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RF Coverage Mapping of Mobile Phone Networks in Nigeria

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Abstract: Over time, the customers of mobile network operators across Nigeria have suffered from the uncertainty of signal coverage at different locations. This uncertainty is created by poor or unavailability of network services due to inadequate coverage by individual mobile operators. This results in subscribers of a given operator not having connectivity in some locations where the operator's service is not covered. To mitigate this, an android-based mobile application and a web application were designed and implemented. This software entity uses a crowdsourcing technique to collect mobile signal data of all operators across the country. The mobile application contains a web service entity that collects signal strength and location data of mobile users on an hourly basis and stores the same in a local mobile database located in the user device. At specified intervals, the content of the local mobile database is forwarded to a centralized secure database located in a webserver. The App maps the crowdsourced data on the google map of Nigeria and displays it on the user device. Thus, users can, ab initio, know the locations where various operators cover and the strength of the signals. This solution will not only help users solve connectivity challenges but will also provoke healthy competition among service providers to improve their network coverage and quality of service (QoS). It will also help communication regulators like the Nigerian Communication Commission (NCC) to independently appraise the level of mobile coverage across Nigeria for appropriate planning and policymaking. Again, the crowdsourced data which with time will become Big Data will serve as a data house for future research on Big Data Analytics and will be used to provide solutions to various connectivity and human mobility problems.

Keywords: Mobile phone, Coverage map, Web service, Mobile application, Web application, Signal strength.

1. Introduction and Overview

Though mobile phone networks claim to have covered all locations in Nigeria, mobile users' experience is not commensurate to this claim[1], they still suffer from connectivity problems due to poor or unavailability of network coverage in different locations across the country. This is because some locations are yet to be covered while some are poorly covered. Thus, a subscriber of a mobile phone network who travels to a location without knowing aforetime that the network is poorly covered in that location will face connectivity problems. Information about coverage given by network operators may not give a correct judgment of their performance since all of them claim to be the best. If subscribers have a means of measuring the QoS of mobile phone network service, operators will put in more effort in boosting the quality of their services. Due to the stochastic nature of wireless channels, subscribers remain the best persons to appraise the coverage level and QoS of wireless services in any area based on their experience. Hence, a system needs to be designed to enable them to do this effortlessly without any form of technical training or bias.

This challenge of network operators' performance evaluation has drawn the attention of different bodies to provide coverage information to users to guide their choice of network as they travel from one place to another. The Office of Communication (OfCom), United Kingdom (UK) for example, and the Telecommunication Regulatory Agency of India (TRAI) have taken measures to measure, analyze and map the coverage level of mobile phone networks in some areas of interest in the UK and India respectively to know the quality of radio service provided by mobile phone operators[2][3][4][5][6]. This measurement and mapping will not only provide users with information about mobile communication coverage in different locations but will also challenge network operators to improve on their QoS[7] and guide them in the installation of new base stations. Some studies have been carried out on the measurement and mapping of Wi-Fi network coverage[6], Wireless Sensor Network (WSN) coverage[8], noise intensity[9], mobile phone network coverage[10], etc. using different measurement techniques. In this study, our focus is on measuring and mapping mobile phone network coverage in Nigeria. We designed a system that runs on users' internet-enabled

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android phones to collect signal strength and location information and route them to a server. In addition, the system can map the collected data through a mobile app for users' consumption. Section 2 highlights some related works, section 3 explains the methodology employed in the study, results obtained are captured in section 4 while section 5 concludes the paper.

2. Related Works

In mapping mobile coverage data, emphases are laid upon the techniques of data collection and visualization[11]. Data collection methods include drive testing and crowd-sourcing approaches[12],[13]. In the drive-testing approach, measurements are taken by driving vehicles containing testing equipment along locations of interest[14],[15]. Though this technique is effective, it is expensive and cannot be used in areas that are not motorable. In the same vein, in the drive-testing approach, measurements are taken at an instance of time. It only gives the nature of wireless service at the point of testing. It cannot be used to describe the continuous behavior of radio signals in a place. It does not account for the variations that occur over time. A less expensive technique is crowdsourcing. It involves getting mobile coverage information directly from users[16][17][18] via phone calls, social media, the use of questionnaires, interactions, and programmatically via a mobile application[19][20][21][22]. The veracity of information obtained by direct interaction with users may be uncertain and not portray the exact user experience due to personal bias. However, crowdsourced data obtained programmatically via a mobile app gives a more accurate picture of user experience because coverage information is estimated by a large dataset received from multiple users in a specified location. This technique also takes into account the changes associated with wireless communication with respect to time. It is very cheap compared to drive-testing and other methods because users themselves send coverage data to a server automatically through their mobile phones at preprogrammed intervals[23]. The bane of this technique is that crowdsourcing via a mobile application requires mobile users to install the application. Thus, this technique becomes effective when the application is installed by a large number of users.

Several researchers have employed some of these techniques in different applications. Vasicek et al.[24] for example proposed an android application for measuring the quality and coverage of mobile networks (2G-4G). Tests were carried out on the quality of speech, the network coverage, speed of website loading and, data rate. Analysis of the results gotten was done on either the application or a web interface. Visualization of measured results obtained is done using a map via Global Positioning System (GPS) location. Individual results derived could also be exported to either a CSV, JSON, or XML file for further analysis. In the same vein, Luckin et al.[13] presented a comparative study of the software prediction of Global System for Mobile Communication (GSM) coverage area signals with measured results gotten from an implemented radio infrastructure. Measurement of the GSM signal coverage area in an urban area was carried out to ascertain the credibility of the GSM coverage area software. It was deduced that there were large deviations from the measured values compared to the predicted values. This deviation was observed to be more in areas with poor signals. Therefore, a more precise technique is required for signal strength measurement of mobile networks. Lack of high-quality maps and folders to represent elevation were pointed out as factors constituting poor results. One of the major drawbacks, highlighted by the authors also a lack of prerequisites for the correct operation of the model as well as a lack of comparisons with valid models. A second test was carried out to obtain a correlation between the results. Steenbruggen et al.[25] presented an extensive overview of studies and projects on the use of data gathered from mobile phone networks to estimated traffic parameters. They pointed out the pros and limitations of gathering these local information and transportation parameters from cellular phones. The authors concluded that: there is high underdevelopment in adopting GSM data, travel speed and time are the most studied estimation issues for traffic management, previous studies were largely based on stretches of roads, not the road network.

Varol and Centi[26] undertook a study on cellular measurements using an android application. The limitation of their work is that measurements can only be done on Oreo devices (devices with android API 27) or devices using latter android API versions. This solution will have a poor penetration in places where older versions of android API are still in vogue. Nkordeh et al.[10] evaluated the signal strength of Nigerian four (4) major mobile phone operators (the same considered in this study) in Canaan land environs of Otta, Ogun state using drive test approach. However, in this study, we employed a crowdsourced approach. Our focus is to provide coverage data to users to help them solve their mobility problems and challenge mobile operators to improve on their coverage, QoS and capacity. Subash et. al.[27] developed a coverage prediction model for GSM using GIS. They obtained their data from Nepa Telecommunication; a leading GSM service provider in Nepal. The coverage data was measured by the provider using a drive test technique.

Sudheesh and Beek[28] measured mobile coverage data in Norrbotten region of rural Sweden to estimate the extend of mobile coverage in the region. The authors[28] didn't use crowdsourced approach for data collection. They obtained data via mobile app on phones placed inside a bag as they move around the region. Each phone was dedicated to each of the three network operators (Telia, Tele2, and Telenor) considered in their study. Like drive test approach, their study only revealed mobile network situation during the study period. This study however, uses crowdsourced data to continue to collect data from places where mobile phone users with the app exist. Unlike Varol and Centi work[26], our application has both forward and reverse compatibility for pre and post marshmallow (android API 23). Our app contains a local database where coverage information is stored temporarily. The content of this database is moved to the web server intermittently when the number of data rows collected is up to 30 and when there is an internet connection. The purpose of the local database is to avoid data loss due to poor internet connectivity and the energy management of users' phone batteries

3. Methodology

The system is composed of a mobile service entity that periodically fetches signal strength and location data automatically from a mobile phone's operating system (OS), a web service entity that routes the collected data to a database installed on a web server, a web, and android application where collected data are visualized from any location through web browsers and mobile app respectively. Thus, the coverage level of the network of mobile operators reported by users via the mobile and web service entities is known by other users from different locations via their web and mobile applications. Figure 1 shows the system model while figure 2 shows the system's block diagram.

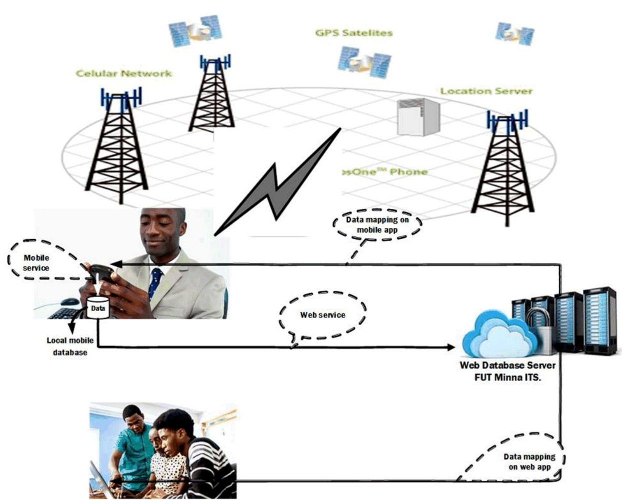

Figure 1. RF Coverage Mapping Model

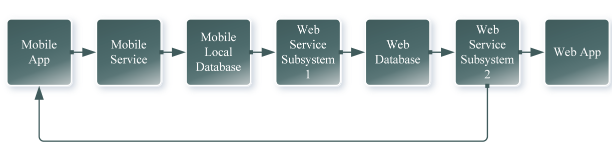

Figure 2. Block Diagram of System

A. *Mobile and Web Service Development*

The mobile service entity is an android-based program written in JAVA programming languages and SQLite Database. This program runs in the background of mobile phones' Android Operating System (OS). It is programmed to fetch data from mobile users' OS periodically and automatically. Upon installation of the app on users' mobile phones, it requests permission to use the user's location service for Application Program Interface (API) of below 23 (i.e., pre-marshmallow). Although for post-marshmallow android OS (API 23 and above), permissions are requested at runtime. Upon installation of the mobile service, a local SQLite database is created on the phone where data is stored temporarily. The data collected by the mobile service entity are the Mobile Network Operator (MNO) identifier, Received Signal Strength (RSS), longitude and latitude, and the date and time of signal reception. The ID of the network operators under this study are shown in Table 1.

TABLE I. MOBILE NETWORK OPERATOR ID

MNO ID	MNO Name
62120	AIRTEL
62130	MTN
62150	GLO
62160	9MOBILE

If the user's location is on, the mobile service collects these data and routes them to the local mobile database of the user else it requests the user to turn on location when the app is opened. When the app is closed, the mobile service runs in the background and collects data when users turn on their locations. Periodically, the content of the local database is routed to a centralized web server via a web service where data are collected for mapping. Figure. 3 shows the steps involved in the mobile and web service development.

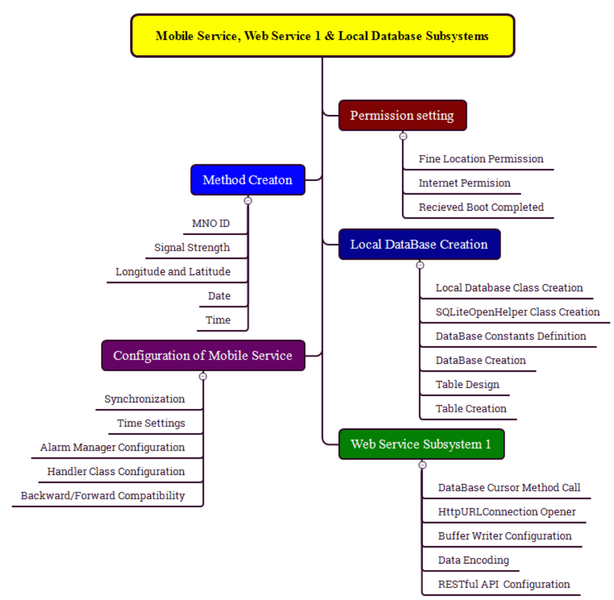

Figure 3. Mobile Service, Web Service 1 and Local Database Development

1) Permission Configuration: This is the first step carried out in the web service development. According to the Mobile Marketing Association (MMA) Mobile Application

Privacy Policy Framework of 2011[29], an application cannot use users' private information and services such as contact, camera, internet, location service, etc. without permission from the user. Thus, a permission request was written and configured on the android manifest to enable the web service access the user's location, internet, and start-up automatically upon phone reboot. 'Fine location permission' enables the app to access location information via the mobile network and GPS satellites while 'Coarse location permission' enables the app to access only location service offered by the mobile phone network. 'Internet permission configuration' enables the app to use the internet service of the user to communicate with the webserver while the 'Received Boot Completed permission' enables the app to start up automatically upon system reboot.

2) Methods Creation: Each data is collected from the android operating system using distinct methods of different JAVA classes. The creation of these methods is detailed below.

a) Signal Strength Method: Mobile phones receive signals from near-by based stations of their service providers using their omnidirectional antennas. The antenna converts the radio waves from the base station to electrical signals measured in Arbitrary Strength Unit (ASU). Received Signal Strength (RSS) varies from 0asu to 31asu[30] which is equivalent to -51dBm and -113dBm respecteively according to (1). An RSS value of 25asu and above is befitting for good connectivity and battery life conservation while a value of below 8asu shows poor connectivity and.impact negatively on battery life[31].

$$RSS_{(dBm)} = 2RSS_{(asu)} - 113 \tag{1}$$

The signal strength was collected using the signal strength listener method from the telephone manager class.

b) Other Methods: The longitude and latitude of the mobile phone at signal reception were collected using the Location listener method from the Location manager class. The MNO ID was collected using the getNetworkOperator() method from the telephone manager class while the date and time data were collected using the date and time method of the date class.

3) Local database creation: This was achieved by creating a database class and extending it to an SQLiteOpenHelper class. Secondly, the database constants such as the database name, table name, and columns names were defined. A table was then designed by assigning appropriate data types to columns such that it is in keeping with the table design on the webserver. If the local and web database structures are not the same, the data from the local database will not be submitted to the web database.

4) Configuration of mobile service: The mobile service is a method that synchronizes all the data and writes them to the local database simultaneously. A Timer method was used to enable the service to run periodically whenever location service is available. The handler class is used to suspend the mobile service when the location service is turned off. The alarm manager method was used to awaken the service upon phone reboot. The service was also configured to request permission at installation (to satisfy android API below 23) and at run-time (to satisfy android API of 23 and above) for backward and forward compatibility.

5) Web Service 1 Creation: The web service 1 is responsible for forwarding data from the local mobile database to the web database periodically. After forwarding, it deletes the sent data from the local mobile database. A database cursor method was configured to enable the web service to access the data of the local database and move them to distinct variables. A HyperText Transfer Protocol (HTTP) Uniform Resource Locator (URL) connection was opened between the mobile app and the web server via a PHP script using the 'httpURLconnection' method. A buffer writer was configured to write the data into the PHP file on the server. The data collected from the local database were encoded using the UTF-8 encoding scheme to enable reception at the server-side. Finally, a POST Representational State Transfer (RESTful) API was used to move the data into the PHP scripting file on the webserver that submits them to the database

B. Methodology of Database Development

XAMPP server was installed and the root and access security of MySQL database was configured to deny unauthorized access. Figure. 4 shows a summary of the web database development. The three major steps employed in the development are; server configuration, database creation, and table creation. The table is designed and normalized before it is implemented to avoid data redundancy

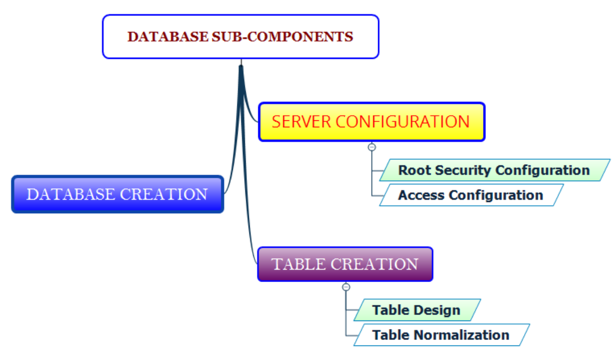

Figure 4. Mobile Service, Web Service 1 and Local Database Development

C. Mobile Application Development Methodology

Figure. 5 presents a summary of the mobile application development. The development comprises the layout development, setting of permissions, google map insertion, connection to server, and mapping as discussed in the following subsection

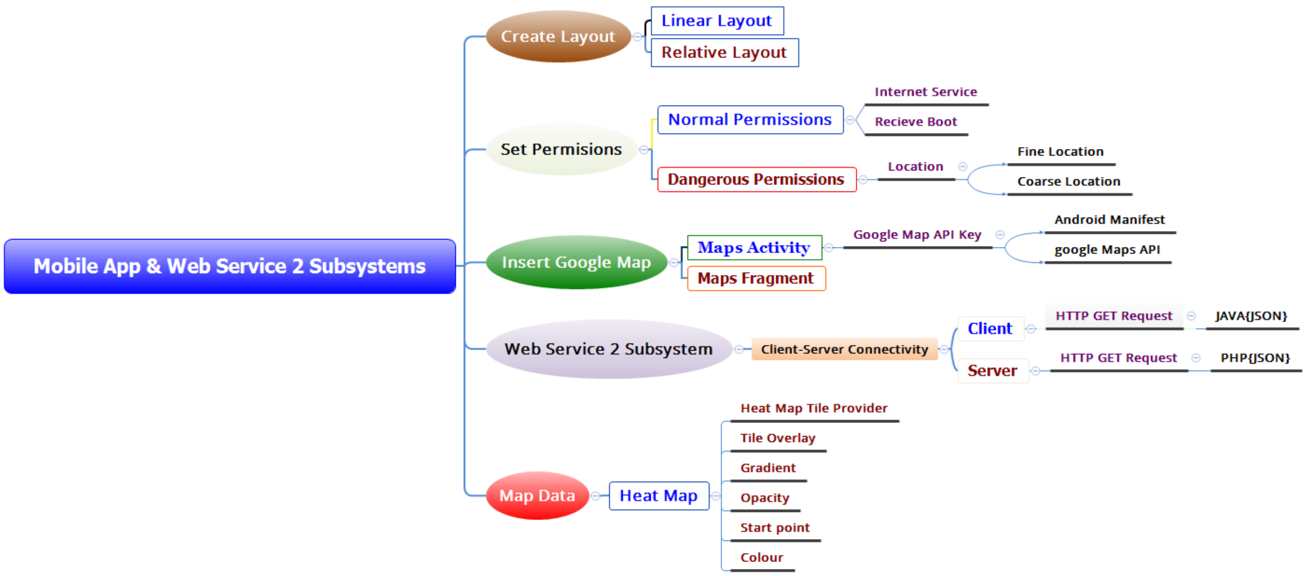

Figure 5. Mobile Service, Web Service 1 and Local Database Development

1) Layout Development: The mobile app user interface was designed using extensible mark-up language (XML). Two view groups were used for the development; a relative and linear layout. View groups are invisible classes used for the arrangement of objects on the interface of an application. Related layout view group arranges objects in position relative to a sibling element such as right, left, center, top, and bottom alignment. Linear layout on the other hand arranges objects in a single direction either vertically or horizontally defined by the orientation function.

2) Permissions Setting: These are the rights to access various services on the user's mobile devices to enable the application run correctly. In the course of this project, two permissions were enabled, the dangerous permission (access to users' location) and the normal permission (access to the internet). Dangerous permissions belong to permission groups that affect user's experience such as Location, Contacts, Camera, Call log, Calendar, microphone, Sensors, SMS, etc. Normal permissions affect the right to access data outside the application's sandbox and have little risk to user's privacy. For example, access to the Internet, Bluetooth, Wi-Fi state, install shortcuts, etc.

3) Google Map Insertion: Google map API key is obtained from Google app development console upon registration[32].Keys are available both for development and production scenarios. The key is configured on the android app manifest. It enables the google map fragment to show on the XML layout of the app's UI.

4) Web Service 2 Subsystem: Another web service that is made of PHP scripts is used to connect the app's UI and the database server. The mobile app uses XML and JAVA for data presentation but PHP is used for server-side programming. The JavaScript Object Notation (JSON) understood by JAVA and PHP are used for data exchange. During an HTTP request from the mobile app to the server, the data retrieved from the server is converted to JSON objects, received using JAVA, and mapped on the XML layout. Figure 6 shows the algorithm for data exchange during an HTTP request.

5) Mapping Data to Google Map: From the web database, collected and processed data retrieved by the mobile app as JSON objects are plotted on the Google map using Heatmap mapping technique. Heatmap distributes weighted signal strength values using different color intensities. Light color represents a weak signal while a thick color represents a strong signal. Heatmap is implemented using the HeatmapTileProvider function. A matrix of signal strength, Latitude and longitude values are passed into the function for representation on the map. The radius, gradient, and opacity of the map are controlled using the TileOverlay function.

4. RESULTS AND DISCUSSION

Streams of signal strength data collected from various subscribers at different locations were collected and stored on the webserver. They are then processed by averaging the data from distinct positions before they are presented on the map according to (2).

$$RSS_{avg}(p) = \frac{1}{N}\sum_{i=1}^{N} RSS(p)_i \tag{2}$$

Where $RSS_{avg}(p)$ is the average signal strength at point P, N is the number of data collected at P, while $RSS(p)_i$ are the signal strength values collected at the point. Thus, every plot on the map is an average of all the data collected from

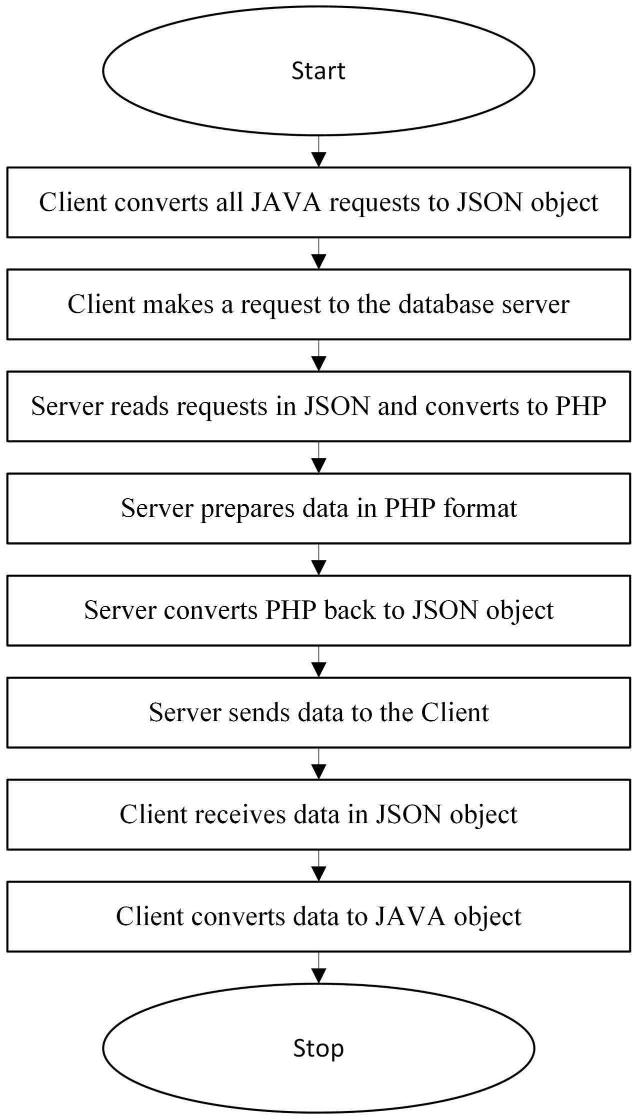

Figure 6. Mobile Service, Web Service 1 and Local Database Development

a distinct location. The average signal strength value of a point is the weight of the color intensity of the plot at that point. A plot of high intensity (Sharp color plot) shows a strong signal while a faint one reveals a weak signal. There is a gradual depletion of color intensity of plots as signal strength falls. As the data grows, further processing will be done to present data on an hourly, daily, weekly, monthly, and yearly basis based on users' preferences on the app.

The app was tested by installing it on the android phones of over a hundred students within and outside the university community. The result was impressive as mobile signals from various locations around the campus and Minna town were being mapped on the user interface in real-time. The results presented in figure 7 depict that on February 1 2021, Glo mobile phone network had the finest coverage around

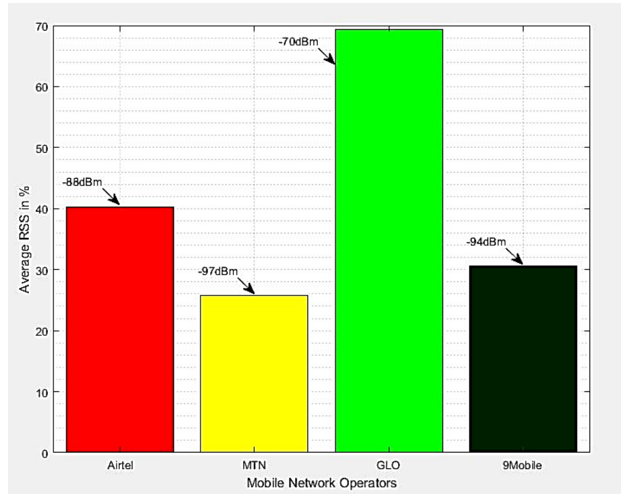

Figure 7. Mobile Coverage information at Male Hostel, FUT Minna on February 1, 2021.

the male hostel, Federal University of Technology (FUT) Minna, having an average RSS of -70dBm (69% signal reception from nearby based station). Airtel had an RSS of - 88dBm (40%), 9mobile network had an RSS of -94dBm (31%) while MTN had the poorest signal reception of -97dBm (26%). On February 1 2021 within the advanced Telecommunication laboratory in the school of Information and Communication Technology (SICT) complex of the university, Glo network top the list with an RSS of -83dBm (48%), MTN had an average RSS of -87dBm (42%), 9mobile, -91dBm (35%) and Airtel was least with an average RSS of -99dBm (23%) as shown in Figure 8. The percentage reception from base station ($RSS_{\%}$) is calculated using (3).

$$RSS_{\%} = \frac{RSS_{dBm} - RSS_{\min}}{RSS_{\max} - RSS_{\min}} \times 100 \quad (3)$$

Where $RSS_{\min}$ and $RSS_{\max}$ are the minimum and maximum RSS values in dBm respectively. $RSS_{\min}$ is -113dBm (0asu) while $RSS_{\max}$ is -51dBm (31asu)[30]. Thus, (3) is simplified as shown in (4)

$$RSS_{\%} = \frac{RSS_{dBm} + 113}{62} \times 100 \quad (4)$$

On June 26 2021, RSS data from the five (5) schools (faculties) in FUT Minna Gidan Kwano campus were analyzed. The faculties include the School of Informational and Communication Technology (SICT), School of Environmental Technology (SET), School of Electrical Engineering and Technology (SEET), School of Agriculture and Agricultural Technology (SAAT), and School of Entrepreneurship Management Technology (SEMT). Results revealed that, Glo network has the best reception in all the faculties. Figures 9 and 10 show the results in dBm and ASU respectively

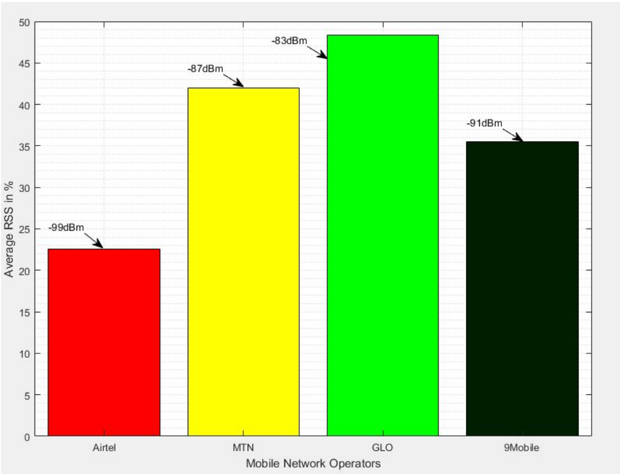

Figure 8. Mobile Coverage information at Advance Telecom Lab, SICT Complex, FUT Minna on February 1, 2021.

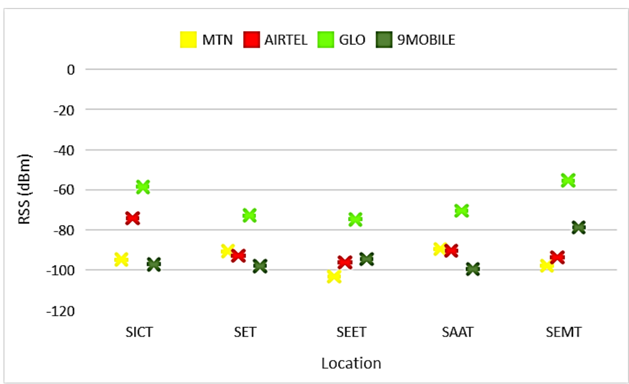

Figure 9. Mobile Coverage information in FUT Minna Faculties' Complexes at GK Campus on June 12, 2021 in dBm

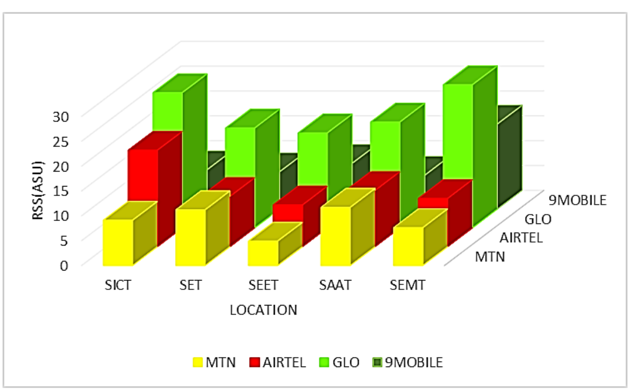

Figure 10. Mobile Coverage information in FUT Minna Faculties' Complexes at GK Campus on June 12, 2021 in ASU

Figures 11 and 12 show the user interface (UI) of the android app with plotted signal strengths of some network operators across FUT Minna university community and Minna metropolis. The app is presently hosted at google play store[33].

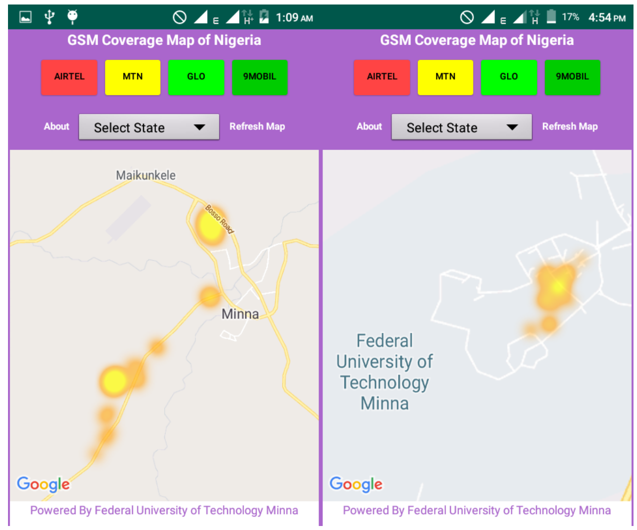

Figure 11. Mobile app showing mobile coverage information in FUT Minna and Minna metropolis.

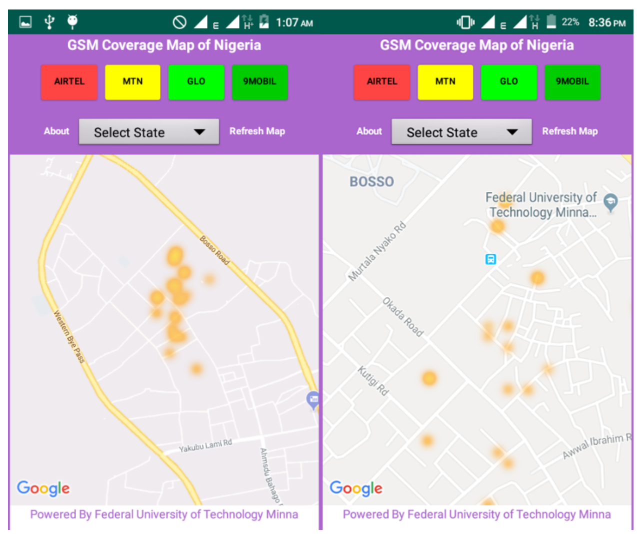

Figure 12. Mobile app showing mobile coverage information in FUT Minna and Minna metropolis.

5. CONCLUSION

From this study, we have established the need for mobile coverage information to be made available and accessible to users. We have also designed and implemented a viable system by which this can be achieved using crowdsourcing approach. This solution will help users solve connectivity challenges and also provoke a healthy competition among service providers to improve on their network coverage and QoS. It will also help communication regulators like the Nigerian Communication Commission (NCC) to independently appraise the level of mobile coverage across Nigeria for appropriate planning and policymaking. The crowdsourced data which with time will become Big Data, will serve as a data house for future research on Big Data Analytics and will be used to provide solutions to various connectivity and human mobility problems. This work will help mobile operators to evaluate the performance level of their base stations across Nigeria, and provide information for the installation of new base stations. A major challenge in this study is getting mobile users to install the app. In our future work, we are planning on providing other services via the app to attract users to install the app. As the data grows, we also plan to apply advance statistical techniques such as regression analysis and Analysis of Variance (ANOVA) for inferential analysis and machine learning models for predictive analysis.

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