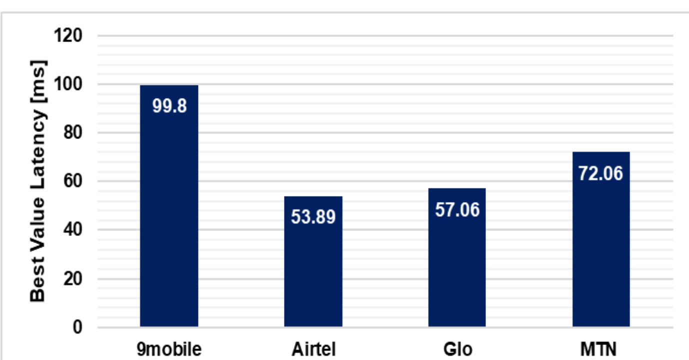

Figure 9: Best Value Latency on the 4G Network (Lower is better)

4.3 Latency

Large latency values have a detrimental effect on applications such as online gaming, live streaming and VoIP services. Such services require low latency to achieve an acceptable user experience. The latency values presented in Figures 8 and 9 are the best values for round trip communication time measured in milliseconds between the user equipment and the nearest Speedtest server for all the four major MNOs. Figure 8 shows the best value 3G latency results obtained for all the MNOs during the period of measurement. Airtel recorded the lowest latency value of 58.02ms while 9mobile had the highest value of 101.48 in this category. This is about 90% more than that of Airtel.

On the 4G network, Airtel still recorded the lowest latency value of 53.89ms followed by GLO and MTN with values of 57.06ms and 72.06ms respectively. 9mobile once again recorded a significantly larger value of 99.8ms. The results for both 3G and 4G networks show the same performance trend for the four MNOs. However, the best value of latency alone cannot tell the responsiveness of a network over time. This can be known using a statistical average of the numerous samples obtained during a long period of measurements.

4.4 Average Latency

The average 3G latency results obtained for all the MNOs are shown in Figure 10. MTN ranked the most responsive network with an average latency of 136.73ms, followed by Airtel at 167.83ms. 9mobile had the highest average latency of 381.64ms, which is significantly higher compared to the other MNOs. Whilst 9mobile performed better in terms of download throughput for the 3G network, its latency results shows that it may not be the most responsive.

For the 4G network, Glo was the most responsive with an average latency of 100.31ms, followed by MTN at 122.49ms as shown in Figure 11. Airtel recorded an average latency value of 136.68ms while 9mboile was the least responsive MNO at 243.43ms, which is significantly higher than all the other MNOs. In general, it is observed that 9mobile is the least responsive on both 3G and 4G networks, while there is no weighty difference in latency values for the other three MNOs.

4.5 Effect Of Time of the Day on Performance Metrics

There are usually perceived inconsistencies in the performance of MBB networks as observed by end-users. Literature reveals that such inconsistency may be caused by network congestion at certain times of the day, known as peak period [27-28]. It is therefore necessary to examine the MBB performance at different hours of the day.

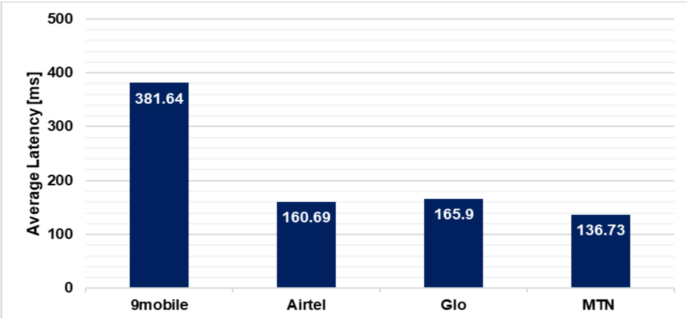

Figure 10: Average Latency on the 3G Network (Lower is better)

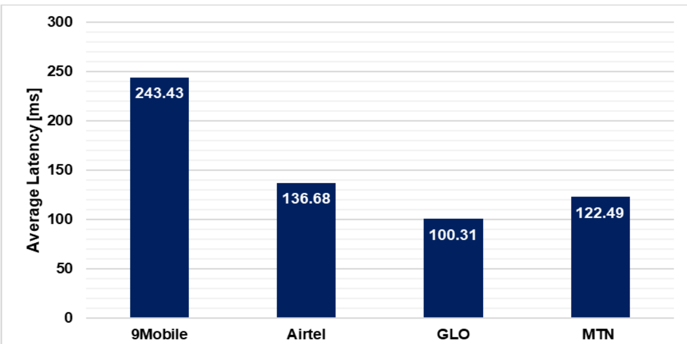

Figure 11: Average Latency on the 4G Network (Lower is better)

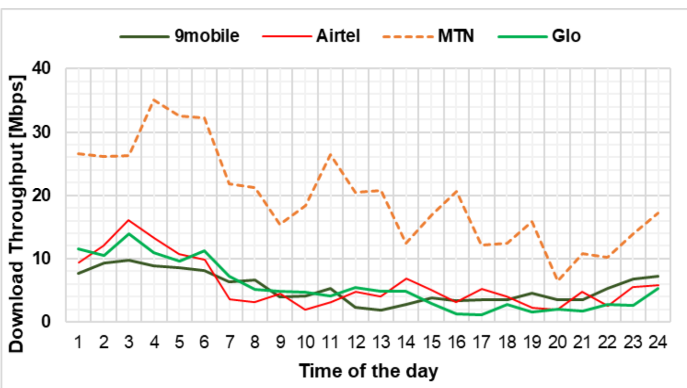

Figure 12: Effect of Time of the Day on Download Throughput for 4G Network

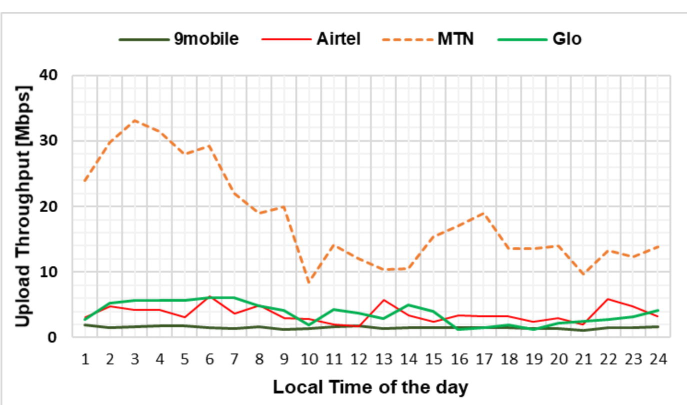

Figure 13: Effect of Time of the Day on Upload Throughput for 4G Network

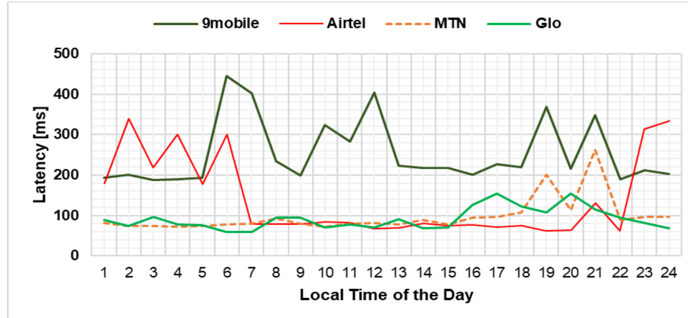

Figure 14: Effect of Time of the Day on Latency for the 4G Network

The peak period in Nigeria is defined as the hours between 7pm and 11pm, where users are presumed to be back from their daily businesses and thus have time to access the Internet. Figure 12 shows the download throughput for the 4G network plotted against the time of the day. The plotted data represents hourly averages calculated from the data samples collected during each day of measurements. It is observed that all the MNOs perform better from 12am to 5am (defined as off-peak period) where there is presumed low network congestion. All the MNOs experienced lower throughputs during the peak period, with significant variations in performance. The results also show that variability in performance increases for all MNOs between 9am and 9pm. The upload throughput follows a similar trend as the download throughput as seen in Figure 13.

Figure 14 reveals the effect of time of the day on the latency of all MNOs for the 4G network. 9mobile shows unstable performance throughout the day but with stability experienced between 10pm and 5am. Airtel on the order hand recorded high and fluctuating latency between 10pm and 6am but with stable performance at other times. Latencies of Glo and MTN were seen to be more stable from the early hours of the morning till evening while higher latency values were recorded during peak periods.

4.6 *Peak and Off-Peak Period Performance*

MBB users must understand how the different MNOs perform during peak periods (7pm to 11pm) and off-peak periods (12am to 6am) to make informed decisions where necessary. Figure 18 compares the average throughput rates during peak period and off-peak period between the four MNOs on the 4G network. The results are averages calculated from the data samples obtained between 7pm to 11pm and 12am to 6pm. It shows that MTN performs significantly better than other MNOs in both scenarios. Additionally, we observed that there is more than a 100% increase in throughput rates across all MNOs during off-peak periods.

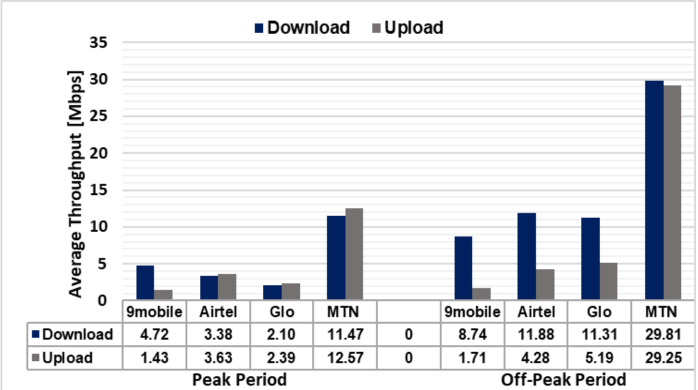

Figure 18: Average Throughput During Peak Period and Off-Peak Period on the 4G Network

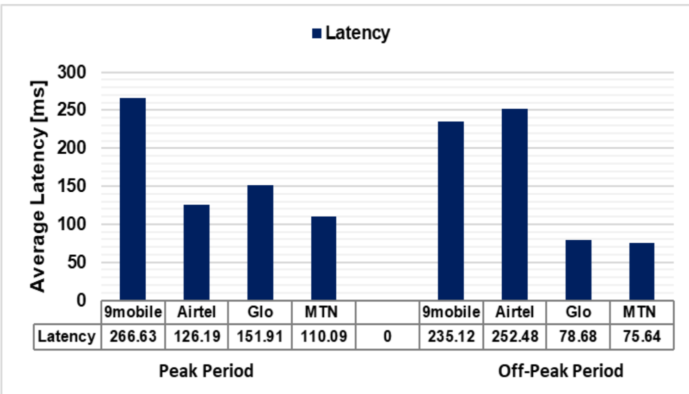

Figure 19: Average Latency During Peak Period and Off-Peak Period on the 4G Network (Lower is Better)

Figure 19 shows the average latency of all MNOs on the 4G network during peak periods and off-peak periods. MTN is the most responsive network in both scenarios while 9mobile records significantly high latency values in both cases. Glo closely follows MTN during off-peak periods with a latency of 78.68ms. Surprisingly, Airtel responds better during peak periods compared to its off-peak period performance. This information may prove valuable to subscribers within the locale where the measurements were taken.

5.0 CONCLUSION

In this paper, a testbed for measuring the performance of MBB networks was presented. The testbed measured the download and upload throughput and latency of four MNOs and the data obtained gave insights into performance offered to end users.

The comparative analysis of the results indicated that Airtel marginally performed better than other MNOs on the 3G network, while MTN outperformed the other MNOs on the 4G network. In terms of latency, 9Mobile was found to be the least responsive network with very high and variable latency. Further analysis revealed that time of the day is a significant factor that affects the overall MBB performance delivered to end users in both 3G and 4G networks.

6.0 CORRESPONDENCE

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