Original Research Article

ANALYSIS OF THE SIGNAL STRENGTH OF THE KEY TELECOMMUNICATION NETWORKS IN NASARAWA STATE

Abstract

Despite the widespread use of mobile phones in Nigeria, the quality of network services, particularly signal strength, remains inconsistent across different parts of Nigeria especially Nasarawa State which is the gateway to Abuja the Federal Capital.This study analyzes the signal strength coverage levels of key telecommunication network providers in Nasarawa State, Nigeria using the Signal Strength Info App for 4G mobile Networks base stations located in Urban, Sub-Urban, and Non-Urban environments of Nasarawa State. The study focused on five selected Local Government Areas including Nasarawa, Karu, Lafia, Keffi, and Akwanga. The data was analyzed to determine the mean signal strength for each network in each LGA and to identify trends and patterns in signal strength across the different networks and LGAs. The results shows that the order of service coverage for urban areas is higher in Lafia (AMN & CMN>BMN>DMN), followed by Karu (AMN>BMN & CMN>DMN) and Keffi (CMN>AMN & BMN>DMN), while for sub-urban areas Nasarawa (CMN>AMN>BMN>DMN), and for non-urban areas Akwanga (CMN & AMN>bmN>DMN). This implies that, AMN & CMN have the best service coverage across the urban terrain, while CMN have the best service coverage across the sub-urban terrain and AMN & CMN have the best service coverage across non-urban terrain. Findings from this study have revealed that, service coverage in Nasarawa State is best at the non-urban terrain, followed by the urban terrain, while it is poor at the sub-urban terrain. Overall, AMN consistently showing the highest signal strength coverage levels of 51.91%, followed by BMN (50.95%), CMN (47.74%) and DMN (21.55%). The findings highlight the importance of improving network infrastructure and BTS placement to enhance signal strength coverage, especially in sub-urban areas. Therefore, telecommunication companies should invest in improving their network infrastructure, strategically place BTS and consider environmental factors that may affect signal strength especially DMN network.

Keywords: Telecommunication network, signal strength, signal info app, 4G, mobile network, coverage level.

1. Introduction

The rapid proliferation of wireless communication technologies has transformed societies globally including Nigeria, where the telecommunications sector has become an integral part of daily life. Mobile phones and related services have revolutionized how people communicate, conduct business and access information. Nigeria, being one of the largest telecommunications markets in Africa, has seen exponential growth in mobile communication, particularly since the introduction of Global System for Mobile Communications (GSM) technology in 2001(Ndukwe, 2006).Nasarawa State, located in North-Central Nigeria, reflects the broader national trend of increasing reliance on mobile telecommunications. The state's diverse geographical landscape, comprising urban centers, rural communities, and remote areas, presents both opportunities and challenges for telecommunication service providers. Despite the widespread use of mobile phones, the quality of network services, particularly signal strength, remains inconsistent across different parts of the state. Factors such as terrain, infrastructure development, population density, and technological limitations all contribute to the variation in signal quality experienced by users (Iwuji &Emeruwa, 2018).

Telecommunication networks, such as MTN Nigeria, Globacom, Airtel, and 9mobile, dominate the Nigerian market and are the primary providers of mobile services in Nasarawa State. These networks have made significant investments in infrastructure, particularly in urban areas like Lafia, the state capital. However, residents in more rural or remote areas often face challenges related to poor signal strength, dropped calls, slow data speeds, and limited access to mobile services. Additionally, inadequate infrastructure development, especially in less populated areas, and reliance on older network technologies, like 2G and 3G, further exacerbate the problem. Despite efforts by telecommunication companies to expand coverage, significant gaps in service remain, affecting the daily lives of many residents (Emeruwa, 2015).

This study seeks to address the problem by analyzing the signal strength of the key telecommunication networks in Nasarawa State, identifying the areas with the weakest coverage, and exploring the factors that contribute to these deficiencies. The results of this study could provide valuable insights for telecommunication companies, policymakers, and other stakeholders working to improve mobile network coverage in the state.

2 Materials and Methods

2.1 Materials

The main materials used for this research are mobile cellular phones (Infinix Note 4 and Infinix X693 LTE/5G Compliant) Subscribers Identification Modules (SIMs) (MTN, Glo, Airtel and 9Mobile), HP ProBook 6550b Version Laptop (computer) and network signal info Application.

2.2 Methods

2.2.1 Research Design

To obtain representative samples for the study, a cluster and purposive sampling technique was used to randomly sample the base station antenna for all major mobile networks that have network coverage in Nasarwa State. Eight (8) base stations from each of the four (4) selected major network providers in five Local Government Areas were selected, making a total of 160 base station used for this study. The study was conducted in three propagation environments: non-urban terrains (Akwanga LGA), sub-urban terrains (Nasarawa LGA), and urban terrains (Karu LGA, Lafia LGA, and Keffi LGA) across Nasarawa State. The collected data was analyzed using statistical methods, with a focus to determine the mean signal strength for each network in each LGA.

2.2.2 Description of the Study Area

Nasarawa State is located in the North-Central region of Nigeria. The state has a population of over 2 million people and is served by multiple telecommunications operators including MTN-AMN, Glo-BMN, Airtel-CMN, and 9Mobile-DMN. Attenuation is caused by multiple reflections, absorption and multiple diffractions off roof tops, trees, cars etc. Most of the houses in Nasarawa State are below 30 meters and an average road width of about 35 meters. The concrete ground and tarred roads have very relative poor electrical conductivity, and therefore, cause attenuation by absorption. Ground reflected waves are blocked by buildings and trees. The State is known for its diverse terrain including plains, mountains and forests.

2.2.3 In Situ Measurements

Network Signal Info software with embedded google map was installed in an Infinix Note 4 phone used to obtain received signal strength (RSS) from fixed selected base stations (BST) at 1 km intervals. This distance was chosen because it represents the theoretical maximum radius of a cell in a cellular network. The cell Identifying Digits (CID) codes were matched with those on the maps to ensure accuracy, while the Transmitter parameters, were sourced as secondary data from the Nigerian Communications Commission (NCC) website. Of the 160 base stations selected for the study, we could no access eight (8) base stations in Karu and four (4) base stations in Akwanga due to kidnapping, armed robbery and banditry activities in those areas, leaving us with a total of 148 base stations for the analysis. Figure 1 shows a samplenetwork signal info app and how it was used for measurement in this study.

2.2.4. Measurement of Received Signal Strength (RSS)

According to the international standard of Radio Signal Strength Level (RSSL) (2020), for a location to have good signal strength, the signal strength received in dBm must be less than 90dBm. However, following the works of Bablu and Komal (2017) and Omorogiuwa (2015) the signal strength coverage level (SSCL) in % and average signal strength level (RSS) in dBm obtained from each measurement location of the different mobile networks studied can be calculated as follows.

$$SSCL = \frac{NSLGC}{TNSL} \times 100\% \quad (1)$$

$$Average\ RSS = \frac{\Sigma SSL}{N} \quad (2)$$

Where, N is the number of signal strength level measured, NSLGC is the number of study locations with good coverage, TNSL is the total number of study locations and SSL is the signal strength level.

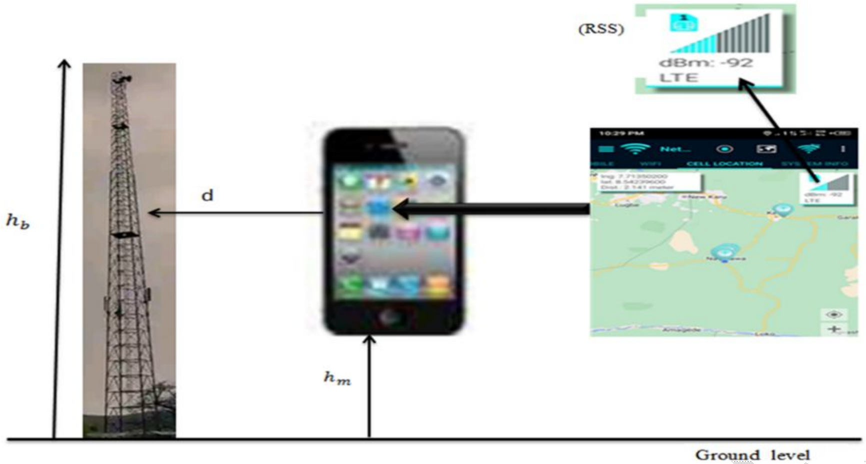

Figure 1: Signal info app and how it was used for measurement

3. Results

The result of the received signal strength obtained for the five different locations are presented in Tables 1 to 5.

Table 1: Measured received signal strength for major mobile networks in Nasarawa LGA

		Mean RSS (dBm)								
Network	**Dist. (Km)**	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	SU_8	Mean (dBm)
AMN	1.00	-82	-81	-84	-85	-71	-80	-82	-80	-80.63
	2.00	-83	-84	-82	-81	-77	-82	-83	-82	-82.50
	3.00	-87	-87	-86	-87	-79	-85	-83	-80	-86.75
	4.00	-85	-86	-84	-88	-80	-88	-86	-85	-85.75
	5.00	-80	-91	-95	-91	-91	-90	-92	-92	-91.38
BMN	1.00	-80	-85	-83	-79	-80	-77	-81	-76	-80.13
	2.00	-85	-89	-87	-83	-84	-84	-85	-79	-84.50
	3.00	-88	-95	-90	-89	-87	-82	-87	-84	-87.75
	4.00	-97	-99	-96	-93	-90	-88	-93	-91	-93.38
	5.00	-99	-101	-99	-100	-99	-91	-102	-99	-98.75
CMN	1.00	-75	-77	-81	-80	-70	-78	-80	-76	-77.13
	2.00	-73	-77	-71	-84	-74	-79	-84	-77	-77.38
	3.00	-79	-79	-73	-85	-78	-85	-87	-71	-79.63
	4.00	-83	-81	-77	-89	-84	-87	-87	-76	-83.00
	5.00	-84	-87	-81	-90	-80	-90	-90	-80	-85.25
DMN	1.00	-89	-90	-88	-80	-90	-89	-88	-90	-88.00
	2.00	-90	-91	-89	-86	-99	-88	-87	-90	-90.00
	3.00	-95	-93	-91	-92	-103	-90	-97	-103	-95.50
	4.00	-101	-109	-103	-100	-105	-107	-100	-106	-103.88
	5.00	-105	-107	-101	-100	-109	-110	-101	-112	-105.63

Table 2: Measured received signal strength for major mobile networks in Karu LGA

		Mean RSS (dBm)						
Network	**Dist. (Km)**	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	Mean (dBm)
AMN	1.00	-80	-76	-70	-88	-84	-81	-76.83

	2.00	-81	-85	-83	-89	-86	-85	-84.83
	3.00	-89	-88	-88	-93	-88	-82	-88.00
	4.00	-90	-88	-89	-97	-85	-84	-88.83
	5.00	-101	-90	-94	-104	-89	-90	-94.66
BMN	1.00	-88	-81	-87	-81	-77	-87	-83.50
	2.00	-85	-84	-93	-86	-81	-89	-86.33
	3.00	-89	-89	-99	-90	-85	-91	-90.00
	4.00	-99	-93	-100	-97	-90	-99	-96.33
	5.00	-108	-103	-106	-100	-99	-102	-103.00
CMN	1.00	-82	-81	-84	-85	-87	-88	-84.50
	2.00	-83	-84	-82	-81	-88	-89	-84.00
	3.00	-87	-87	-86	-87	-87	-92	-87.67
	4.00	-95	-96	-94	-98	-90	-97	-95.00
	5.00	-104	-105	-105	-103	-99	-99	-102.50
DMN	1.00	-88	-80	-85	-89	-90	-91	-87.16
	2.00	-90	-90	-87	-90	-95	-96	-91.33
	3.00	-95	-95	-89	-94	-99	-99	-95.16
	4.00	-99	-99	-107	-105	-104	-103	-102.80
	5.00	-101	-105	-100	-112	-109	-106	-105.50

Table 3: Measured received signal strength for major mobile networks in Lafia LGA

		Mean RSS (dBm)								
Network	**Dist. (Km)**	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	SU_8	Mean (dBm)
AMN	1.00	-81	-85	-79	-67	-70	-77	-84	-87	-78.75
	2.00	-81	-87	-89	-67	-73	-79	-86	-89	-81.38
	3.00	-86	-89	-95	-87	-78	-85	-88	-90	-87.25
	4.00	-89	-90	-91	-82	-88	-88	-89	-93	-88.75
	5.00	-99	-95	-99	-90	-89	-92	-95	-101	-95.00
BMN	1.00	-81	-75	-83	-82	-77	-79	-70	-73	-77.50
	2.00	-80	-79	-81	-82	-79	-80	-76	-75	-79.00
	3.00	-82	-80	-81	-83	-80	-85	-78	-76	-80.63
	4.00	-83	-82	-84	-81	-87	-89	-80	-78	-83.00
	5.00	-84	-81	-83	-85	-99	-99	-85	-88	-88.00
CMN	1.00	-80	-85	-80	-66	-69	-76	-83	-87	-78.75
	2.00	-80	-87	-88	-67	-70	-82	-85	-90	-81.38
	3.00	-86	-89	-95	-87	-78	-85	-88	-90	-87.25
	4.00	-89	-90	-91	-82	-88	-88	-89	-93	-88.75
	5.00	-99	-95	-99	-91	-88	-90	-96	-100	-95.00
DMN	1.00	-81	-88	-82	-82	-89	-87	-81	-80	-88.75
	2.00	-95	-90	-95	-90	-93	-80	-80	-88	-88.88
	3.00	-107	-105	-106	-94	-99	-99	-94	-99	-100.40
	4.00	-113	-109	-100	-99	-100	-101	-99	-107	-103.50
	5.00	-113	-109	-107	-108	-104	-104	-105	-115	-108.10

Table 4: Measured received signal strength for major mobile networks in Keffi LGA

		Mean RSS (dBm)								
Network	**Dist. (Km)**	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	SU_8	Mean (dBm)
AMN	1.00	-89	-88	-84	-87	-80	-81	-82	-82	-84.13
	2.00	-90	-85	-83	-88	-86	-87	-88	-89	-87.00
	3.00	-91	-87	-89	-90	-89	-89	-90	-90	-89.38
	4.00	-92	-88	-90	-91	-90	-90	-98	-85	-89.38
	5.00	-99	-98	-91	-99	-94	-95	-94	-95	-95.63
BMN	1.00	-79	-80	-78	-81	-80	-79	-87	-88	-81.50
	2.00	-85	-84	-83	-86	-87	-83	-87	-88	-85.38
	3.00	-88	-88	-89	-87	-89	-90	-88	-89	-88.75
	4.00	-89	-89	-88	-90	-90	-90	-89	-90	-89.38
	5.00	-95	-90	-94	-95	-95	-94	-90	-92	-93.13
CMN	1.00	-83	-81	-84	-85	-86	-87	-89	-88	-85.38
	2.00	-87	-84	-92	-91	-87	-87	-88	-77	-86.63
	3.00	-89	-88	-96	-97	-88	-89	-82	-87	-89.50
	4.00	-90	-89	-90	-90	-90	-84	-90	-90	-89.13
	5.00	-94	-95	-100	-101	-94	-90	-98	-96	-96.00
DMN	1.00	-90	-88	-81	-86	-88	-86	-83	-89	-86.38
	2.00	-100	-99	-88	-88	-98	-99	-88	-90	-93.75
	3.00	-109	-108	-93	-94	-108	-100	-99	-99	-101.30
	4.00	-110	-110	-99	-99	-118	-118	-100	-100	-106.80
	5.00	-112	-117	-101	-104	-119	-118	-111	-113	-111.90

Table 5: Measured received signal strength for major mobile networks in Akwanga LGA

		Mean RSS (dBm)							
Network	**Dist. (Km)**	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	Mean (dBm)
AMN	1.00	-85	-87	-80	-81	-85	-86	-87	-84.43
	2.00	-85	-89	-88	-81	-87	-88	-89	-86.71
	3.00	-88	-90	-83	-89	-89	-87	-78	-86.29
	4.00	-92	-93	-91	-99	-95	-102	-76	-92.57
	5.00	-94	-95	-93	-90	-97	-100	-99	-95.43
BMN	1.00	-83	-82	-81	-85	-87	-81	-88	-83.86
	2.00	-82	-81	-84	-85	-88	-85	-88	-84.71
	3.00	-83	-84	-82	-81	-89	-87	-87	-84.71
	4.00	-87	-87	-86	-87	-90	-88	-89	-87.71
	5.00	-85	-86	-84	-88	-91	-92	-90	-88.00
CMN	1.00	-82	-84	-80	-80	-85	-83	-87	-83.00
	2.00	-86	-89	-88	-86	-81	-88	-89	-86.29
	3.00	-88	-91	-83	-89	-89	-87	-79	-86.57
	4.00	-90	-90	-94	-99	-95	-99	-88	-93.57
	5.00	-94	-95	-93	-90	-97	-101	-99	-95.57
DMN	1.00	-87	-88	-92	-82	-79	-87	-81	-85.14
	2.00	-88	-90	-90	-90	-88	-89	-84	-88.43
	3.00	-90	-95	-96	-94	-90	-94	-90	-92.71
	4.00	-93	-99	-99	-99	-97	-98	-97	-97.42
	5.00	-93	-99	-100	-108	-99	-100	-101	-100.00

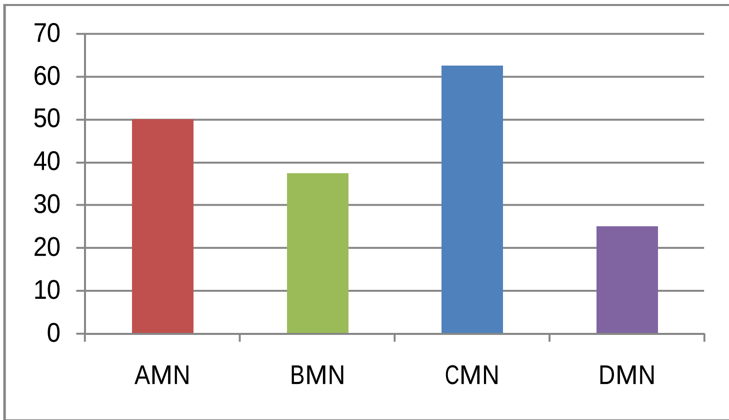

Fig. 2: Mobile Networks Signal Coverage Level in Nasarawa

It can be deduced from Fig.2that the signal strength in Nasarawa is low, except for CMN which provides better network coverage with 62.5%and AMN with moderatenetwork coverage of 50.0% compared to BMN 37.5% and DMN 25.0%.This may be as a result of the location of the base transmitting stations.Most of the base transmitting stations are sited ata distance away from the study locations which leading to poor network within the suburban and urban terrains of Nasarawa. This implies that, receive signal strengths are influenced by distance from base transmitting stations. Furthermore, the received signal strength witnessed aloss in its strengthwhen the distance increases for various mobile networks.

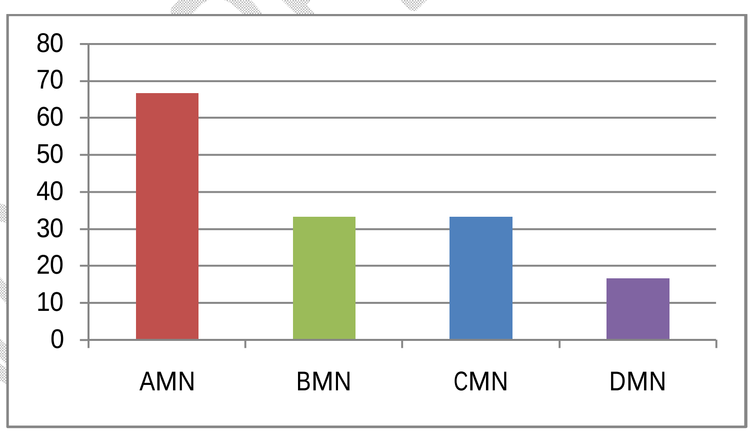

Fig. 3: Mobile Networks Signal Coverage Level in Karu

It can be seen from Figure 3 that the network coverage in Karu is generally very poor except for only AMN that has good signal strength coverage level 66.67%. BMN and CMNhave similar distribution 33.33%,while DMN16.67% is the worst ascompared to all other networks. High dense population in urban terrains of Karu could be a possible reason for the poor signal,suggesting a need for improvement in network infrastructure in Karu.

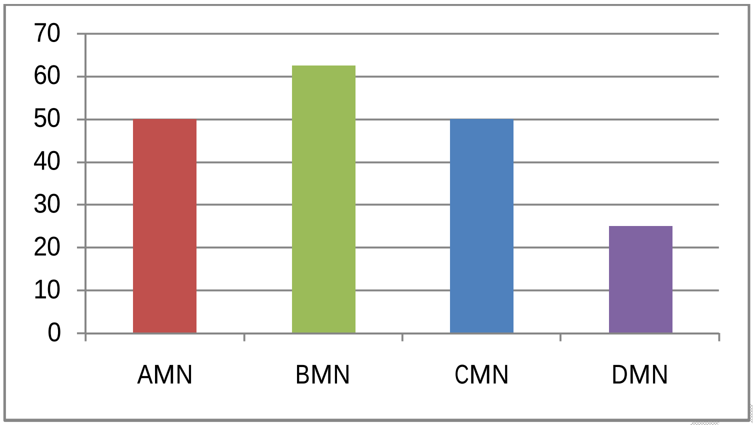

Fig. 4: Mobile Networks Signal Coverage Level in Lafia

At Lafia(Fig. 4), the signal strength of the various GSM networks studied was observed to be very good(75.0% for AMN and CMN, and 62.5% for BMN). Thus, this resulted to good network coverage level in the selected locations (suburban and urban area) within Lafiawhere signal strength measurement was carried out, except for DMN network which has a bad network coverage level 37.5%. The bad signal strength recorded may be due to the lack of repeater stationsin the BTS for 9mobile or it appear to be few and also far away from the study area. Therefore, more base transmitting stations or installation of repeater stations at 9mobileBTS strategic places in Lafiawould improve the quality of the signal strength received and thus increase the coverage levels of the various networks in Lafia.

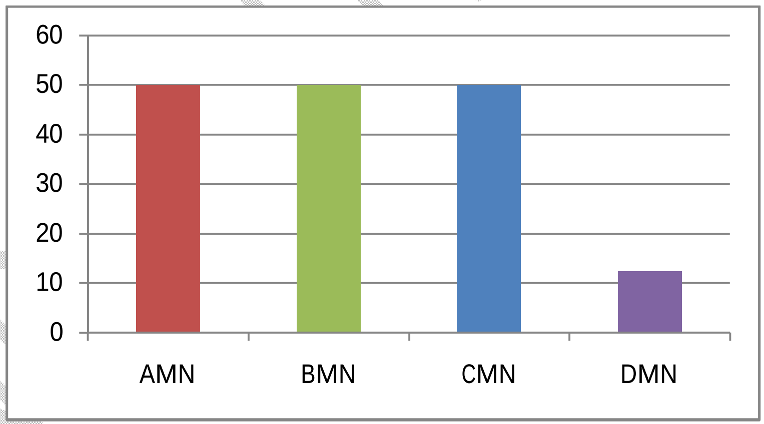

Fig .5: Mobile Networks Signal Coverage Level in Keffi

At Keffi, it was observed that the quality of received signal strengths is generally poor. The signal for AMN, BMN and CMN is moderate with 50% network coverage each and has a similar distribution pattern while that ofDMNis only 12.5% coverage. However, the random drop in RSS distribution, isprobably due to the presence of tall trees and building in the urban area. This implies that the undulating of RSS that was witnessed is duplicated at various geographical locations and by the mobile communication networks.

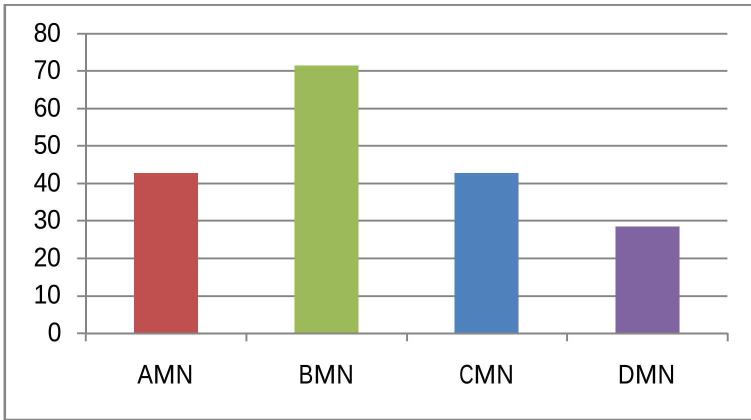

Fig. 6: Mobile Networks Signal Coverage Level in Akwanga

The received signal strength of the various mobile networks in Akwanga is very good as shown in Fig. 6 except for DMN 28.57%.AMN and CMN leads with 85.71% coverage followed by DMN with 71.42%. It was also observed that the received signal strengthtransmitted is not the same from the various BTS located at various areas of Akwanga. This implies thatvarious geographical locations witnessed adifferent level of RSS on the mobile station.

Table 6: Mean received signal strength for major mobile networks in Nasarawa State at 5km

Network	Dist. (Km)	Mean RSS (dBm)				
		Nasarawa	Karu	Lafia	Keffi	Akwanga
AMN	5.00	-91.38	-94.66	-95.00	-95.63	-95.43
BMN		-98.75	-103.00	-88.00	-93.13	-88.00
CMN		-85.25	-102.50	-95.00	-96.00	-95.57
DMN		-105.63	-105.50	-108.10	-111.90	-100.00

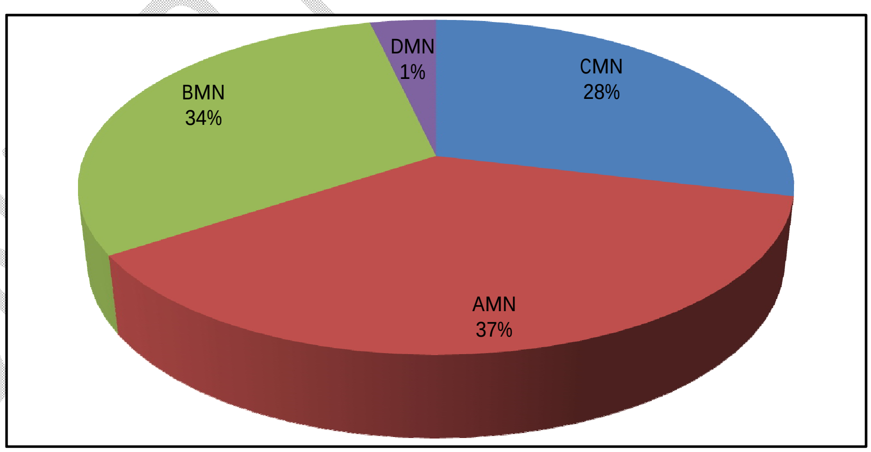

Fig. 7: Signal strength coverage levels of major networks in Nasarawa State

Table 6 shows the summary of signal strength coverage level of AMN, BMN, CMN, and DMN networks in Nasarawa State.AMN covers about 37% of Nasarawa State, followed by BMN 34%, CBN 28% and DMN only covers 1%. Therefore, as the network continuously changes in response to changes in offered traffic, monitoring and optimizing the QoS are considerably recommended. Also, to foster competitiveness and a fair market, DMN most focus on infrastructure development especially increase base stations across Nasarawa State.

4. Discussion

The findings of this study provide valuable insights into the signal strength coverage levels of key telecommunication networks in Nasarawa State. The analysis revealed significant differences in signal strength coverage levels between the networks as the quality of signal strength depends on the location within Nasarawa State and different networks perform better in different areas of the State. This finding is in similar to that of Adegoke, *et al.* (2019). AMN have good service coverage in Karu (66.67%), Lafia (75.00%) and Akwanga (85.71%) but may need to improve their service in Nasarawa and Keffi. BMN have good coverage in Lafia (62.50%) and Akwanga (71.42%) but will need to improve their serfvice in Nasarawa, Karu and Keffi. CMN have good service coverage in Nasarawa (62.50%), Lafia (75.00%) and Akwanga (85.71%) but will also need to improve their service in Karu and Keffi. However, DMN network is consistently very poor in all the regions studied which may require them to step up their game in other not to be left out. The order of service coverage for urban areas is higher in Lafia (AMN & CMN>BMN>DMN), followed by Karu (AMN>BMN & CMN>DMN) and Keffi (CMN>AMN & BMN>DMN), while for sub-urban areas Nasarawa (CMN>AMN>BMN>DMN), and for non-urban areas Akwanga (CMN & AMN>bmN>DMN).This implies that, AMN & CMN have the best service coverage across the urban terrain, while CMN have the best service coverage across the sub-urban terrain and AMN & CMN have the best service coverage across non-urban terrain.This finding is in line with that of Sharma and Singh (2019) but not in line withSa’adu (2019).

Findings from this study have revealed that, service coverage in Nasarawa State is best at the non-urban terrain, followed by the urban terrain, while it is poor at the sub-urban terrain.Overall, AMN consistently showing the highest signal strength coverage levels of 51.91%, followed by BMN (50.95%),CMN (47.74%) and DMN (21.55%). This finding is in line with that of Galadanci and Abdullahi (2018) and Sharma and Singh (2019). However, not in line with that of Igwe et al. (2022) who obtained good signal quality for all the four networks and contradicts that of Adewale *et al.* (2024).The differences in signal strength coverage levels can be attributed to several factors, including the location of base transmitting stations (BTS), network infrastructure, environmental factors, and proximity of BTS in non-urban and urban areas. Therefore, the importance of improving network infrastructure and BTS placement to enhance signal strength coverage, especially in sub-urban areas is recommended. Improving signal strength coverage in these areas could help bridge the digital divide and improve access to telecommunication services for all residents of Nasarawa State.

5. Conclusion

In conclusion, this study highlights the varying signal strength coverage levels of different mobile networks across Nasarawa State. It underscores the importance of strategic placement of transmitting stations to improve network coverage and signal strength, especially in areas with poor coverage like urban and sub-urban locations within the entire State.Based on the findings of this study,it is recommended that the telecommunication companies should invest in improving their network infrastructure, including the installation of more BTS especially in sub-urban areas to enhance signal strength coverage.Telecommunication companies should also strategically place BTS to ensure optimal signal strength coverage across all areas of Nasarawa State.Consideration should be given to environmental factors such as tall buildings and trees, which can affect signal strength. Companies should assess and mitigate these factors to improve signal strength coverage, and regulatory body (NCC) should monitor and enforce standards for signal strength coverage to ensure that telecommunication companies provide adequate coverage across all areas of Nasarawa State. Finally, collaboration between telecommunication companies and government agencies can help improve signal strength coverage, especially in underserved areas.

References

Adegoke, A. O., Bakura, M. U., Mustapha, M. I. & Sani I. M. (2019). Comparative Analysis of Received Gsm Signal Strength Network in University of Maiduguri, Borno State, Nigeria. *Arid Zone Journal of Engineering, Technology & Environment, 15*(4), 61-1066.

Adewale, A. S., Adigun, O. O. & Yusuf, Y. (2024). Assessment of Signal Strength of Mobile Communication Networks Within the School of Engineering Federal Polytechnic, Ado Ekiti. *JEES., 17*(1), 131 – 139.

Agim, L.C. (2015). Variability of Selected Soil Properties of a River Slope in Amaigbo, Southeastern Nigeria. *FUTOJournalSeries(FUTOJNLS), 1*(2), 8-16.

Akanni, J. (2014). *Signal Strength Analysis of GSM of Selected Service Providers in Ilorin, Nigeria.* An B.Eng. Project Submitted to the Department of Electrical and Electronics Engineering, University of Ilorin (Unpublished).

Akanni, J., Avazi-Omeiza, I. &Olufeagba, B. J. (2015). *A Study of GSM Signals in Nigeria*. An B.Eng. Project Submitted to the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin (Unpublished).

Alumona, T.L. & Kelvin, N. N. (2015). Path Loss Prediction of Wireless Mobile Communication for Urban Areas of Imo State, South East Region of Nigeria at 910 MHz.*Journal of Academia and Industrial Research (JAIR), 2*(7), 234-456.

David, G. (2012). Measurements and Models for Radio Path Loss and Penetration Loss in and Around Homes and Trees at 5.85 GHz. *American Journal of Scientific and Industrial Research, 46*(11), 38-245.

Galadanci, G.S.M. & Abdullahi, S.B. (2018). Performance Analysis of GSM Networks in Kano Metropolis of Nigeria. *American Journal of Engineering Research (AJER), 7*(5), 69-79.

Igwe, J., Anani, N. & Emmanuel, A.L. (2022). Performance Assessment of four Major GSM Networks in Nigeria. *Journal of Computer Science Research, 3*(4), 20-25.

Jones, Y. (2015). Radio Propagation models. Message posted to “People Seas Harvard”. Accessed on 23 April, 2023 from http://people.seas.harvard.edu/~jones/es151/prop_models/propagation.html.

Kasliwal, M. H. &Suryawanshi, S. B. (2018). Electric Field Strength Prediction Model Based Upon Artificial Neural Networks. *International Journal of Engineering Sciences & Research Technology, 40*(3), 4 -23.

Mawjoud, S.A. (2003). Path Loss Propagation Model Prediction for GSM Network Planning. *International Journal of Computer Application, 84*(7), 97-20

Moinuddin, A. A. & Singh, S. (2007). AccuratePath Loss Prediction in WirelessEnvironment. *International Journal of Advanced Research in Computer and Engineering, 8*(8), 09-13.

Muhammed, M. A. (2014). *Collocation of GSM Base Stations for Multilple Operators in University of Ilorin.* A B. Eng. Project work Submitted at the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin.

Ndukwe, E.C. (2011). ComparativeAnalysis of Quality of Signal of Different Service Providers.*International Journal of Innovative Research in Science, Engineeringand Technology (IJIRSET), 6*(4), 5629-5633

Nwankwere, A. (2002). Modern Approaches in Modeling of Mobile Radio Systems Propagation Environment.Message Posted to “Academia”. Accessed on 27th March, 2023 from http:/academia.edu.com/chapter/10.1007/978-1-4302-6014-1_2.Agrawal,

Olawole, M. U. (2008). Investigation of Propagation Characteristics of UHF Waves in Akwa Ibom State, Nigeria. *Indian Journal of Radio and Space Physics, 3*(7), 197-203.

Parsons, J. D. (2000). The Mobile Radio Propagation Channel. Message posted to “Acadamia”. Accessed on 23rd May, 2023 from http://www.academia.edu.

Patrick, J.D. (2014). Radio Wave Propagation Through Woods. *International Journal of Engineering Sciences & Research Technology (IJESRT), 2*(5), 33–37.

Sa’adu, S.D. (2019). Assessment of the Signal Strength in Decibels (dBm) for three GSM Network Service Providers Airtel, GLO, and Etisalat at the Federal University, Gusau. *International Journal of Advanced Computer Science and Applications, 13*(3), 521-528.

Sharma, P. K. & Singh, R.K. (2019). Signal Strength and Quality of Signal of Some Cellular Networks in Ogoni, South – South Nigeria. *International Journal of Wireless & Mobile Networks (IJWMN), 8*(3), 55-70.

Wojuade, M. D. (1993). System for Mobile Communication (GSM) in Nigeria. *Journal of Wireless Networking and Communications, 1*(1), 8-15.

Thomson, I. K., Nancy, S.&Mohammad, M.T. (2000). An Assessment of the Disparity Urban Housing Quality in Keffi, Nasarawa State, Nigeria. *International Journal of Innovations in Environmental Sciences and Technology, 2*(1), 130-139.

Ushie, E. M. (2013). A Smart-bin prototype for in-house waste management. Strathmore University. Message Posted to"Plus Strathmore". Accessed on 23rd May, 2023 from http://su plus.strathmore.edu/handle/11071/5659.